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ABSTRACT BOOK

Chorus waves in the outer radiation belt driven by recurrent solar wind structures

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Coronal Holes (CH) are predominant at the solar disk through the descending phase of the solar cycle. They can persist in the solar disk for several rotations, and thus be often a source of high-speed solar wind stream (HSS), which leads to a corotating interaction region (CIR) generation. At the magnetosphere, the arrival of CIR-HSS increases magnetospheric convection, triggers the onset of substorms and also transport Alfvénic fluctuations through magnetosphere. Our results show that these three mechanisms, associated to the source (few keV) and seed (10s to 100s of keV) particles injection may drive changes in the outer radiation belts. In this paper, we use Van Allen Probes data to investigate the chain of significant magnetospheric events related to the arrival of CIR followed by HSS, throughout seven recurrences of the same CH, observed from November 2017 to May 2018. Our results show that the VLF wave activity and changes in the electron flux parameters occurs in three main periods. First, the arrival of a CIR causes magnetopause shadowing, enhancement of Alfvénic fluctuations, and oblique Chorus waves. These events are related to initial relativistic electron flux dropout observed in several events. Then, as the following HSS comes right after, seed injections are observed simultaneously to the increase of the magnetospheric disturbance and the persistence of raised solar wind speed. The conjunction of these latter conditions favored the occurrence of whistler mode chorus waves to cause acceleration. Otherwise, in the absence of seed injections, the relativistic outer radiation belt dropout is observed.

First results from the ELFIN mission and equatorial spacecraft conjunctions.

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The Electron Loss and Fields Investigation with a Spatio-Temporal Ambiguity-Resolving option (ELFIN-STAR, or ELFIN*) mission, comprised of two identical 3U+ CubeSats, was launched in September 2018 to explore the mechanisms responsible for relativistic electron loss during magnetic storms. All instruments and spacecraft are functioning nominally providing at least one complete scan of the radiation belt L-shells once per orbit (90 min period) from each satellite. Pitch-angle resolved energy spectra of electrons between 50-5000keV are measured at ±22.5deg resolution clearly separating trapped, precipitating and backscattered electrons. Satellite separations from one to tens of minutes along-track enable resolution of spatial and temporal variations to determine the latitudinal width and temporal evolution of the precipitation. First results include: A. There is a statistically significant up-going population that is present both at quiet and active times, likely due to atmospheric scattering. We explain its dependence on activity, local time, trapped flux and precipitation level. B. There are many cases where >1MeV particles are observed to have been scattered into the loss-cone at fractions greater than at lower energies – these are candidates for EMIC wave scattering. Simultaneous measurements from equatorial satellites support this hypothesis. C. There are numerous observations of intense precipitation in the 50-500keV range that qualify for whistler mode chorus scattering – these too are consistent with equatorial observations. D. There are routine nightside observations of broad precipitation across all energies that exhibit energy-latitude dispersion. These are candidates for field-line curvature scattering. They can be used to adjust magnetic field models for mapping precipitation boundaries and field-aligned currents to their drivers in near-Earth space, and compare those with equatorial spacecraft measurements. The very low noise background and high count rates allow for future operational modifications. Those are expected to extend observations to the inner radiation belt, and to improve the pitch-angle resolution of the measurements to <34deg allowing, after some modeling, for better resolution of the loss-cone gradient.

Acceleration and loss of the outer radiation belt electrons and auroral processes

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Outer radiation belt (ORB) relativistic electron fluxes dropouts during storm main phases, around 45%–50% after storms enhancements, 20%–25% after storms depletion, and 25%–28% almost unchanged continue to be unsolved problems in spite of many researches including the realization of RBSP/Van Allen mission. Ordinarily discussed mechanisms of particle precipitation and magnetopause shadowing can not explain the existence of magnetic storms when particle fluxes after storm restore till the level of the fluxes before the storm. Popular "quasilinear" models cannot explain time intervals of great increases of ORB fluxes near to substorm time intervals. Such situation is explained by the underestimation of the role of auroral processes in the ORB dynamics. We summarize the latest findings in the ORB and auroral processes connections including outer part of ORB intersection with the region of the auroral oval mapping to the equatorial plane, auroral oval motion to lover latitudes during magnetic storms, great magnetic field variations at the equatorial plane during storms and a number of other effects. The dominant role of adiabatic mechanism in the ORB dynamics during storm main and recovery phases is demonstrated. The ORB dynamics prediction and plans of future works including analysis of data of auroral missions are discussed.

Perpendicular heating of low-energy ions by fast magnetosonic waves observed by Arase (ERG) satellite

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Fast magnetosonic (MS) waves are commonly observed in the equatorial region of the inner magnetosphere. Past numerical simulations show MS waves can accelerate low-energy ions through cyclotron resonance, although the observational evidence is still unclear. Arase (ERG) satellite found events of perpendicular heating of cold ions simultaneously with plasma wave activities of the MS waves. We have applied the WPIA (wave-particle interaction analysis) method to the selected ion heating event with the MS waves. The results show that the MS waves accelerate the low-energy (< ~10keV) ions with pitch angles near 90 degrees. We also found these ions give their energy to EMIC waves which appears just below the local proton cyclotron frequency. Since MS waves are considered to be generated by the ring distribution of ions, this analysis indicates energy transfer from higher-energy ions to the lower-energy ions in the inner magnetosphere.

Measurements of geomagnetic pulsations and aurora at Zhigansk and VLF registration at Maimaga as part of PWING project

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PWING network consist of eight stations at subauroral latitudes (~ 60° geomagnetic latitude) in the northern hemisphere, distributed longitudinally in Canada, Iceland, Finland, Russia, and Alaska to obtain the longitudinal distribution of plasmas and waves in the inner magnetosphere. PWING has been developed as a part of the ERG (Arase)-ground coordinated observation network. SHICRA SB RAS has long-term and productive scientific relationships with ISEE (former STEL), Nagoya University. In the framework of PWING project Nagoya University provided SHICRA SB RAS scientific equipment, described in [Shiokawa et al., EPS, 2017, DOI 10.1186/s40623-017-0745-9]. At present time, SHICRA SB RAS operate all-sky airglow camera, 64-Hz sampling induction magnetometer and broad-beam riometer at Zhigansk (66.8 N, 123.4 E), and 40-kHz sampling VLF receiver with loop antenna and electronic recorder of low-frequency electromagnetic radio waves at Maimaga (63.1 N, 129.6 E). We present some results on interaction of electromagnetic electron and ion-cyclotron waves and with particles in the inner magnetosphere in the sector which manifesting in generation of discrete low-frequency signals in the Earth's magnetosphere, such as chorus in VLF emissions, "pearls" in the Pc1 range, and also irregular pulsations of diminishing period (IPDP).

Declining solar activity trends during solar cycles 25 and 26

A.Bhargawa and A.K. Singh

We have used the already observed data of solar parameters viz. sunspot numbers, F10.7 cm index and Lyman alpha index recorded for last seventy years (1947–2017).We have applied the Hodrick Prescott filtering method to bifurcate each time series into cyclic and trend parts. The cyclic part of each time series was used to analyse the persistence while the trend part was used to obtain the input data for the study of future predictions. Further, the cyclic component of each parameter was analysed by using the rescaled range analysis and the value of Hurst exponent was obtained for sunspot numbers, F10.7 cm index and Lyman alpha index as 0.90, 0.93 and 0.96 respectively. By using the simplex projection analysis on the values of amplitude and phase of the trend component of each time series, we have reconstructed the future time series representing solar cycles 25 and 26. When extrapolated further in time, the reconstructed series provided the maximum values of sunspot numbers as 89 ± 9 and 78 ± 7; maximum values of F10.7 cm index were 124 ± 11 and 118 ± 9 and Lyman alpha index were 4.61 ± 0.08 and 4.41 ± 0.08 respectively for solar cycles 25 and 26. In our analysis we have found that the solar cycle 25 will start in the year 2021 (January) and will last till 2031 (February) with its maxima in year 2024 (February) while the solar cycle 26 will start in the year 2031 (March) with its maxima in 2036 (June) and will last till the year 2041 (February).

Fermi acceleration in Saturn magnetosheath at corotating magnetic reconnection site

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We found field aligned electrons (FAE) and anti-parallel electrons (APE) in the ion and electron diffusion region at corotating magnetic reconnection site in Saturn magnetosphere at the magnetosheath. The FAE can reach closer to the planet with fermi accelerated electrons while APE confine at the equator give betatron acceleration. The betatron acceleration is not expected because total magnetic field value is decreased from 3.45 to 1.11 nT. We found heated electron peaks which confirms fermi acceleration between 49.3Rs to 48.7Rs at 0.4° latitude. The electron density was between 0.062m^-3 to 0.549m^-3 and temperature was between 10.87eV to 25.55eV.

ULF wave observations in the ionosphere using the EKB coherent radar

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Ultra low frequency (ULF) waves can be efficiently observed at the ionosphere, where they map from the magnetosphere. Radars provide steady opportunity to study their structure, localization, and relations with other phenomena. A midlatitude coherent decameter radar similar to SuperDARN radars was launched in 2012 near Ekaterinburg (EKB), Russia. During the experiment conducted in 2013–2015 its three adjacent beams were scanning the ionosphere at high time resolution mode, providing 18 s cadence at each beam. These three beams are directed approximately towards the magnetic pole. Therefore, they register the poloidal component of ULF waves. A review of several interesting events studied using the data from the radar are presented. (1) A number of waves with frequencies considerably lower than the appropriate field line resonance (FLR) frequencies were registered. The FLR frequencies for each case were inferred from spacecraft data on particle density and magnetic field. It is assumed that at least a part of the waves observed with the radar should be identified with the drift compressional mode, whose frequency can be lower than Alfvén frequency. (2) A wave with a synchronous decrease both in frequency and azimuthal number m was observed. Such linear dependence of frequency on m, together with sub-Alfvénic frequency and westward propagation is a characteristic of the drift compressional mode. (3) A case of merging of two waves was shown. Apparently, they represent the drift compressional and Alfvén modes, which can merge at some critical value of azimuthal wave number m. (4) A wave was registered at the radar and Van Allen Probe spacecraft simultaneously. It was poloidal and diamagnetic (magnetic and plasma pressure oscillations are in anti-phase). Its frequency was lower than the FLR fundamental frequency. Therefore, it was some kind of compressional mode, apparently the drift compressional one.

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Detection of auroral kilometer radiation from the northern and southern hemispheres using the ERG satellite

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Auroral Kilometric Radiation (AKR) signals from sources in the auroral regions of the northern and southern hemispheres are simultaneously recorded and analyzed using the data of the ERG satellite. Initially, type III solar radio bursts are applied as a calibration signal and it is shown that there is no polarization of this signal that is in good agreement with previous results and indicates the correct calculation of the polarization parameter on board the ERG satellite. In our study, two sources of AKR spaced apart in frequency are distinguished. Most likely, this is due to spatial-frequency filtering of sources separated in space. It is noted that there are differences in the AKR generation in the northern and southern hemispheres. It is shown that either northern or southern sources of AKR prevail at different times.

Quantifying the drivers of electron loss from the Earth's radiation belts

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We use observations from the Van Allen Probes, together with electron lifetime calculations from quasilinear diffusion modeling, to identify and quantify the drivers of electron precipitation from the Earths inner radiation belt and slot region. We build on our recent work that examined the role of ground-based Very Low Frequency (VLF) transmitter waves in precipitating electrons from the inner belt, which was demonstrated to exhibit a bifurcated structure (two-belt inner zone) due to the action of the VLF transmitter waves. We present new results that explicitly account for the role of lightning-generated whistler (LGW) waves in the electron lifetime calculations, using a statistical database of LGW waves recently obtained from the Van Allen Probes. In addition to these calculations of electron precipitation via quasilinear wave-particle interactions, we also consider a revised formulation of Coulomb scattering and examine the role of Coulomb energy drag in reducing the electron lifetimes. The theoretical calculations and modeling results are compared with observed electron decay rates to identify the physical processes most relevant for radiation belt electron precipitation.

Athabasca University, PWING, and Arase

M. Connors (Athabasca University and University of Calgary)

Athabasca University's cooperation with Japanese scientists began twenty years ago with the visit of the late Tsuruda-sensei. He taught the value of patience, as a first visit under two full weeks of cloudy skies led to a second one with amazing aurora viewing. In 2004, Athabasca began cooperation with the late Hayashi-sensei to maintain the STEP Polar Network, some of whose stations are still operating, and even enhanced. In 2005, Nagoya University installed equipment at the original Athabasca University Geophysical Observatory (now an equipment test site). Due to early successes, funding was obtained a decade ago for the GeoSpace Observatory (AUGSO) in a very dark site, and which opened with a visit by a Nagoya University team in early 2012. This talk will review work done, mainly on subauroral phenomena including detached proton auroras, SAR Arcs, and STEVE. The focus will be on observations with complementary instruments, including those of the AUTUMN East-West magnetic array. The most recent AUGSO thrust is in time-domain magnetotellurics, in which direct measurements of induced electric fields is relevant to space weather studies. Athabasca University's MAMA-MIA project will link geoelectric measurements and proton auroras, and AUGSO will be a site in the University of Calgary's large TREx observatory network project covering much of western Canada.

SafeSpace: Designing Radiation Belt Environmental Indicators for the Safety of Space Assets

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The SafeSpace project aims at advancing space weather nowcasting and forecasting capabilities and, consequently, at contributing to the safety of space assets through the transition of powerful tools from research to operations (R2O). This will be achieved through the synergy of five well established space weather models (CNRS/CDPP solar disturbance propagation tool, KULeuven EUHFORIA CME evolution model, ONERA Neural Network tool, IASB plasmasphere model and ONERA Salammbô radiation belts code), which cover the whole Sun – interplanetary space – Earth's magnetosphere chain. The combined use of these models will enable the delivery of a sophisticated model of the Van Allen electron belt and of a prototype space weather service of tailored particle radiation indicators. Moreover, it will enable forecast capabilities with a target lead time of 2 to 4 days, which is a tremendous advance from current forecasts that are limited to lead times of a few hours. SafeSpace will improve radiation belt modelling through the incorporation into the Salammbô model of magnetospheric processes and parameters of critical importance to radiation belt dynamics. Furthermore, solar and interplanetary conditions will be used as initial conditions to drive the advanced radiation belt model and to provide the link to the solar origin and the interplanetary drivers of space weather. This approach will culminate in a prototype early warning system for detrimental space weather events, which will include indicators of particle radiation of use to space industry and spacecraft operators. Indicator values will be generated by the advanced radiation belt model and the performance of the prototype service will be evaluated in collaboration with space industry stakeholders. The work leading to this paper has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870437 for the SafeSpace (Radiation Belt Environmental Indicators for the Safety of Space Assets) project.

Conjugate ground-spacecraft observations of VLF emissions

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A review of recent results on conjugate ground-spacecraft observations of various types of VLF emissions such as quasi-periodic and chorus emissions will be given. For quasi-periodic emission, it will be shown that quasi-parallel propagation with respect to the geomagnetic field and the appopriate Poynting flux direction away from the equator are not sufficient to infer the location of a spacecraft within a generation region of such signals. Using the whistler mode growth rate calculations serve as important tool for identifying the spacecraft passage in a probable generation region. For chorus emissions we demonstrate a persistence of a discrete element structure for a two-hop pass from a generation region to the ground and back to the magnetisphere after the reflection from the ionosphere or from the ground. In all cases the use of propagation properties of VLF emissions detected on the ground can greatly help in resolving ambiguities with respect to the possible location of the signal generation region. Examples of simulations of related wave-particle interactions will be given.

A theoretical study of mirror-point altitude variability due to geomagnetic field variations

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The Earth's intrinsic magnetic field has been weakening at ~5% per century from at least 1840 mostly determined by the decrease in the dipolar magnetic moment component. This may point out an undergoing reversal or excursion, or maybe the possibility of a recovery without any extreme event. In any case, the global field intensity will very probably continue to decrease in the near future with a consequent weakening of our planet's magnetic shield capacity. In the current dipole like geomagnetic field, where the field intensity gets stronger with increasing magnetic latitude, there exist points in the northern and southern hemisphere, called magnetic mirror points, where charged particles traveling along a field line bounce between them. This motion is one of the three cyclic motions of trapped particles in the magnetosphere. The mirror points altitude depends directly on the magnetic moment, which means that a magnetic decrease may induce an altitude lowering eventually reaching the atmosphere. A theoretical estimate of magnetic mirror points lowering rate due to the current geomagnetic field decrease is estimated and compared to the shrinking of the upper atmosphere due to greenhouse gases increase during the last 120 years.

Electromagnetic ion cyclotron (EMIC) waves in Earth's magnetosphere: Recent satellite and ground-based observations and some future prospects

M. J. Engebretson (Augsburg University)

Observations from the Van Allen Probe, Magnetospheric Multiscale, and ERG spacecraft missions, often complemented by ground-based observations, have spurred a large number of studies of waves in the Pc1-2 band, including especially electromagnetic ion cyclotron (EMIC) waves, and of their impact on ultrarelativistic radiation belt electrons. This presentation will review several recent studies of the origins, properties, and impacts of these waves, and will highlight several continuing issues and new techniques that may attract increased attention in the next few years.

A comparison of upper atmospheric Joule heating resulting from CMEs and HSSs using SWMF/BATS-R-US model

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Upper atmospheric Joule heating is an indication of the magnetospheric energy and momentum downloaded into the upper atmosphere in the ionospheric heights during the magnetospheric substorms. Both coronal mass ejections (CMEs) and high speed streams (HSSs) are shown to cause magnetospheric substorms. They have distinct characteristics in the solar wind. Therefore, the response of the magnetosphere is expected to be different during these events. In this study, we investigate the Joule heating resulting from these two solar disturbances. We chose two geomagnetic storms/magnetospheric substorm events, one that corresponds to a CME and the other one to HSS, and used SWMF/BATS-R-US MHD model to evaluate the Joule heating in the upper atmosphere. We determined the Joule heating rates according to the substorm and storm phases. We showed that the Joule heating rates are higher during the CME driven storm/substorm when compared to the HSS driven storm/substorm. Also we found that the Joule heating rate is higher during the main phase of the storm in both cases. For the events we studied, we also obtained that Joule heating rate is higher during the expansion phase of the HSS driven substorm. We quantify the Joule heating in each case. We will present and discuss the results from our preliminary search in this meeting.

Modeling the Inner Magnetosphere with the CIMI Model

Mei-Ching Fok (NASA GSFC), Alex Glocer (NASA GSFC), Jonathan Krall (NRL), Joe Huba (Syntek Technologies), Naomi Maruyama (university of Colorado), and Cristian Ferradas (Catholic University of America)

A Comprehensive Inner Magnetosphere-Ionosphere (CIMI) model was developed to study the dynamic variations of the radiation belts, ring current, and plasmasphere as well as the interactions between these populations and with the ionosphere. Recently, the CIMI model was coupled with two well established models: SAMI3 (Sami3 is Also a Model of the Ionosphere) and IPE (Ionosphere-Plasmasphere-Electrodynamics) models. Ring current heating to the plasmasphere is calculated in the CIMI model. This heating is added to the electron temperature equation in SAMI3 in a form of ring current heating function. With this additional heating, a cold (<1 eV) oxygen ion outflow is produced, with O+ density and location similar to observations of the so-called "oxygen torus". On the other hand, the electric field calculated in CIMI is used to drive the plasma convection in the IPE model during the storm on 7-9 September 2017. The severe erosion of the plasmasphere observed by the Van Allen Probes and ERG satellites during the storm is reproduced by the IPE model. The strongest erosion observed on the dawn side can be explained by ring current shielding and day-night asymmetry in ionospheric conductance that are accounted for in the CIMI model. The CIMI model and it predecessors have been coupled with global MHD models for more than two decades, but just recently the core plasma simulated in the CIMI model is treated as an additional fluid in the BATSRUS MHD model. The inclusion of the plasmasphere is found to have a system-wide impact. Specifically, when the plasmasphere drainage plume reaches the magnetopause, it can reduce the reconnection rate, suppress ionospheric outflow and change its composition, change the composition in the magnetosphere, and reduce the ring current intensity. We are working toward to a comprehensive modeling of the inner magnetosphere considering all the important physical processes and interactions.

Forecast of energetic electron flux variations of the outer belt using the machine learning

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The relativistic/sub-relativistic electron flux variations often cause serious damage on the satellite operations through the dielectric charging. In order to forecast flux variations of these electrons, various forecast methods based on the physical based simulation and empirical modeling have been developed. For the physics-based simulation, the SUSANOO that operates a code-coupling simulation of heliosphere and radiation belt provides MeV electron flux variations for the next couple of days. For the empirical modeling, the linear prediction filter and the auto-regressive moving average are popular methods, which have been used for the forecast of MeV electrons at geosynchronous Earth orbit (GEO). Recently, the machine learning techniques have widely been used for the space weather forecast, for example, ionospheric variations, the flare prediction, etc. In this study, we have developed the forecast system of relativistic/sub-relativistic electron flux variations based on long short-term memory recurrent neural network (LSTM-RNN). As the training data, we use the solar wind data and energetic electron data observed by Arase/HEP, XEP instruments at different L-shells of the outer belt. Our developed network provides time variations of the energetic electron flux around L=4,5,6 using the solar wind data as an input parameter. In this presentation, we will present the initial results of our developed network and discuss effective solar wind parameters to reproduce the observed flux variations at different L-shells.

Driving parameters for energetic electron fluxes variation in outer radiation belt

B.Geletaw, M.Negussie, G.D.Reeves, S.Wing

The Earth's outer radiation belt is highly dynamic and the variations of energetic electron population in the region depends on solar wind and interplanetary magnetic field (IMF) parameters. Recently, observations of Van Allen probes have used to analyze the electron flux variations; however, the causes for different response to electron fluxes are still unclear. The main objective of this work is to analyze the causal relationship of solar wind and IMF parameters on the variation of energetic electron fluxes in outer radiation belt using information theory approach. We attempt to characterize the influence and timing of the solar wind and IMF parameter activities on the radiation belt environment based on time-shifted cross-correlation, mutual information and transfer entropy tools. We have used Van Allen probes energetic electron flux data with energy channels of 3.4, 4.2, 5.2 and 6.3MeV in the period from 01 January 2017 to 31 December 2018. Our analysis applied for three ranges of L-shell which are ~ 4.0 ($3.95 \leq L < 4.05$), ~ 4.5 ($4.45 \leq L < 4.55$) and ~ 5.0 ($4.95 \leq L < 5.05$). The results indicate that the information transfer from solar wind and IMF parameters to energetic electron flux in outer radiation belt is dependent on ranges of L-shell, type of driving parameter and energy of electrons in outer radiation belt. We ranked the driving parameters based on transfer information level while causing energetic electron flux variation. The results also illustrate that solar wind velocity is the dominant driving parameter for the variation of energetic electron flux. Moreover, the time shifted dependency analysis of the variables confirmed that the lag time is decreasing as L-shell increasing. For instance in the case of Vsw(t) and Je(t + τ) peak correlation functions, we have observed that $\tau max = +7$ days for L-shell of $4.95 \leq L < 5.05$ and $\tau max = +10$ days for $4.45 \leq L < 4.55$. Such dependency analysis can help to select the model parameters that influence the variation of energetic electron fluxes and to improve the existed models of the dynamical system.

Multi-event conjugate measurements of the SAR arcs detachments using all-sky camera at Athabasca, Canada and DMSP satellites (F13-F19)

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Stable auroral red (SAR) arcs are one of the phenomena of atmospheric emission at 630.0 nm associated with magnetosphere-ionosphere coupling. It is considered that SAR arc emission is driven by energy transported from the ring current into the ionosphere at subauroral latitudes during magnetic storms. The energy deposited in the thermal plasma at high altitudes is transported into the subauroral ionosphere along geomagnetic field lines as a heat flow or low-energy particles flux (few eV) and leads to electron temperature elevation up to and sometimes in excess of 3000 K at a height of about 400 km. These temperatures are required for observable 630.0 nm emissions. In the present work we report the first multi-event conjugate measurements of SAR arc detachment from the auroral oval using DMSP satellites (F13-F19) and ground-based all-sky imager at Athabasca (Canada) (54.6o W, 246.36o E, MLAT=61.5o, MLON=308.3o, L=4.4). We found 86 events of SAR arc detachment conjunctions in the northern hemisphere and 98 events of conjugate pass in the opposite hemisphere from 2006 to 2018. Measurement aboard DMSP satellites shows that detached SAR arcs are usually associated with electron temperature (Te) enhancement and electron density (ne) trough. We also found that SAR arc detachment sometimes co-located with localized westward or eastward drift which may be associated with Subauroral Ion Drift (SAID) or abnormal SAID (ASAID) events, respectively. The Te measured by DMSP associated with detached SAR arcs positively correlates with F10.7 solar activity index. The measured values of ne, Te and horizontal ion drift velocity (Vh) have a better correlation with the AE and PCN index than with the SYM-H index, indicating that SAR arc detachment related primarily to substorms and solar wind - magnetosphere coupling. The measurements aboard DMSP satellites in the conjugate point in the southern hemisphere corroborate the possibility of association of detached SAR arc with localized westward or eastward horizontal drifts. We speculate that SAR arc detachment may be related to the energization of the ring current during the substorm process and following energy transfer from the ring current through the field lines downward to the ionosphere.

Atmospheric physics/ external Geophysic

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The Equatorial Electrojet (EEJ) is a day-side eastward electric current that flows along the geomagnetic dip equator in the E-layer the ionosphere at 105 km altitude. The EEJ was discovered at Huancayo (Peru) in 1922, where the amplitude of the daily regular variation of the geomagnetic field horizontal component was found to be 2 to 2.5 higher than that observed at mid-latitudes. Most of the spatial and temporal characteristics of the EEJ, such as its half-width, position of the center, the current intensity at the center, etc., are usually estimated from its magnetic effects observed on ground and on board low altitude orbiting satellites. However, the parameters resulting from the electrodynamics processes of the low latitude ionosphere cannot be estimated from geomagnetic field data. In the present work, the electrodynamics parameters (Ey, EP, JP1, JH2 JEEJ) was estimated from a semi-empirical approach. This method consisted of using the ionosonde data along with models such as the IRI, IGRF, NHPC_421, SAO-Explorer and MSIS-E-90. In addition, by integrating JEEJ in height, the peak current density (I0) at the EEJ center was estimated. The results were compared with the peak current density (I0) inferred from magnetic data in order to evaluate the electrodynamic consistency of the method and the estimated values. Then, we examine the longitude dependence of the equatorial electrojet (EEJ). In order to understand the background physical process responsible of remarkable feature is the “wave-four” structure of the EEJ longitude profile, we have examined the influence of the geomagnetic-field intensity and that of migrating thermospheric tides. Then, By means of simulation through the National Center for Atmospheric Research (NCAR)’s Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIEGCM), we have shown that the combination of the longitudinal inequalities of the main geomagnetic-field intensity and the tidal-wave longitudinal structures is necessary to produce the wave-four structure of the EEJ longitude profile. Finally, we have shown the seasonal variability of the EEJ longitude profiles, which may be controlled by the seasonal behaviors of the wind system in the thermosphere.

Geomagnetic Field Variations During Quiet and Disturbed Days Over Iznik, Turkey

E. Gülay, Z. Kaymaz, and E.C. Kalafatoğlu Eyigüler (Istanbul Technical University)

In this study, we investigate the possible effects of the geomagnetic activity on the magnetic field measured on the ground at Iznik geomagnetic station (40.5°N, 29.72°E) in Turkey. We select two magnetically active days using Dst and AE magnetic indices. We determine the geomagnetic field deviations occurring during these magnetic storms from the background geomagnetic field obtained during magnetically quiet days. We evaluate the variations according to the storm/substorm phases and quantify the differences with respect to the quiet days. In addition, we study the variations in the time derivatives of the geomagnetic field during the active and quiet times. Time derivatives of the magnetic field are associated with the electric field through Maxwell equations, which in turn are related to the currents. We infer the geomagnetically induced currents (GICs) using these time derivatives and emphasize on the differences between the active and quiet days. Our results will bring insights in magnetosphere-ionosphere-ground coupling at mid-latitudes. We will present our preliminary results and discuss our findings in the context of the available literature.

Long term features of geomagnetically trapped particles

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The trajectory of energetic particles trapped by the geomagnetic field is usually defined by three cyclic motions: gyration, bounce along field lines, and drift around the earth, which are all controlled by this field. The geomagnetic field, in turn, has been declining at a rate of ~5% every hundred years since at least ~1840. A possible future scenario is a steady decrease of the dipole component with a field complexity increase through the relative growth of non-dipolar components. The expected variations in trapped particle trajectories, which describe an overall drift shell, is analyzed in the present work through an analytical approach helped by computer simulations using the Rice Adaptive Particle Tracer (RAPT) that is a Python framework for tracing relativistic charged particles in general electromagnetic fields. The main results are the decrease of drift shells mean distance to the Earth, decrease of mirror point altitudes, increase of conjugate mirror points asymmetry, and the split of radiation belts for pure multipolar configurations. The idealized and simplified structures here analyzed could shed light on the study of plausible radiation belt enhancements during polarity transitions which can have wide-range implications for man-made technologies that operate in space.

Inter-Hemispheric Comparisons of the Ground Magnetic Response during Past and Future Eclipses

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During a solar eclipse, reductions in solar illumination affect the ionospheric conductivity and can in turn perturb the geomagnetic field and related magnetosphere-ionosphere current systems. We discuss (1) how expanded networks of ground magnetometers in both hemispheres can be used to characterize magnetosphere-ionosphere coupling processes, (2) how eclipses serve as unique experiments to test predictions for magnetosphere-ionosphere coupling processes, and (3) whether past eclipses significantly perturbed the geomagnetic field. The focus of this presentation is on ground magnetometer and SuperDARN radar observations in both hemispheres during the 23 November 2003 total solar eclipse event (including observations at Syowa station and other locations in East Antarctica). We place the observations from this eclipse in context with other eclipse events. We also use results from past eclipses to inform plans for satellite and ground-based measurements during the upcoming 4 December 2021 Antarctic eclipse.

Investigating EMIC/IPDP source regions with conjugation ERG-PWING observations

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Despite over 60 years of study, there is still much we are yet to fully understand about Electromagnetic Ion Cyclotron (EMIC) waves. While recent flagship missions such as the Van Allen probes and Arase have proved invaluable for furthering our knowledge of EMIC waves, the nature of these waves makes it difficult to study them from a single location. It is only through the combined effort of in-situ and ground-based instrumentation that we are able to properly understand and explain fundamental characteristics of EMIC waves.

One such aspect of EMIC waves that is still a matter of considerable inquiry is the interaction between EMIC wave and radiation belt electrons. In recent years there has been an increased interest in EMIC-driven electron loss from the radiation belts, with numerous studies showing electron precipitation occurring at sub-MeV energies, far lower than previously thought possible. Precipitation at these energies has the potential to be important not only for radiation belt dynamics, but also for upper atmosphere chemical balance and as a driver of ozone loss. Some studies have suggested that the primary driver of this sub-MeV electron precipitation may be IPDP waves (intervals of pulsations with decreasing period), a subset of EMIC waves first identified in the early 1960s, but still fairly poorly understood.

In this talk we will discuss the limitations of our understanding of IPDP-type waves, and how we can use a combination of in-situ measurements from ERG, PWING, and other data sources to help fill these gaps in our knowledge, and further our understanding of IPDP waves, and EMIC waves in general.

Spatial evolution of injected energetic electrons as observed by Arase and Van Allen Probes

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In this study, we investigate how drifting energetic electron populations evolve in the inner magnetosphere, using the Arase and Van Allen Probes (RBSP) satellites. Electrons and ions of the plasma sheet origin are energized up to tens to hundreds of keV and abruptly transported on the night side into geosynchronous distance and even further inward during substorms, which is referred to as substorm injection. Then injected electrons drift eastward and disperse along their drift path with azimuthal drift velocities depending on their energies. Extensive observations with geosynchronous satellites have shown that energy dispersion signatures can be quantitatively explained by magnetic drift velocities, while its two-dimensional (radial and azimuthal) evolution has not been well examined except for a few case studies where many satellites were available simultaneously at different radial distances and local times. In this regard, we examine simultaneous observations by Arase and RBSPs to examine how injected energetic electrons spread radially in the course of their eastward drift. A case study in which the three satellites were located on the dawn side shows that Arase (L ~ 7.7, MLT ~ 10h) and RBSP-B (L ~ 5.8, MLT ~ 4h) observed an energy-dispersed electron population nearly at the same time (within a few minutes), despite the large difference in MLT sector. This result strongly suggests that the leading edge of energetic electrons goes significantly ahead at farther radial distances even if they have started drifting at the same MLT, forming a spiral-shaped drift front. Our statistical study shows that such events are frequently found in the dawnside magnetosphere, in addition to those showing later arrival of electrons at a later MLT. Based on many simultaneous observations, we address how the spatial shape of drifting populations looks like and how it evolves as drifts eastward from night to the dayside.

Active auroral arc powered by accelerated electrons from very high altitudes

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Bright, discrete, thin auroral arcs are a typical form of auroras in nightside polar regions. Their light is produced by magnetospheric electrons, accelerated downward to obtain energies of several kilo electron volts by a quasi-static electric field. These electrons collide with and excite thermosphere atoms to higher energy states at altitude of ~100 km; relaxation from these states produces the auroral light. The electric potential accelerating the aurora-producing electrons has been reported to lie immediately above the ionosphere, at a few altitudes of thousand kilometres. However, the highest altitude at which the precipitating electron is accelerated by the parallel potential drop is still unclear. Here, we show that active auroral arcs are powered by electrons accelerated at altitudes reaching greater than 30,000 km. We employ high-angular resolution electron observations achieved by the Arase satellite in the magnetosphere and optical observations of the aurora from a ground-based all-sky imager. Our observations of electron properties and dynamics resemble those of electron potential acceleration reported from low-altitude satellites except that the acceleration region is much higher than previously assumed. This shows that the dominant auroral acceleration region can extend far above a few thousand kilometres, well within the magnetospheric plasma proper, suggesting formation of the acceleration region by some unknown magnetospheric mechanisms.

Computer simulations of precipitating energetic electrons through chorus-wave particle interactions

Y. Ito(ISEE, Nagoya University), S. Saito(NICT) and Y. Miyoshi(ISEE, Nagoya University)

Whistler mode chorus waves cause scattering and acceleration of energetic electrons in the inner magnetosphere, and recent Arase observations identified that chorus waves cause the pulsating aurora. The interaction processes have been modeled as diffusions in the velocity space, and it has been supposed that the scattering rate increases with increasing the wave amplitude. However, the wave-particle interactions with chorus waves are non-linear process, so that it is expected that the scattering rate does not simply depend on the wave amplitude. In this study, we investigate chorus wave amplitude dependence of electron scattering using the GEMSIS-RBW simulation code. The GEMSIS-RBW simulation calculates variations of local pitch angle and energy of each test particle by the imposed chorus waves. In this simulation, chorus bursts that consist of multi rising tone elements are imposed at the equatorial plane, and these waves propagate along the field line with L= 4 by calculating the Maxwell equations.

We calculate the trajectory of a number of electrons with various energy with various wave amplitudes. We analyzed the electron motion in the phase space as well as the parameter ρ [Bortnick et al., 2008] that is a proxy of the ratio of the wave-induced and the background inhomogeneity effects for the momentum change of the resonant electron. We identified that the phase trapping effect decreases the precipitating flux and generates the butterfly type pitch angle distributions.

Overview of the DSX Satellite Mission

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Launched on 25 June 2019 into a medium-Earth orbit, the Demonstration and Science Experiments (DSX) satellite is comprised of a number of experimental payloads designed to: (1) validate models of Very Low Frequency (VLF) wave injection, propagation and particle scattering in the magnetosphere; (2) measure the distribution of energetic particles and plasmas; and (3) investigate radiation effects on advanced spacecraft technologies. The primary mission goal of DSX is to determine the feasibility of injecting VLF waves into the magnetosphere and explore the dynamics of magnetospheric wave-particle interactions in a controlled manner. The Wave-Particle Interactions Experiment, which includes a VLF transmitter (UMass/Lowell), broadband receiver (Stanford University) and a magnetometer (UCLA), has been successful in injecting VLF waves into the far-field. This has been demonstrated through bistatic detection of DSX transmissions by the Arase satellite and monostatic detection of DSX pulses reflected off the bottom of the magnetosphere. An overview of the DSX mission and highlights of the first year of operation will be presented.

Inner Magnetosphere Plasma and Field Dynamics

V. K. Jordanova

In this lecture, we review the dynamics of energetic particles in the near-Earth space environment, which are strongly coupled to the variations of the electric and magnetic fields. On one hand, the electric and magnetic fields guide the particle acceleration and loss as particles drift through the inner magnetosphere and precipitate into the ionosphere or flow out of the dayside magnetopause. On the other hand, the fields themselves are influenced by the particle dynamics, since the magnetic field depends on the plasma pressure, while the electric field depends on the ionospheric conductance and particle precipitation. In addition, the major processes that contribute to particle loss such as charge exchange, Coulomb collisions, and wave-particle interactions and their aeronomical effects are discussed.

The characteristics of EMIC (ElectroMagnetic Ion Cyclotron) waves in the magnetosphere using the Van Allen Probes and Arase observations

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Electromagnetic ion cyclotron (EMIC) waves have been driven by temperature anisotropy of energetic ions near the magnetic equator. These waves constitute a significant loss process of energetic protons and sub-relativistic electrons through pitch-angle scattering by wave-particle interactions. We investigated the statistical characteristics of EMIC waves in the magnetosphere observed by the Van Allen Probes (RBSP) and Exploration of energization and Radiation in Geospace (Arase) satellite. In our recent studies, we found that EMIC waves show significantly different characteristics at the different peak occurrence regions depending on geomagnetic environments. During disturbed geomagnetic conditions, EMIC waves are predominantly observed in the afternoon sector where cold plasma dominates ($L < 6$). These waves mainly appear in the morning sector at $L > 8$ during extremely quiet conditions. On the dayside, EMIC waves have peak occurrence at L~4-8 in the recovery phase of a magnetic storm. This observational fact suggests that the major driver of EMIC waves depends on geomagnetic conditions and environments. In this presentation, we show spatial distributions and wave properties of EMIC waves in the magnetosphere, and discuss possible free energy sources causing EMIC waves at different regions. We will demonstrate the influence of different generation processes of EMIC waves on energetic proton distributions using in-situ satellite observations and theoretical model calculations.

Study of Phase Relationship of Sunspot Numbers with F 10.7 cm Solar Radio-Flux and Coronal Index using Wavelet-Transform Technique

S.K. Kasde and D.K. Sondhiya

In this work advanced wavelet based techniques such as Continuous Wavelet transform (CWT), Cross Wavelet Transform (XWT) and Cross-Recurrence Plot's (CRP) are used to study the phase relationship between Sunspot numbers, solar radio flux at 10.7cm Coronal index. All the parameters were analyzed for complete solar cycle 23 and ascending phase of solar cycle 24 (i.e. time span 1 January 1996-31 December 2013) on the basis of daily and monthly count. We have identified the essential characteristic of solar cycle maxima and found the asynchronous behaviors between the parameter analyzed. Our results are in agreement with the previous findings and suggested that the solar activity maxima occur at least twice during a cycle: first, near the end of the increasing activity phase and then in the early beginning years of the declining phase. It was also found that odd and even numbered Solar Cycles(i.e. solar cycle 23 and 24) are essentially not in phase and have a phase difference of two months. The sunspot number shows significant phase relation of 27 days with solar radio-flux and coronal index (CI) corresponding to one solar rotation, during the maximum phase of the cycles. It suggests that the magnetic field system originated in the photosphere in form of active regions and their evaluations are inadequately coupled in the entire solar cycle.

Auroral substorm events as seen from Syowa-Arase-Tjornes conjugate observations

Ryuho Kataoka, Herbert Akihito Uchida, and Kiyoka Murase (NIPR)

We introduce our recent papers on substorm-related auroral phenomena as obtained from the event studies of magnetically conjugate observations among Syowa station in the Antarctic, the Arase satellite, and Tjornes in Iceland. The major topics to be introduced are the conjugacy of breakup auroras and the mesospheric ionization during different phase of substorms.

Energetic particle precipitation characteristics and its atmospheric impacts derived from electron density profile measurements

A. Kero (SGO/OU)

The height-dependent electron density profile, and its time-dependent response to variable ionising radiation from space, yields information on both the ionisation source processes (solar electromagnetic radiation, energetic particle precipitation, cosmic rays) and their consequences on the atmosphere (changes in chemistry, energetics and dynamics).

An inversion technique for determining the EPP characteristics, i.e., precipitation flux density spectrum and ionisation rate profile is introduced. In addition, potential chemical consequences of the energetic particle precipitation are assessed. In this approach, a detailed ion chemistry model (SIC) is used as a time-dependent forward model in the MCMC based inversion.

The Role of Injected Ring Current Ions in Generating EMIC Waves and Scattering Radiation Belt Particles

Hyomin Kim, Sung-Jun Noh, Ilya Kuzichev, Louis Lanzerotti, Andrew Gerrard (New Jersey Institute of Technology), Quintin Schiller (Space Science Institute), Mark Engebretson (Augsburg University), Khan-Hyuk Kim (Kyung Hee University), Marc Lessard, Harlan Spence (University of New Hampshire), Dae-Young Lee (Chungbuk National University), Jürgen Matzka (GFZ Potsdam), Tanja Fromm (Alfred-Wegener Institute), Lauren Blum (University of Colorado, Boulder)

We report on observations of electromagnetic ion cyclotron (EMIC) waves and their interactions with injected ring current particles and high energy radiation belt electrons. The magnetic field experiment aboard the twin Van Allen Probes spacecraft measured EMIC waves and proton flux data from the spacecraft show that the waves were associated with particle injections. The wave activity was also observed by a ground-based magnetometer near the spacecraft geomagnetic footprint over a more extensive temporal range. Phase space density (PSD) profiles, calculated from directional differential electron flux data from Van Allen Probes, show that there was a significant energy-dependent relativistic electron dropout over a limited L-shell range during and after the EMIC wave activity. The NOAA spacecraft observed relativistic electron precipitation associated with the EMIC waves near the footprint of the Van Allen Probes spacecraft. The observations suggest EMIC wave-induced relativistic electron loss in the radiation belt. In addition, a statistical survey of EMIC wave occurrences has been conducted using Van Allen Probes data over the entire mission period (September 2012 to July 2019). Approximately 10% of the entire set of EMIC waves were generated or intensified during ring current ion injection events. Injection-associated EMIC waves occurred predominantly over the noon to dusk sectors and peak occurrences coincided with where the plasmaspheric plume is most likely to occur. The particle data from the spacecraft positioned in the heart of the ring current system present complex, energy-dependent hot proton anisotropy variations during most of the injection-associated EMIC waves. We aim to understand the role of injected ring current ions in generating EMIC waves and scattering radiation belt particles.

On the use of three-component ELF/VLF measurements of radio atmospherics in investigation of lightning related phenomena

I. Kolmasova (IAP CAS and Charles University) and O. Santolik (IAP CAS and Charles University)

We present results of three-component ELF/VLF measurements of radio atmospherics, which we have recorded in a favorable electromagnetic environment on the summit of La Grande Montagne (1028 m, 43.94N, 5.48E), Plateau d Albion, France.

These measurements were used to obtain information about properties of causative lightning strokes of transient luminous events or long-duration whistler echo-trains. We also analyzed tweek atmospherics to study the properties of the winter-time Earth-ionosphere waveguide.

To detect radio atmospherics we used a 10-cm spherical electric antenna located 2 m above the ground and two 12-turn magnetic loop antennas of 4 square meters oriented in E-W and S-N directions. The sensors were coupled with a receiver sampling at 50 kHz. The 3-component measurements allowed us to determine the direction of arrival of recorded atmospherics. The polarity of causative lightning strokes was derived from the polarity of their ground wave pulses in the electric field records. Using the Hilbert transform we calculated the analytical signal and instantaneous frequency of the recorded dispersed tweek atmospherics and estimated their propagation distance. The magnetic field records of these dispersed atmospherics were examined to obtain their polarization properties.

Statistical Properties of Auroral Kilometer Radiation

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In the present study, a detailed statistical analysis of more than 20 months of continuous AKR measurements on the ERG satellite (also called Arase) is carried out. This made it possible to confirm the previously obtained results on the location of AKR sources and seasonal changes in the radiation intensity. Open issues about the processes in the AKR source can be solved using data on the radiation pattern under various geomagnetic conditions. In order to get answers to these questions, an estimate is made of cone angle of directional diagrams in the evening and morning sectors of the Earth's magnetosphere.

Evolution of the energetic electron flux observed by ARASE satellite and simultaneous aurora over Kola Peninsula

B. V. Kozelov, A.V. Roldugin, Z. V. Dashkevich, A. G. Demekhov (PGI, Russia), S. Oyama (Nagoya University, Japan), Y. Miyoshi (Nagoya University, Japan), S. Kasahara (University of Tokyo, Japan)

The data of simultaneous observation of the energetic electron flux by ARASE satellite and aurora by ground-based all-sky cameras in Murmansk region (Russia) have been analyzed for time interval 00:00-01:00 UT, March 31, 2017. The energetic spectra of middle-energy electrons observed by MEPE detectors in the loss cone have been used for simulation of the aurora emissions in the atmosphere. The temporal evolution of the simulated emission intensity has been compared with emissions observed near the magnetic field-aligned footprint point for the satellite. The data from cameras located in Apatity and Lovozero have been used. It was found that the projection along magnetic field has been distorted by developing disturbance. These distortions have been analyzed by magnetosphere model simulation.

Contribution of electron pressure to ring current and ground magnetic depression using RAM-SCB simulations and Arase observations during geomagnetic storms

Sandeep Kumar, Y. Miyoshi (ISEE, Nagoya University) V. K. Jordanova, M. Engel (Los Alamos National Laboratory, Los Alamos, NM, USA) K. Asamura (ISAS/JAXA, Japan), S. Yokota (Osaka University, Japan), S. Kasahara (University of Tokyo, Japan), Y. Kazama, S-Y. Wang (ASIAA, Taiwan), T. Mitani (ISAS/JAXA, Japan), K. Keika (University of Tokyo, Japan), T. Hori, C. Jun (ISEE, Nagoya University), and I. Shinohara (ISAS/JAXA, Japan)

Understanding the physical processes that control the dynamics of energetic particles in the inner magnetosphere is important for both space-borne and ground-based assets essential to the modern society. The storm time distribution of ring current particles in the inner magnetosphere depends strongly on their transport in evolutions of electric and magnetic fields along with acceleration and loss. In this study, we investigated the ring current particle variations using observations and simulations. We compared the ions (H+, He+, and O+) and electrons flux variations using Arase observations with the self-consistent inner magnetosphere model: Ring current Atmosphere interactions Model with Self Consistent magnetic field (RAM-SCB) during 7-8 November 2017 geomagnetic storm. We investigated the contribution of the different species (ions and electrons) to the magnetic field deformation observed at ground magnetic stations (09-45° MLat) using RAM-SCB simulations. The results show that the ions are the major contributor with ~ 88 % and electrons contribute ~ 12% to the ring current pressure. It is also found that the electrons contribute to ~ 18 % to the ring current in dawn-side during the main phase of the storm. Thus, electrons contribution to the storm time ring current is important and should not be neglected.

Disturbances of the Subpolar ionosphere over the Asian part of Russia during the geomagnetic storms of 2017-2020

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The paper presents the results of a comprehensive analysis of data from optical, radiophysical and magnetometric instruments during ten weak and moderate geomagnetic storms of the autumn-winter seasons 2017-2020. We used the measurement data of the ISEE, Nagoya University instruments (broad-beam riometer system, all-sky airglow imager system, VLF/ELF loop antenna system) and ISTP SB RAS (three-component induction magnetometer LEMI-30,wide-angle RGB-camera, patrol spectrometer and photometer with silicon photomultipliers detectors) at the Istok station, the complex of radiophysical instruments of the ISTP SB RAS located in the Asian part of Russia (the Yekaterinburg HF radar, ionosonde DPS-4 in Norilsk, chirp oblique incidence sounding along Norilsk-Irkutsk and Magadan-Irkutsk paths) and 2 SuperDARN Hokkaido radars (East / West) operated by ISEE, Nagoya University. The features of spatial distributions and temporal variations of disturbances in this sub-polar ionospheric region under conditions of low activity at the end of the 24th solar cycle are revealed.

Specific artifacts in ELF/VLF loop antenna system data, which could influence on the data interpretation, were revealed. We analyze the occurrence rate of the artifacts, discuss their possible sources and ways of dealing with their interference. The prospects of experimental studies related to the introduction of the Magadan HF radar are outlined.

The relationship between substorm-onset related IPDP-type EMIC waves and drift-shell splitting

Marc R. Lessard (Univ of New Hampshire), Michelle Salzano (Univ of New Hampshire), Sungjun Noh (Univ of New Jersey), Hyomin Kim (Univ of New Jersey), Mark J. Engebretson (Augsburg University), Richard Horne (British Antarctic Survey), Mark Clilverd (British Antarctic Survey), Akira Kadokura (National Institute of Polar Research), Yoshimasa Tanaka (National Institute of Polar Research), Khan-Hyuk Kim (Kyung Hee University), Jürgen Matzka (GFZ Potsdam), Tanja Fromm (Alfred Wegener Institute) and Colin Waters (University of Newcastle)

The relationship between Pi1B and IPDP-type EMIC waves was first discussed in 1971 by R. R. Heacock, who found that Pi1B and IPDPs occur near-simultaneously in ground observations, though they are spatially separated; IPDPs appear at lower geomagnetic latitudes (60-65 degrees) than PiBs, which are more prominent at ~70 degrees. It is well understood that Pi1B waves are correlated with substorm onset, but it is often overlooked that IPDP-type EMIC waves can be as well; they are thought to be associated with increased fluxes of 40-60 keV substorm-injected protons, which was first modeled in 1980 by F. Søraas. Others have postulated that IPDP waves are excited by protons that undergo gradient-curvature drifting and eventually interact with the cold plasmapause population, but oft-neglected is the important role that drift-shell splitting plays in the process. Our research attempts to understand the different pathways that Pi1B and IPDPs take from their shared origin in substorm onset to their distinct observations on the ground, including the effects of drift-shell splitting en route. We present two case studies showcasing data from an array of four ground-based Antarctic magnetometers that cover the evening sector, as well as in-situ magnetometer data, proton fluxes, and proton pitch angles from the Van Allen Probes. Our observations corroborate the separation in MLAT between Pi1B and IPDPs and additionally pinpoint a separation in MLT, with IPDPs occurring roughly two hours earlier than Pi1B observations. Building from our observations we model the drift-shell splitting which injected particles undergo post-onset, with the expectation that this work will provide an improved model for the process.

Ionospheric climatology at South American sector using amplitude scintillation index S4

E. Macho, E. Correia (Universidade Mackenzie)

Scintillations are caused by ionospheric irregularities and can affect trans-ionospheric radio signals. One way to understand and predict such irregularities is through ionospheric climatology using scintillation indexes during different periods of times of solar cycle in different regions, including the Equatorial Ionospheric Anomaly (EIA) and the South Atlantic Magnetic Anomaly (SAMA) regions. In this work we are using amplitude scintillation index S4 during the full solar cycle 24 at South American sector. Preliminary results show a significant intensification of ionospheric fluctuation at northern and southern crest of EIA, especially during the southern hemisphere's spring/summer seasons, with a higher increase during solar maximum. In the SAMA region, where the intensity of field magnetic lines is lower, the fluctuation is much higher during the spring/summer months of solar maximum.

Ionosphere Behavior during the Geomagnetic Storms over the different latitude Regions

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In the present study, we have done the investigation of the ionospheric perturbations during geomagnetic storms which are disturbed conditions in earth's magnetic field. Geomagnetic storm leads to a number of disruptions in technological applications such as space vehicle operation, interrupt radio communication, and disrupt power grids. Quantitative analysis has been done in three different storm criterions, strong, weak and moderate ones and their response in the ionosphere has been investigated over different latitude. Fair enough results have been witnessed in different longitudinal and latitudinal regions over the globe. An attempt has been made to find some qualitative and quantitative relationship between the storm and ionospheric perturbations with different latitudinal indices.

Why it is important to have simultaneous ground-based ELF-VLF observations in every satellite project?

J. Manninen (SGO, University of Oulu), C. Martinez-Calderon (ISEE, Nagoya University), and T. Turunen (SGO, University of Oulu)

The ERG (Exploration of energization and Radiation in Geospace) project is a mission to elu-cidate acceleration and loss mechanisms of relativistic electrons around Earth during geospace storms. The project consists of a satellite observation team, a ground-based network observation team, and integrated data analysis/simulation team. After launch, the ERG satellite was renamed Arase.

All satellite projects observing geospace also need reliable and high-quality ground-based data in order to explain different kinds of events observed by the satellites. While the Arase satellite has several particle, plasma waves and magnetic field instruments, it is sometimes difficult to separate spatial and temporal features in the observations. In such cases, the availability of ground-based instruments can be very helpful.

It is also important to remember that most of satellites are moving very rapidly. They are covering several L shells, many longitudes, different MLTs, nightside/dayside, etc. within hours or even minutes. It means that every single satellite data sample is related to a different location of the satellite, i.e., such data easily shows the spatial distribution of the observed events. If we want to study temporal changes of the same events we need ground-based observations.

In this presentation, we will show ground-based ELF-VLF observations made at Kannuslehto (KAN) in northern Finland during the conjugated observation campaigns of Arase.

Recent characteristics and propagation of unusually high frequency VLF emissions at Kannuslehto, Finland

C. Martinez-Calderon (ISEE, Nagoya University), J. K. Manninen (SGO, University of Oulu), J. T. Manninen (SGO, University of Oulu), and T. Turunen (SGO, University of Oulu)

First reported by Manninen et al., 2016, Kannuslehto High-Frequency VLF (KHF-VLF) waves have been observed at the ground station of Kannuslehto in northern Finland (KAN, MLAT=64.4°N, L=5.46) since 2006. These VLF emissions are observed above the local electron gyrofrequency for the L-shell of KAN (fce ~ 5- 6 kHz) where these type of waves should not usually propagate. KHF-VLF have different spectral features, but are mostly composed of hiss-like bursts with durations of a few seconds. KHF-VLFs have been observed in at least 60% of the observation campaign days at KAN, and seem linked with high solar activity.

Using case studies and statistical analysis from the 2017-2020 KAN campaigns, we present the general properties and propagation characteristics of KHF-VLF waves. We show examples of KHF-VLF, their occurrence rate as a function of MLT, wave type, periodicity, and number of bursts. We found that their occurrence is related to more usual VLF waves suggesting their generation is not ionospheric in nature. Using observed frequencies combined with conjugated events and ray tracing, we discuss the likely location of the source of these emissions, and the mechanisms allowing for propagation to the L-shells of KAN. Occurrence of KHF-VLF waves appear positively correlated with AE index, however their detection on the ground is coupled with a local decrease of the magnetic field.

Identifying the Physical Mechanisms to Explain the Extreme Plasmaspheric Erosion for the September 2017 Storm

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An extreme erosion of the plasmasphere (LPP < 2) occurred during the September 2017 storm. The cold electron density is identified from the upper limit frequency of upper hybrid resonance waves observed by the Plasma Wave Experiment instrument onboard the Exploration of energization and Radiation in Geospace/Arase satellite. The electron density profiles reveal that the plasmasphere was severely eroded during the recovery phase of the storm and the plasmapause was located at L = 1.6 at 23 UT 8 September 2017. The degree of the severity is much more than what is expected from the relatively moderate value of the SYM - H minimum (−146 nT). Observations of ground-based magnetometers near the magnetic equator indicate a long duration penetration electric field. It is not fully understood why the electric field disturbance lasted for several hours and whether it was caused by the long duration penetration electric field. In this presentation, we will address these questions by using numerical simulations of a combination of two physics-based models: the Ionosphere-Plasmasphere-Electrodynamics (IPE) model and Comprehensive Inner Magnetosphere Ionosphere (CIMI) model. Furthermore, we will discuss the role of the ionospheric conductance in the electric field disturbance.

Experimental observation of the transverse Alfvénic resonator for Pc4 pulsations: a Van Allen Probes case study

Olga S. Mikhailova, Pavel N. Mager, Olga V. Mager, Dmitri Yu. Klimushkin

A Pc4 ultralow frequency wave was detected nearby the plasmapause by spacecraft Van Allen Probes B. The strong periodical modulation of the wave was observed that means a beating of oscillations close in frequency. There were at least two harmonics with frequencies of 15.3 and 13.6 mHz. It is shown that these harmonics can be the eigenmodes of the transverse resonator near the plasmapause at the local maximum of the Alfvén velocity. It was found that the observed wave was in a drift resonance with energetic 80-keV protons. An unstable bump on tail distribution of protons simultaneously observed with the wave is supposed to be source of the wave. The estimate of the azimuthal wave number m is about −100, that means a westward propagating azimuthally small-scale wave.

The work was supported by the Russian Science Foundation under grant 18-17-00021.

Geomagnetic and solar activity in solar cycles 23 and 24

R. Miteva (IANAO), S. W. Samwel (NRIAG)

We present statistical analysis of geomagnetic storms and accompanied solar activity events (solar flares, coronal mass ejections and energetic electrons) in solar cycles 23 and 24. Both directions of associations are explored for each paired phenomena. The results are summarized and discussed.

Highlight and future perspective of the ERG/Arase project

Y. Miyoshi (ISEE, Nagoya University)

The ERG project aims to understand variations of gepspace and radiation belts by comprehensive research teams consist of the satellite, the ground-based observations and simulations. The Arase satellite has observed dynamical evolutions of geospace since March 2017 and is providing new findings from collaborative researches with ground-based observations and other satellite observations. In this lecture, we will present several highlight results from Arase/ERG project and discuss future perspectives for geospace research.

Statistical investigation of cross energy coupling during magnetic storms; Arase observations

Y. Miyoshi, S. Kurita, R. Kataoka, T. Mitani, I. Shinohara, M. Teramoto, I. Park, S. Kasahara, S. Yokota, K. Keika, T. Hori, N. Higashio, S. Imajo, C-W.Jun, A. Matsuoka, F. Tsuchiya, A. Kumamoto, Y. Kasahara, S. Matsuda, M. Shoji, D. Turner, and J. F. Rippole

The Arase satellite has observed a number of magnetic storms since March 2017, which corresponds to the declining phase of the solar cycle 24. We performed the superposed epoch analysis of energetic electrons and related parameters in the inner magnetosphere using data obtained by Arase satellite. The electron measurements in the wide energy range are utilized to clarify the cross energy coupling process during storms. The energetic electron flux variations strongly depend on the storm phase and L-shell as well as the electron energy. Electrons with energies ranging from tens of keV to ~200 keV largely increase their fluxes in the outer radiation belt during the main phase, and the electron fluxes gradually decrease during the recovery phase. The sub-relativistic/relativistic electrons show different flux variations. The electron fluxes decrease at the outer part of the outer belt during the main phase, and the fluxes gradually increase from the inner part of the outer belt during the recovery phase. The variations in the energy spectrum and phase space density indicate that the local accelerations mainly contribute to enhancements of MeV electrons in the outer belt. In this study, we discuss variations in the energy spectrum by considering different roles of each energy range in the cross energy coupling process, i.e., source population for generating waves, seed population for subsequent acceleration, and relativistic electrons.

The ionospheric response to 27 September magnetic storm on 2017 at the equator.

Heba S.Mohamed(CIC) , Ayman M. Mahrous (E-Just)

In this study we monitor the ionospheric response for 26th September magnetic storm at the magnetic equator over Asia and South America through the magnetic equator using IGS stations and some magnetic and solar parameters. The used stations are CUSV from Thailand (13.7 lat/100.5 long) and KOUR from French Guiana (5.2 lat/-52.8 long) geographically. We observed a magnetic disturbance -100 nT in DST due to a south ward Bz component triggered from a high speed solar wind from coronal hole 32. The solar wind gone beyond 700km/s and the AE index is 1000nT. The kp index is 7. The ionospheric response (time since the SSC till the maximum value of DTEC) within 31 hr range in Thailand. The ionospheric response in French Guiana within the range 26 hr. however it occurs in the nightside. Despite the difference in location and local time occurrence of the stations, the both stations show a positive ionosphere TEC value.

Kinetic instability driven by using non-Maxwellian kappa (k) and (r, q) distribution function.

Thesis in progress

Electrosatic model basically such as ion-acoustic and dust-acoustic and Langmuir waves generated in plasma have been usually study by using fuild and Boltzmann kinetic vlasov models. These studies had assumed Maxwellian velocity distribution function for the plasma particle. However, with more empirical data becoming available it is realize that the Maxweelian is not a realistic distribution under all situation. Because Maxwellian distribution is applicable to a system in thermodynamics equillibrium. Howeeve, a realistic system may be far away from this state since the plasma may be subject to a whole variety of different effect.

Vasyliunas is the first to apply the general form of the non-Maxwellian (kappa) distribution. On the basis of theory, application and observation, it is notice that the space and astrophysical environment (plasma) often contain superthermal particle and high energy tails that the kappa distribution offer a useful fit to there "spectral" distribution. So msotly space plasma problem can be moduled more affectively by superposition of kappa distribution fumction intead of Maxwellaian distribution fuction.

The generalize kappa distribution function is reduce back to Maxweellian behaviour. In the limit as $\kappa \rightarrow \infty$, the Kappa distribution approaches the well know Maxweellian distribution function.The condition $\kappa > 1/2$ is necessary for this integral to converge.

The another non-Maxweellian distribution we introduce a three dimenssional generalized (r, q) distribution. This distribution function is of a more genral form than the above mentioned kappa distribution and hence better suited to module plasmas exhibiting characteristic which cannot explain by the kappa distribution function. This distribution function containing spectral indices r and q. We also note that the spectral indices r and q satisfy the constraints $q>1$ and $q(1+r)>5/2$. The generalized (r, q) distribution function reduce back to the kappa distribution function if $r=0$ and $q= k+1$ and also to the Maxwellian if $q\rightarrow \infty$ and $r= 0$. If we fix the value of q and increase the value of r then the contribution of high-energy particle reduces but the shoulders in the distribution function increase. The same situation also occurs increase the value of q and keepimg fix the value of r.

We adopt this distribution function because it give a better data fit to the emperical data, especially when there are shoulder in the profile of distribution function along with a high-energy tail.

Applying kappa and generalized (r,q) distribution function with a real valued spectral indices k and (r, q), we determine the disperssion relation for some electrostatic mode in cometry plasma.

The real and imaginary part of the dielectric response function D(k, w) for these modes are calculated and then compared with those of the Maxwellian distribution.

Observations of drifting hole structures in radiation belt electrons induced by EMIC waves

S. Nakamura, Y. Miyoshi, K. Shiokawa, T. Hori, S. Imajo (ISEE, Nagoya Univ.), T. Mitani, T. Takashima, I. Shinohara(ISAS/JAXA), Y. Omura, A. Matsuoka (Kyoto University)

We present observations of drifting hole structures in radiation belt electrons. The Arase satellite and Van Allen Probes often detect fine structures in energy spectra of particle fluxes. We examined time variations of energetic electron fluxes normalized by their averaged fluxes over the previous 10 minutes. The flux variation shows 1-min scale depressions with clear energy dispersion, which appear only in the relativistic energy ranges (500 keV - a few MeV) and small pitch angles. We find that these "drifting hole structures" are frequently observed with EMIC waves in space or around the ionospheric footprint of a satellite. The energy range and the pitch-angle dependency of drifting hole is consistent with nonlinear cyclotron resonances with EMIC waves. These observational characteristics suggest that EMIC waves cause a strong pitch-angle scattering, leading to a sharp loss of small pitch-angle electrons. We show some examples of simultaneous observations of drifting hole structures and EMIC waves observed by the Arase satellite and Van Allen Probes, and compare the results with nonlinear resonance theory and drift periods of relativistic electrons.

Statistical analysis of spatial distribution of wave spectra observed by PWE/OFA on board the Arase

K. Nakashima (Kanazawa Univ.), Y. Kasahara (Kanazawa Univ.), S. Matsuda (ISAS/JAXA), and A. Matsuoka (Kyoto Univ.)

The Arase satellite was launched in December, 2016 to achieve comprehensive observations of plasma/particles, fields, and waves. The Plasma Wave Experiment (PWE) is one of scientific instruments aboard the Arase, and it measures electric field from DC to 10 MHz and magnetic field from a few Hz to 100 kHz (Kasahara et al., 2018). The OFA (onboard frequency analyzer) is one of the receivers of the PWE and it continuously measures electric and magnetic wave spectra in the frequency range from 64 Hz to 20 kHz (Matsuda et al., 2018). This frequency range is crucial for the plasma wave observation because chorus waves, magnetospheric hiss, lightning whistlers and magnetosonic waves are detected, with a time resolution of 1 second as a nominal operation mode.

In the present paper, we statistically analyzed the data from OFA in order to clarify the spatial distribution of the electric and magnetic field intensity of the typical emissions observed in the inner magnetosphere. First we compared our result with the previous statistical work which was done using the spectrum data from the EMFISIS aboard Van Allen Probes (e.g. Malaspia et al., 2017). Furthermore, we examined the spatial distribution of the wave activities in the off-equatorial region, as the inclination of the Arase is 31 degrees which is much larger than the ones of Van Allen Probes (~10 degrees). In the presentation, we will report the global distribution of various kinds of plasma waves as a function of magnetic latitude, magnetic local time and L-value.

Kasahara et al., Earth Planets Space, 2018.
Matsuda et al., Earth Planets Space, 2018.
Malaspia et al., J. Geophys. Res., 2017.

Study of ionospheric plasma dynamics at sub-auroral latitudes using the SuperDARN radars

N. Nishitani (ISEE, Nagoya University)

The sub-auroral ionosphere is the region equatorward of the auroral precipitation region. Owing to the effect of the polarization electric field in the presence of sub-auroral plasma density depletion region, a wide variety of phenomena such as intense plasma flows denoted as Sub-Auroral Polarization Streams (SAPS), as well as their wave variations (SAPS wave variations: SAPSWS) due to plasma instabilities, are observed. In addition, there are also phenomena related to the dynamical interactions between the ionosphere and the neutral atmosphere, leading to Traveling Ionospheric Disturbances (TIDs), although they are not limited to the sub-auroral ionosphere. Since these phenomena contain both temporal and spatial variations, two-dimensional observations with high temporal resolution such as mid-latitude Super Dual Auroral Radar Network (SuperDARN) are crucial for studying them. In this lecture, a brief introduction of the (mid-latitude) SuperDARN, and recent progress of understanding the plasma dynamics in the sub-auroral ionosphere, will be presented.

A statistical investigation of magnetospheric and Ionospheric effects on EMIC wave propagation

Sung-Jun Noh (CSTR, NJIT), Hyomin Kim (CSTR, NJIT), Marc Lessard (UNH), Mark Engebretson (Augsburg University), Eun-Hwa Kim (PPPL, Princeton University), Viacheslav Pilipenko (SPACE Research Institute RAS), Robert Redmon (NCEI, NOAA)

Electromagnetic ion cyclotron (EMIC) waves are known to play an important role in inner magnetospheric dynamics. EMIC waves are generated with L-mode polarization near the magnetic equator where the intensity of the magnetic field is minimum. The generated EMIC waves propagate along the background magnetic field and can reach the ground. We investigated propagation characteristics of EMIC waves using data from a space-ground conjugate pair: a ground magnetometer at Sanikiluaq, Canada (56.32°N, 280.86°E) located at a geomagnetic footprint of the GOES 13 spacecraft (at a geosynchronous orbit, 285°E). This study focuses on two observational aspects. First, we surveyed EMIC waves observed by GOES 13 to examine whether the waves were observed both in space and on the ground simultaneously. The wave properties and geomagnetic conditions were then investigated to address which factors mainly affect the conjugacy of the EMIC wave. Second, using the simultaneously observed wave events, we explored the higher frequency ($f > 0.5$Hz) wave filtering effect related to the ionospheric effect.

Field-aligned Low-energy Ion Flux Enhancements of H+ and O+ in the Inner Magnetosphere Observed by Arase

M. Nosé (ISEE, Nagoya University), A. Matsuoka (Kyoto University), Y. Miyoshi (Nagoya University), K. Asamura (ISAS/JAXA), T. Hori (Nagoya University), M. Teramoto (Kyushu Institute of Technology), I. Shinohara (ISAS/JAXA), and M. Hirahara (Nagoya University)

The present study examines the low-energy ion flux variations observed by the Arase satellite in the inner magnetosphere. From the magnetic field and ion flux data obtained by the fluxgate magnetometer (MGF) and the low-energy particle experiments–ion mass analyzer (LEPi) onboard Arase, we find 55 events of the low-energy O+ ion flux enhancement accompanied with magnetic field dipolarization in the periods of April 1–October 31, 2017 and July 1, 2018–January 31, 2019. The low-energy O+ flux enhancements (1) start a few minutes after the dipolarization onset, (2) have energy-dispersed signatures with decreasing energy from a few keV down to ~10 eV, (3) can be observed in both storm and non-storm periods, (4) have a field-aligned distribution (pitch angle ~ 0 deg below the equator and pitch angle ~ 180 deg above the equator), and (5) increase the O+ density and the O+/H+ density ratio by ~8 times and ~3 times, respectively. We perform numerical simulations to trace ion trajectories backward and forward in time from the Arase positions. From the backward tracing results, we find that the low-energy field-aligned ions observed in the inner magnetosphere by Arase are coming from the upper ionosphere at altitude around 300–2,500 km after acceleration in the perpendicular direction. The ion acceleration appears to be mass-dependent and take place immediately after the onset of dipolarization. The forward tracing reveals that both H+ and O+ ions drift eastward and reach the dawn-to-morning sector without being lost in the ionosphere, when the pitch angle scattering effect is considered near the equatorial plane. This result suggests that these low-energy field-aligned ions can contribute to formation of the warm plasma cloak and the oxygen torus.

Energetic Electron Precipitations Showing ULF Modulation of VLF/LF Transmitter Signals

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Ultra low frequency (ULF) modulation of energetic electron precipitations has been observed by satellites, GPS-total electron content (TEC), riometers and X-ray [e.g., Brito et al., 2012]. However, there are few reports for the ULF modulation of the D-region ionosphere using very low frequency (VLF)/low frequency (LF) transmitter signals which are useful probe to observe >100keV electron precipitations. In this study, we investigate the D-region signatures of the modulation due to the ULF waves using a network of VLF/LF transmitter signals in North America. The transmitter signals from NLK (USA, 24.8 kHz, L = 2.88), NDK (USA, 25.2 kHz, L = 2.98) and WWVB (USA, 60.0 kHz, L = 2.26) were observed by a receiver at ATH (Athabasca, Canada, L = 4.31). We show oscillations in intensities and phases on the NDK-ATH and WWVB-ATH paths with periods of 3-6 minutes during a small substorm of 05:25-05:50 UT (22:25-22:50 LT) on 4 June, 2017, and 05:00-05:30 UT on 5 May, 2011 (geomagnetically quiet day). As for the event of 2017, the ground-based H-component magnetic field variations and Doppler velocity observed by the SuperDARN (Super Dual Auroral Radar Network) HF (high frequency, 8-20 MHz here) radars showed the same periodic changes as seen in the VLF/LF oscillations. Based on ground-based magnetic observations, there were Pi2 pulsations with the same periods with the VLF/LF oscillations both at high- and low-latitudes. On the other hand, rising tone chorus emissions were observed at ATHA in the frequency range of 4.5-6.5 kHz. Using Tsyganenko 2001 and 2004 magnetic field models, half of the electron gyrofrequency at the magnetic equator was estimated to be ~4 kHz. If the observed rising-tone emissions were the lower band chorus waves excited at the magnetic equator, the source region was at a lower L-shell than ATHA, where half of the electron gyrofrequency was just above 6.5 kHz and the chorus waves propagated obliquely to the field line and reached the outer L-shell. Such an obliquely propagating whistler-mode wave could cause resonant electron pitch angle scattering and precipitation of energetic electrons into the atmosphere. As for another event of 2011, there were similar oscillations in the VLF/LF intensities and phases on the NDK-ATH and WWVB-ATH paths with periods of 4-6 minutes. During the oscillations, variations in the Doppler velocity observed by the SuperDARN were detected around the VLF/LF paths. In this presentation, we will discuss the cause of these VLF/LF oscillations.

Results from a 3-D electron density model developed from COSMIC radio occultation data using artificial neural networks

Daniel Okoh (CAR-NASRDA)

A 3-D electron density model is developed from COSMIC radio occultation electron density profiles. Motivation for this work is based on the fact that the COSMIC radio occultation electron density profiles usually smear over wide range latitudes/longitudes, and so they are not precise representations of vertical electron density profiles for particular locations as often approximated in many research. Artificial neural networks are trained to learn 3-D ionospheric electron density distribution from numerous COSMIC radio occultation profiles. From the developed model, vertical electron density profiles that compare well with ionosonde vertical profiles are derived. Additional advantages for the developed model are that the COSMIC profiles used for the model development include topside measurements that reach about 800 km, and they also have good spatial coverage. Results from the developed model also enhance our understanding of phenomena like the equatorial ionization anomaly in 3-D space.

Estimation of ionospheric critical plasma frequencies from GNSS-TEC measurements using artificial neural networks

Vivian Otugo, Daniel Okoh, Charity Okujagu, Sylvester Onwuneme1, Babatunde Rabiu, Jean Uwamahoro, John Bosco Habarulema, Mpho Tshisaphungo, Nicholas Ssessanga

This paper describes a new neural network-based approach to estimate ionospheric critical plasma frequencies (f0F2) from GNSS-VTEC (Global Navigation Satellite System – Vertical Total Electron Content) measurements. The motivation for this work is to provide a method that is realistic and accurate for using GNSS receivers (which are far more commonly available than ionosondes) to acquire f0F2 data. Neural networks were employed to train VTEC and corresponding f0F2 observations respectively obtained from closely located GNSS receivers and ionosondes in various parts of the globe. Available data from 52 pair of ionosonde-GNSS receiver stations for the 17-year period from 2000 to 2016 were used. Results from this work indicate that the relationship between f0F2 and TEC is mostly affected by the seasons, followed by the level of solar activity, and then the local time. Geomagnetic activity was the least significant of the factors investigated. The relationship betweenf0F2 and TEC was also shown to exhibit spatial variation; the variation is less conspicuous for closely located stations. The results also show that there is a good correlation between the f0F2 and TEC parameters. The f0F2/TEC ratio was generally observed to be lower during enhanced ionospheric ionizations in the day time, and higher during reduced ionospheric ionizations in the nights and early mornings. The analysis of errors show that the model developed in this work (known as the NNT2F2 model) can be used to estimate the f0F2 from GNSS TEC measurements with accuracies of less than 1 MHz. The new approach described in this paper to obtain f0F2 based on GNSS TEC data represents an important contribution in space weather prediction.

The Effect of Prompt Penetration Electric (PPE) on Total Electron Content during Intense and Super Geomagnetic Storm Events at Low and Mid Latitude Regions

Owolabi T.P., Ariyibi E.A., Olatunbosun L.G.

This study evaluated the diurnal variations of ionospheric Total Electron Content (TEC) and determined the dependence of TEC on geomagnetic storms during different geomagnetic storm events at low- and mid-latitude stations with a view to understanding the effects of prompt penetration electric (PPE) field during the identified four intense and two super geomagnetic storm events that occurred between 2013 and 2015.

GPS data from the low-latitude and mid-latitude stations of Cotonou, Benin Republic at Geomag Lat. 8.71°N, Long. 76.42°E and Marseille, France at Geomag Lat. 44.32°N, Long. 87.25°E for 2013, 2014 and 2015 were obtained from the GPS receiver located at the stations.

The results of the diurnal variation of TEC showed that the maximum daytime TEC values of ~70 TECu at low latitude station of Cotonou is more than double the values of ~30 TECu at mid-latitude station of Marseille for the years considered. The intense storm event of 1 June, 2013 indicated that the percentage deviation of TEC from the mean TEC for the month was 11 and -20% and for Cotonou and Marseille stations respectively. Also, for the super storm event of 17 March 2015, 26 and 67% were the percentage deviation of diurnal TEC during storm from the monthly mean TEC for Cotonou and Marseille. The effect of PPE observed during the intense storm of 19 February 2014 revealed a gradual increase in daytime TEC value at low latitudes and a corresponding fluctuation in TEC values of ~10 TECu at mid-latitudes.

Event study of the M-I-T coupling in the ionospheric trough region for Kp = 0+

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Ionospheric trough is a low plasma-density area occasionally appeared at subauroral latitudes, typically seen for period of geomagnetic disturbances. On 20 February 2018, a zonally elongated ionospheric trough was developed from Fennoscandia to North America. Of notable interest was the geomagnetic activity, which was considerably quiet level as represented by Kp index of 0+ for the time interval interested in this study. The ionospheric trough was located at 70-71 deg N and the main auroral oval stayed at 74-76 deg N in the Fennoscandia sector. A minor but obvious auroral enhancement occurred at about 18:35 UT (~21 MLT) near Svalbard archipelago. We call this "pseudo-breakup" in this study. Coinciding with the pseudo-breakup, a red arc emerged from a breakup auroral blob appeared at the equator side edge of the auroral oval. Swarm measurements show a notable enhancement of the electron temperature at the trough minimum, which is the location of the red arc. This experimental evidence suggests that the event has captured a moment of the SAR-arc birth, which is usually masked by bright dynamical aurorae at the substorm expansion phase. Looking at the dynamics in the ionosphere and the thermosphere, westward turning of the ionospheric ion velocity from +200 m/s to -200 m/s was detected with the Dynasonde at Tromsoe, Norway (69.6 deg N), that is, in the ionospheric trough or slightly its equatorward side. At the same time, the collocated Fabry-Perot interferometer (FPI) also detected westward acceleration of the wind starting from +100 m/s (positive eastward) but without change its direction. The anti-directional velocities lasted for 19 min, and the energy flow for that period may have been from the ionosphere to the magnetosphere. Furthermore, Poynting flux derived from the Swarm measurements revealed upward energy flow at the trough minimum and Tromsoe latitude. These spatiotemporal sporadic and local phenomena coinciding with the pseudo breakup may be signatures induced by transitional processes in the M-I-T coupled system during the substorm expansion phase.

Flash-type auroral model using chorus-ray tracing analysis

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Flash-type aurora is a rapid (less than the duration of 1 s) auroral phenomenon driven by a single discrete chorus element. Flash aurora is useful for understanding the spatial-time evolution of wave-particle interaction regions in the magnetosphere. We simulate flash auroral morphology using chorus-ray tracing analysis to evaluate the effects of wave propagation to the auroral morphology in subauroral latitudes. The initial ray paths were injected at the magnetic equator from a point source. Then, resonant particles traced the magnetic field lines from the chorus ray paths in the magnetosphere to the ionosphere, and estimated column emissions using volume emission rate for N2 1st positive bands. The calculated column emissions for flash aurora showed a clear spatial dependence with respect to the latitudes. In this presentation, we will present the calculation model of flash aurora using chorus-ray tracing and volume emission rate and discuss the effects of chorus wave propagation on the flash auroral morphology (spatial size, anistropic spatial evolution etc.) in detail.

Extracting Plasmaspheric Contributions from Total Electron Content using Digisonde, COSMIC, and GPS Observations and Model Comparisons

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The ionosphere is defined as the layer of the Earth's atmosphere between 60 to 1,000 km that is ionized predominantly by solar radiation, resulting in the generation of free electrons and ions. Free electrons in the ionosphere and its overhead plasmasphere constitute a serious challenge to space-based trans-ionospheric radio propagation and satellite communication by introducing delays in the signals and thereby degrading the positioning accuracy. It has been a challenging task to develop a reliable model for estimating the accurate amount of delays introduced with the traversing radio signal in the plasmasphere and ionosphere. A realistic representation of bottomside (BTEC), topside (TTEC) total electron content, and plasmasphere electron content (PEC) is a crucial task for the accurate representation of ionosphere and plasmasphere model configurations. This is because the complete altitudinal electron density profile specification is restricted by a synchronised adequacy of data from ground or space-based instruments. In this article, we present sensible assimilation of peak parameters in the topside profiles from the FormoSat-3/COSMIC ionospheric occultations with the auto-scaled bottomside profiles from 39 global Digisonde rather than peak to topside extrapolation. Under a strict space-time collocation criterion, the integral electron content from the assimilated electron density profiles along with GPS derived TEC demonstrates altitude dependent contributions. The corresponding estimations from the empirical ionospheric and plasmaspheric models (IRI-2016, NeQuick-2, and IRI-Plas 2017) are also assessed to realize their discrepancies with respect to the observed ionospheric parameters. The statistical comparison metrics show relatively closer ionospheric electron content estimates from IRI with the assimilated results, followed by NeQuick and IRI-Plas models, with the last two models apparently showing an opposite behavior between bottomside and topside electron content discrepancies. However, although the TEC estimations reveal a relatively superior performance of IRI-Plas with successive proficiency of NeQuick and IRI models, the retrieved PEC data does not evident any clear statistical metrics and dictates further investigation. Nevertheless, this assimilation work leads towards improving the altitudinal representation of ionospheric models, particularly in the context of real-time representation of topside, bottomside, and plasmaspheric electron content through a reconstruction of the complete electron density profile.

Comparison of the ionospheric F2 peak height between digisonde measurements and IRI-2016 predictions over Irkutsk, Russia

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The International Reference Ionosphere (IRI) is the most commonly used community empirical model. The latest version IRI-2016 provides three options for the F2 peak height hmF2: AMTB 2013 (AMT), SHU-2015 (SHU), and BSE-1979 (BSE). In this paper, we used the hmF2 data derived by the digisonde at Irkutsk, Russia (52.5°N, 104.3°E) ranging from one year (a moderate solar activity Year: 2012) to assess the performance of these three options in the model. The results show that the variability of the observed hmF2 versus local time and seasons could be reproduced similar trends by the three options. However, the SHU-2015 option performs best at this station, followed by BSE-1979, and the AMTB2013.

Interaction of magnetospheric Pc1 waves with the ionospheric resonators and waveguides

Pilipenko V.A. (IPE)

The following topics are to be discussed:

-High-latitude Pc1 emissions as observed in Arctic and Antarctic;

-Filtering of magnetospheric waves upon transmission though the ionosphere;

-Distant Pc1 signal propagation along the ionosphere;

-Ionospheric ULF-ELF electromagnetic response to ground transmitters and lightning discharges;

-Man-made excitation of Pc1 emissions;

-New stations and databases for Pc1 studies.

EMIC wave induced proton precipitation during the 27-28 May 2017 storm: Comparison of BATSRUS+RAM-SCB simulations with ground/space based observations

Shreedevi P.R, Yiqun Yu, Yoshizumi Miyoshi, Xingbin Tian, Chae-Woo Jun, Kazuo Shiokawa, Vania Jordanova

Electro Magnetic Ion Cyclotron (EMIC) waves are known to initiate the ion precipitation into the mid latitude ionosphere during geomagnetic storms. Recent studies have shown that the EMIC wave induced ion precipitation can contribute significantly to the total energy flux deposition into the ionosphere and severely affect the magnetosphere-ionosphere coupling. In this study, the temporal and spatial evolution of the proton precipitation into the ionosphere and its correspondence to the EMIC wave activity in the inner magnetosphere is examined using simulations from the BATSRUS+RAM-SCB model. During the geomagnetic storm of 27-28 May 2017, the Van Allen Probes satellite observed typical signatures of EMIC waves in the inner magnetosphere i.e., at 4 to 6 Re in the evening sector. Ground magnetometers at high latitude stations also showed the presence of PC1/EMIC waves after 1600 UT on 27 May 2017. During the main phase of the storm, the DMSP satellites observed enhanced proton precipitation at locations where the ground/space based magnetic field measurements showed the presence of enhanced EMIC wave activity. The plasma source and distributions of associated temperature anisotropy in the equatorial plane are investigated to understand the excitation of the waves. A comparison of the precipitating proton fluxes obtained from the simulations with the particle measurements from the DMSP satellites show that EMIC wave scattering can account for the 30 keV proton precipitation at sub auroral latitudes. This study shows that the EMIC wave-particle interaction plays a significant role in the spatio-temporal evolution of the ion precipitation in the mid latitude ionosphere.

Analysis of Relativistic Electron Fluxes in the Outer Radiation Belt during an Intense and a Moderate Storm:-

S. Rathi, M.V.S. Krishna (IIT Roorkee)

We have analyzed the Radiation Belts Electrons(E~2.0 MeV) fluxes for two magnetic storms, an intense storm from 25-Aug-2018 to 30 Aug-2018 and a moderate storm 6-Nov-2017 to 10-Nov-2017, using the Van Allen A & B-REPT and ARASE-XEP data. Both the storms result in the increase of electron fluxes in the radiation belts. Enhancement is also observed using the GOES 15 data.

During the Intense storm recovery phase, the electron flux increases throughout the outer belt by more than one order of magnitude, and the peak shifts inward towards lower L(Re). A similar pattern is observed in all three satellite data. We also observed that these satellites show the flux enhanced only in dawn and dusk region and dawn-dusk asymmetry is seen. The flux enhancement is more in the dawn than dusk by one order of magnitude for L<5.6Re. For REPT A & B, the dawn-dusk flux ratio increases with L<4.29Re and decreases for higher L(<6Re). But ARASE shows an increasing dawn-dusk enhancement ratio with L(L<6Re).

The moderate storm results in order of magnitude enhancement of electrons for L<3.8Re but a slight decrease for 3.8Re<L>3Re and the peak of outer belt flux shits slightly outward towards high L, for both REPT and ARASE. The REPT shows enhancement in the dawn and noon sector whereas ARASE in noon and dusk sector. A dawn-dusk flux ratio is calculated using the REPT dawn and ARASE dusk data.

In both the storms, the dusk side flux decreases faster than the dawn side with increasing L suggesting a faster acceleration in the dawn sector by chorus waves(local acceleration) or the dusk losses are fast.

Geoeffectiveness of CME Clusters

J. M. Rodriguez Gomez (Skolkovo Institute of Science and Technology (Skoltech))

Rodriguez Gomez et al. 2020 shows that clusters of fast CMEs are statistically associating with the disturbance storm time index at Earth. It suggests that fast CMEs occurring in clusters tend to produce larger geomagnetic storms than isolated fast CMEs. In this work, the planetary K index were explored to find their relationship with clusters of fast CMEs during solar cycles 23 and 24.

Global observation of poloidal Pc4-5 waves in the magnetosphere before and during substorm

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We present a preliminary analysis of global observation of the first harmonic poloidal Pc4-5 waves observed on the dayside of the magnetosphere. Waves were observed for ~15 hours by widely spaced satellites of three missions (Van Allen Probes, THEMIS, GOES): 7–17 MLT and L = 4.5–8 RE. The first appearance of the waves was ~20 minutes before the substorm injection on the nightside (observed by GOES15) and ~30 minutes before AE index increase. Note that the solar wind conditions were quiet and there were no magnetic storm or substorm activities within at least 12 hours before. The combined observations demonstrate discrete frequency dependence on L-shell and no specific azimuthal frequency distribution. The observations at the same L-shell at different time show frequency increase with time. Some oscillations in energy range 25–100 keV were observed in both ion and electron data. The azimuthal wave number were preliminary calculated using finite gyroradius effect and equals –(20-80).

The reported study was funded by RFBR and NSFC according to the research project 20-55-53009.

On the influence of the orientation of pulsating auroral structure on associated geomagnetic pulsations in 3±1 Hz frequency range

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Two situations in pulsating auroras have been analyzed, in which the orientation of pulsating quasi-arcs was different - along and across the meridian. In both cases, geomagnetic pulsations associated with high-frequency pulsations of luminosity were more pronounced in the magnetic component perpendicular to the pulsating arc than in the component along the arc. This makes it possible to associate geomagnetic pulsations of this frequency range with the modulation of the ionospheric current along the arc, rather than with the arrival of a modulating wave in the ionosphere. The result should be taken into account in searching for the causes of high-frequency modulation of the flux of precipitating electrons.

Spacecraft measurements of whistler mode waves as a tool for investigation of the inner magnetosphere

Ondrej Santolik

In-situ observations of the whistler mode waves continue to play an important role in the investigation of the inner magnetosphere. These experimental results provide us with valuable feedback on how well the existing theories describe interactions of electromagnetic waves with inner magnetospheric plasmas and energetic particles. Multicomponent and multipoint measurements of recent scientific missions, such as Arase, Van Allen Probes, Themis and Cluster, also stimulate development of novel theories and numerical simulations, especially concerning nonlinear emissions of whistler mode chorus but also other types of electromagnetic waves occurring in the inner magnetosphere. The lecture will be devoted to a review of these measurements, with selected examples of results.

Relationship between the locations of the mid-latitude trough and plasmapause using GNSS-TEC and Arase satellite observation data

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Relationship between the locations of the mid-latitude trough minimum in the ionosphere and plasmapause in the inner magnetosphere has been statistically investigated using global navigation satellite system (GNSS) – total electron content (TEC) and electron density data obtained from the Arase satellite from March 23 2017 to May 31 2020. In this analysis, we identify the mid-latitude trough minimum as a minimum value of GNSS-TEC at sub-auroral and mid-latitude regions, and determine the plasmapause as an electron density decrease by a factor of 5 or more within L <0.5 in the inner magnetosphere. As a result, the plasmapause does not always coincide with the mid-latitude trough minimum in all magnetic local time (MLT) sectors under all geomagnetic conditions. During the geomagnetically quiet periods, the mid-latitude trough minimum is located at higher and lower geomagnetic latitudes (GMLAT) of the plasmapause in the MLT ranges of 5–21 and 21-5 h, respectively. This implies that both the features could not be on the same magnetic field line. On the other hand, during the storm main phase, the mid-latitude trough minimum and plasmapause move toward a low-latitude region with day-night and dawn-dusk asymmetries and the correlation becomes highest, compared with that under other geomagnetic conditions. Both the features are located at almost the near GMLAT in the afternoon-midnight sectors. This suggests that the formation of the mid-latitude trough and erosion of the plasmasphere occur on almost the near magnetic field line due to an enhanced sub-auroral polarization stream during the storm main phase.

Ground-based observation of aurora and plasma waves for investigation of the inner magnetosphere

Kazuo Shiokawa (ISEE, Nagoya University)

Ground-based instruments take important role for measurements of plasma dynamics in the inner magnetosphere. The plasma and waves tend to move along geomagnetic filed lines and make it possible to monitor them from the ground. Ground-based stations at subauroral latitudes can monitor various phenomena occurring in the inner magnetosphere continuously at a fixed point. Aurora and airglow imagers and multi-point GNSS receivers can provide two-dimensional distribution of plasma structures in the ionosphere. In this lecture, we review various ground-based instruments with their advantages for investigation of the plasma dynamics in the inner magnetosphere.

Arase observation of the source region of auroral arcs and diffuse auroras in the inner magnetosphere

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Auroral arcs and diffuse auroras are common phenomena at high latitudes, though characteristics of their source plasma and fields have not been well understood. In this presentation, we report the first observation of fields and particles including their pitch-angle distributions in the source region of auroral arcs and diffuse auroras, using data from the Arase satellite at L~6.0-6.5, based on the report by Shiokawa et al. [2020]. The auroral arcs appeared and expanded both poleward and equatorward at local midnight from ~0308 UT on 11 September 2018 at Nain (magnetic latitude: 66o), Canada, during the expansion phase of a substorm, while diffuse auroras covered the whole sky after 0348 UT. The top part of auroral arcs was characterized by purple/blue emissions. Bi-directional field-aligned electrons with structured energy-time spectra were observed in the source region of auroral arcs, while source electrons became isotropic and less structured in the diffuse auroral region afterwards. We suggest that structured bi-directional electrons at energies below a few keV were caused by upward field-aligned potential differences (upward electric field along geomagnetic field) reaching high altitudes (~30,000 km) above Arase. The bi-directional electrons above a few keV were probably caused by Fermi acceleration associated with the observed field dipolarization. Strong electric-field fluctuations and earthward Poynting flux were observed at the arc crossing, and are probably also caused by the field dipolarization. The ions showed time-pitch-angle dispersion caused by mirror reflection. These results indicate a clear contrast between auroral arcs and diffuse auroras in terms of source plasma and fields, and generation mechanisms of auroral arcs in the inner magnetosphere.

Reference: Shiokawa, K. et al., Arase observation of the source region of auroral arcs and diffuse auroras in the inner magnetosphere. Journal of Geophysical Research: Space Physics, 125, e2019JA027310. https://doi.org/10.1029/2019JA027310, 2020.

Statistical analyses on low energy ion heating by electromagnetic ion cyclotron waves via wave-particle interaction analyses: Arase observations

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Electromagnetic ion cyclotron (EMIC) waves are generated through the cyclotron wave-particle interaction, affecting the plasma environment in the magnetosphere. Heating of the ions by EMIC waves in the inner magnetosphere has also been investigated by spacecraft observations by comparing the pitch angle distribution of the ions and the wave emissions. We can directly detect the energy transfer between the plasma waves and the ions via the wave-particle interaction analysis (WPIA) method which calculates the inner product between the wave electric fields and the ion velocities. We adapt the WPIA method to the Arase spacecraft data and investigate the spatial distribution of the positive $qV \cdot E$ region in the inner magnetosphere. From March 21st 2017 to September 27th 2019, we select 149 EMIC wave events associating flux enhancement between 10 eV to 100 eV which are suitable dataset for the WPIA method observed by PWE/EFD, MGF, and LEP-i onboard the Arase satellite. The peaks of the proton heating appear in the dayside and post noon regions. Typical EMIC waves inside the plasma plume contribute to the peak in the afternoon sector in both quiet and active times. On the other hand, in the dayside region, the proton heating takes place during quiet times. It suggests that the protons in the region are energized by the EMIC waves generated by the EMIC waves generated by compression of the magnetic field. We also discuss the heavy ion heating.

Study of the polarization jet using satellite data

A.A. Sinevich, A.A. Chernyshov, D.V. Chugunin (IKI RAS)

The subauroral region of the ionosphere is currently a hot topic for research, since many of the phenomena occurring in it are not fully understood. One of such phenomena is a polarization jet. A polarization jet is a narrow jet of fast ionic drifts to the west near the projection of the plasmapause at the heights of the F-layer ionosphere, which appears during increased geomagnetic activity. The mechanism of the formation of a polarization jet, as well as the structure of small-scale irregularities in the parameters of the ionosphere within it are open questions. To study small-scale plasma density inhomogeneities, devices are needed that measure plasma characteristics at a high frequency. Until recently, the average frequency of instrument measurements on satellites was 2–5 Hz, until the NorSat-1 satellite was launched, equipped with 4 Langmuir probes and capable of measuring the parameters of the ionosphere with a frequency of up to 1 kHz. The presented work is to study small-scale polarization jet inhomogeneities using satellite data.

Statistical (ANOVA) analysis of variations in Solar and Geomagnetic Parameters for Solar Cycle 24

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Analysis of plages and spots on the photosphere is very important to study the magnetic field of the sun and dynamic processes associated with Sun and other stars. It also influences the magnetic field of earth and other planets. Sunspot numbers are considering as prime indicator of solar activity prominent feature of 11 year cycle known Schwabe cycle. Schwabe cycle shows the long term variation in interplanetary and geomagnetic parameters. In the present work, we have analyzed the sunspot number and their interrelationship with other solar activity parameters using statistical ANOVA method. The observed irregularities in the relationship between sunspot number and other solar activity parameter have been discussed. Also develop a suitable regression based model to explain the various long-term characteristics of solar activity.

Keywords: Schwabe cycle, ANOVA, Interplanetary magnetic field, Dst Index

Simultaneous observations of a low-altitude ion upflow by the EISCAT radar and molecular ions in the ring current by the Arase (ERG) satellite

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Molecular ions (O2+/NO+/N2+) originating from the ionosphere have been observed in the magnetosphere during the magnetic storms [e.g., Klecker et al., 1986; Christon et al., 1994] and also recently observed by Arase satellite even during weak geomagnetic disturbance periods [Seki et al., 2019]. It suggests that the molecular ions are commonly supplied from the ionosphere. However, it is not revealed how these molecular ions are transported from the low-altitude (<300 km) ionosphere where molecular ions usually exist. These molecular ions are considered to be transported upward by some heating mechanisms such as ion frictional heating, particle precipitations and local plasma instabilities. However, previous observations indicate that those mechanisms are not efficient enough to transport molecular ions by overcoming loss due to the dissociative recombination [Peterson et al., 1994].

In this study, we aim at quantitative assessment of the ion upflow process for the molecular ions from the low-altitude ionosphere based on the simultaneous observations by the EISCAT radar and the Arase (ERG) satellite on September 8, 2017. During the magnetic storm started from September 7, 2017, the Arase (ERG) satellite observed molecular ions (O2+/NO+/N2+) in the ring current. The EISCAT radar simultaneously observed the ion upflow (~50-150 m/s) in the low-altitude (250-350 km) ionosphere together with strong ion heating (>2000 K) during the main phase around the second Dst minimum of the storm. The convective electric field derived from the electron heating observed by EISCAT around 110 km altitude was also enhanced by a factor of 2. The observations suggest that the additional ion heating at the low-altitude ionosphere helped to cause the fast upflow and transport molecular ions upward. We also estimated flux decrease of molecular ions (O2+/NO+) from 280 to 350 km altitudes due to the dissociative recombination. It was about two orders of magnitude without any production processes. But we could not directory compare with the molecular ions observed by Arase and EISCAT in this case. However, these results suggest the possibility that the low-altitude ion upflow caused by the ion frictional heating enables molecular ions to escape to space against rapid loss by the dissociative recombination.

Relative Contribution of ULF Waves and Whistler-mode Chorus to the Radiation Belt Variation during the May 2017 Storm

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The Earth's radiation belt exhibits a dramatic variation during the active condition of the magnetosphere such as magnetic storms. The dynamic variation of the radiation belt is, in part, contributed by various wave-particle interactions, including: (1) the radial diffusion of electrons driven by ultra-low-frequency (ULF) waves in Pc5 frequency ranges (2-7 mHz), and (2) the local acceleration caused by wave-particle interactions between whistler-mode chorus and radiation belt particles. Over the past decade, multi-point observations and numerical simulations have separately demonstrated evidence for the contribution of ULF waves and whistler-mode chorus to the relativistic electron flux enhancement. However, comparison of the contribution of ULF waves and whistler-mode chorus has not been extensively studied yet. To our best knowledge, there are few papers that have demonstrated the global picture of wave contribution to the total radiation belt content with relative comparison.

We investigate when and where ultra-low-frequency (ULF) waves and whistler-mode chorus contribute to the net flux of relativistic electrons during the May 2017 storm. During the early recovery phase, ULF waves mainly contribute to the global enhancement of relativistic electron flux in the dusk. In the nightside, both waves are related to the flux variation. During the late recovery phase, both Van Allen Probe (RBSP)-B and Arase show that whistler-mode chorus contributes to the flux enhancement confined in L-value. The Comprehensive Ring Current Model (CRCM) coupled with Block-Adaptive-Tree Solar-Wind Roe-Type Upwind Scheme (BATS-R-US) simulation qualitatively reproduces the global evolution of ULF waves. The estimated region where the anisotropy of hot electrons is large shifts toward dusk during the recovery phase. In addition, the estimated magnetic field curvature at dayside is small during the recovery phase. We also investigate what controls the wave evolution. Both observations and simulation suggest that observed ULF waves are excited by the enhancement of the solar wind dynamic pressure. Observations also indicate that whistler-mode chorus in the nightside is predominantly excited by the anisotropic distribution of hot electrons, whereas dayside chorus is affected by the magnetic field line configuration. Estimated spatial distributions of electron anisotropy and magnetic field curvature give an explanation for observational results that enhanced whistler-mode chorus exists in the dusk, which is far from the ordinary location of wave generation.

A Direction finding Method Considering Different Signal to Noise Ratio among Sensors

Y. Tanaka, Y. Kasahara (Kanazawa University), and M. Ota (Toyama Prefectural University)

The analysis of plasma waves obtained from in-situ observations by scientific satellites is an effective method to investigate the plasma environment in the inner magnetosphere. Direction finding of plasma waves provides important information for understanding not only local plasma environment but also the global features of the inner magnetosphere.

One of the methods about direction finding is the wave distribution function (WDF) method, which derives directional distribution of wave energy density using a priori information such as the propagation mode, plasma density and geomagnetic field intensity. The WDF method is attracting attention as a method to realize detailed propagation analysis of plasma waves, as this method can be applied when multiple waves are superimposed or the wave source is widely distributed.

Among the solutions of the WDF methods, the Markov random field model (MRF) is known as a robust model that provides accurate estimation results even in noisy environments. The MRF takes into account an integration kernel corresponding to white noise (noise integration kernel) used for the estimation, which improves the robustness. The noise integration kernel is conventionally designed under the assumption that the noise levels of all electromagnetic field sensors are equal. However, the noise levels of the electromagnetic field sensors on board a scientific satellite often change due to the degradation of the sensors during long-term operation period of the instruments.

In this study, the estimation accuracy of MRF with different noise levels of electromagnetic field sensors was verified by simulation. We also propose a design method of the noise integration kernel to improve the estimation accuracy and verify its effectiveness.

Statistical survey of Energetic Electron Precipitation events using coordinate observations from Arase and ground Riometer network

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The energetic electrons present in the radiation belt and that injected into the nightside magnetosphere in association with substorm intervals are known to accelerate and precipitate into the Earth's atmosphere under favorable conditions. In this study, the Energetic Electron Precipitation (EEP) events are investigated using coordinate observations from the ground riometer network and inner-magnetospheric satellite mission, Arase. We have analyzed one and a half years of data between March 2017 to September 2018. EEP events are firstly identified using the Finnish ground riometer network (located between Geographic Latitude: 60°N to 77°N and Geographic longitude: 15°E to 28°E) by estimating the cosmic noise absorption (CNA). The Arase conjunctions with the ground riometer stations during the study period are considered. Based on the riometer absorption values, the events are categorized as CNA (absorption>0.5 dB) and non-CNA (absorption<0.5 dB) periods. The riometer observations are then compared with the comprehensive dataset of plasma waves and flux observations from Arase satellite. The relation between the plasma flux/waves observed at the satellite with the ground riometer absorptions are investigated by performing statistical analysis of the spectra measured by the Arase during CNA and non-CNA periods separately. During CNA period, the plasma flux/wave measured by Arase is found to be highly correlating with the riometer absorption in certain parts (energy/frequency range) of the spectra. Our study provides an estimate of the statistical dependence of the plasma flux observations at satellites with the ground reality of actual precipitating electron flux and also the contribution of plasma waves on it. The statistical results along with representative events will be presented and discussed.

Spatio-temporal characteristics of the precipitating electron energy of pulsating aurora derived from multi-wavelength optical measurements

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Pulsating aurora (PsA) is characterized by quasi-periodic intensity modulations with a period of 2-20 s which is known as the main modulation. Electrostatic Cyclotron Harmonic waves and whistler-mode waves are known to cause the pitch angle scattering of energetic electrons in the magnetosphere. In particular, whistler-mode chorus waves play a crucial role in the pitch angle scattering of the electrons. The lower-band chorus causes precipitation of electrons whose energy is greater than several keV [Miyoshi et al., 2015]. The energy of precipitating electrons causing PsA may be estimated from ground-based optical observations. Ono et al. [1993] observed the emission intensities of PsAs at wavelengths of 427.8 and 844.6 nm using a photometer in Antarctica, and estimated the energy of the precipitating electrons by combining the ratio of the two emission intensities and the model calculation. However, Ono[1993] conducted observations using the instrument with a narrow field-of-view, and the energy estimation using all-sky imagers has not yet been performed. In Tromsoe, Norway, several highly-sensitive EMCCD cameras have been operated, which have simultaneously observed all-sky images of the emission intensity at the two wavelengths (427.8 and 844.6 nm) with a sampling frequency of 10 Hz. In this study, we investigate the spatio-temporal variations of precipitating electron energy using these EMCCD cameras. We estimated the precipitating electron energy of PsA by comparing the emission intensity ratio of the two emission lines using the all-sky image and the emission intensity calculation results obtained by the Global airglOW (GLOW) model [Solomon, 2017]. In the presentation, we show the spatio-temporal characteristics of the precipitating electron energy of PsA and discuss energy spectrum of precipitating electrons.

Energetic electron precipitations associated with pulsating aurora: statistical analysis of low altitude satellite and VLF subionospheric propagation

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Whistler mode chorus wave is one of candidate plasma waves which causes pitch angle scattering of relativistic electron trapped in the radiation belt and precipitation of the electrons into the atmosphere. The energetic electron precipitation (EEP) caused by the chorus wave could influence significantly on chemistry in the mesosphere and lower thermosphere. Observational evidence of the EEP associated with pulsating aurora (PsA) which is also caused by the chorus wave have been reported. However, these results were based on case studies. Here, we used a long-term data set of VLF subionospheric propagation in subauroral latitude to investigate statistical property of the EEP with energy >100keV. We used 25.2 kHz VLF radio signal which is transmitted at North Dakota (L=3.0) and received at Athabasca University GeoSpace Observatory (L=4.3) to identify occurrence of EEP in the subauroral latitude. We identified quasi-periodic change in the VLF amplitude whose time scales are similar with PsA and assumed that power spectrum density of the amplitude changes integrated from 4 to 20 sec range reflects occurrence of EEP associated with PsA. We surveyed the EEP from October 2016 to December 2017 and found occurrence distribution of the EEP with respect to magnetic local time (MLT) and its dependence on AE and Dst indices. The result shows that the EEP occurrence show strong dependences on MLT and geomagnetic activities. The EEP preferentially occurs in the post-midnight sector during high AE period (the occurrence rate reaches 7% around 2 MLT for AE>300nT). EEP does not occur when AE<100nT (below 1%). It is worth to note that the occurrence rate reaches 20% around 1-2MLT for Dst<-40nT while the occurrences are smaller than 3% for -40nT<Dst<0nT and almost zero % for Dst>0nT. This means that occurrences of the EEP in subauroral latitude is significant during magnetic storms. We also found 24 EEP events which had good conjunction with POES /NOAA 19 satellite during the period of the statistical analysis. NOAA 19 satellite observed short lived spikes of EEP when the satellite passed over PsA regions or closed to the VLF radio propagation which was detecting the EEP. Among them, 22 and 12 events accountancies >100keV and >300keV EEP, respectively, and 6 events include >800 keV EEP. These results suggest that the chorus wave is responsible for EEP with energy >100keV and the energy of EEP extents up to relativistic energy.

Efficient particle acceleration in Earths magnetotail and injection of energetic particles into the radiation belts and ring current

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Earth's magnetosphere operates as a very effective particle accelerator. Seed populations of solar wind protons, electrons, and heavier ions initially gain entry along the magnetopause and via open field lines in the magnetotail, and can then be accelerated up to significantly high energies (100s keV to > 1 MeV) via a number of acceleration mechanisms active in the central plasma sheet throughout the magnetotail and the inner magnetosphere. Here, we briefly summarize details of the latest theory and understanding of those acceleration mechanisms, with a particular focus on relativistic electrons. We show new evidence from a combination of Van Allen Probes and MMS data supporting the tremendous efficiency of electron acceleration locally within Earth's magnetotail and the significance and implications of such acceleration to the radiation belts in the inner magnetosphere and more generally to solar, planetary magnetosphere, and other astrophysical systems. We show that: 1) the plasma sheet is at times capable of serving as a source of relativistic (>500 keV) electrons directly into the radiation belt via substorm-related injections; 2) those relativistic electrons are accelerated locally in the central plasma sheet, possibly through several different acceleration processes acting in concert; and 3) injections of MeV electrons directly into the outer radiation belt are possible, though rare despite there frequently being sufficient sources of those electrons in the plasma sheet. We will also present details and results from test-particle simulations in high-resolution, global MHD fields, which provide further insight and global context for understanding particle acceleration and sources the energetic particle populations in Earth's inner magnetosphere.

High-energy particles - atmosphere interaction

E. Turunen (SGO, University of Oulu)

The Earth is continuously bombarded by energetic charged particles coming from Sun and outer space. In addition, the geospace environment includes populations of various high-energy particles, a fraction of which is known to precipitate into atmosphere, both driven by solar wind conditions and intrinsic magnetospheric processes. The multitude of related processes and their dynamical variability leads to high variations in spatial, temporal, flux and energy distributions of the precipitating particles. Interestingly, the precipitation of these high-energy particles may affect the chemical composition of the atmosphere.

In this lecture we review shortly the processes related to the precipitation of the high-energy particles into the atmosphere, specially the ionization of the atmosphere caused by the high-energy particle precipitation and show how related chemical changes appear and my even affect the dynamical variability of the atmosphere.

As ability to forecast of the effects by extreme individual space weather events and knowledge of space climate related coupling features in the geospace environment and atmosphere are a must in the future modern society, we need to pay attention to integrated studies utilizing space-based measurements, modeling and ground-based measurements. We also emphasize the integrated studies using satellite measurements, ground-based observations of various types and theoretical modeling efforts.

Van Allen Probes Mission: a Remarkable Journey and Discoveries in Earth's Radiation Belts

A. Ukhorskiy (JHU/APL)

The morning of 30 August 2012 saw an Atlas 5 rocket launch of the twin Van Allen Probes, the second spacecraft mission in NASA's Living with a Star program. The Probes settled into an elliptic orbit that cut through Earth's radiation belts, home to highly variable populations of energetic particles dangerous to astronauts' health and spacecraft operation. The twin spacecraft were equipped with instruments designed to determine how these high-energy particles form, respond to solar variations, and evolve in space environments. Twentieth century observations of space and astrophysical systems throughout the solar system and out into the observable universe show the universality of processes that generate intense particle radiation within magnetized environments such as Earth's. In this talk we will briefly overview the mission goals and designs, and discuss a wide rage of fundamental science results and unexpected discoveries made by the Probes over 7 years of the mission that shed light on the particle energization processes that operate across the universe.

Simulations of the Relativistic Radiation Belt Electrons Using the VERB-3D Code

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Using the three-dimensional Versatile Electron Radiation Belt (VERB-3D) code, we perform simulations to investigate the dynamic evolution of relativistic electrons in the Earth's outer radiation belt. In our simulations, we use data from the Geostationary Operational Environmental Satellites (GOES) to set up the outer boundary condition, which is the only data input for simulations. The magnetopause shadowing effect is included by using last closed drift shell (LCDS), and it is shown to significantly contribute to the dropouts of relativistic electrons at high L*. We validate our simulation results against measurements from Van Allen Probes. In long-term simulations, we test how the latitudinal dependence of chorus waves can affect the dynamics of the radiation belt electrons. Results show that the variability of chorus waves at high latitudes is critical for modeling of megaelectron volt (MeV) electrons. We show that, depending on the latitudinal distribution of chorus waves under different geomagnetic conditions, they cannot only produce a net acceleration but also a net loss of MeV electrons. Decrease in high - latitude chorus waves can tip the balance between acceleration and loss toward acceleration, or alternatively, the increase in high - latitude waves can result in a net loss of MeV electrons. Variations in high - latitude chorus may account for some of the variability of MeV electrons.

Our simulation results for the NSF GEM Challenge Events show that the position of the plasmapause plays a significant role in the dynamic evolution of relativistic electrons. We also perform simulations for the COSPAR International Space Weather Action Team (ISWAT) Challenge for the year 2017. The COSPAR ISWAT is a global hub for collaborations addressing challenges across the field of space weather. One of the objectives of the G3-04 team "Internal Charging Effects and the Relevant Space Environment" is model performance assessment and improvement. One of the expected outputs is a more systematic assessment of model performance under different conditions. The G3-04 team proposed performing benchmarking challenge runs. We 'fly' a virtual satellite through our simulation results and compare the simulated differential electron fluxes at 0.9 MeV and 57.27 degrees local pitch-angle with the fluxes measured by the Van Allen Probes. In general, our simulation results show good agreement with observations. We calculated several different matrices to validate our simulation results against satellite observations.

Inter-hemispheric asymmetries in the ground magnetic response and interplanetary shocks inclination

Zhonghua Xu (Virginia Tech), M.D. Hartinger(SSI), D. M. Oliveira(UMBC), V.A. Pilipenko(SRIR), S. Coyle(Virginia Tech), C.R. Clauer(Virginia Tech)

Interplanetary (IP) shocks drive magnetosphere-ionosphere (MI) current systems that in turn are associated with ground magnetic perturbations. Previous modelling work has shown that IP shock impact angle plays a significant role in controlling the subsequent geomagnetic activity and magnetic perturbations. In this research work, the main question is investigated: How does the IP shock impact the response time and intensity of the ground magnetic variations and perturbations in high latitude regions? When the inclined shock strikes one of the hemispheres, will this hemisphere have the most intense ground magnetic response? Will this hemisphere have the first ground magnetic response? In order to answer these questions, we use data from a chain of Antarctic magnetometers, combined with magnetically conjugate stations on the west coast of Greenland, to investigate the impacts from these inclined shock conditions from 2009 to 2017. The statistical results show that interhemispheric asymmetries of the ground magnetic variations and waves are strongly related to the IP shocks' impact angles. However, the results suggest that several factors affect the intensity of ground magnetic response, including not only the IP shock impact angle, but also local time of the observation, ionospheric conductivity, and other underlying ionospheric conditions.

On the origin of equatorward detachment of auroral arc inferred from conjugate space - ground observations and the BATS-R-US - CIMI model

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One of the key questions in understanding the origin of detached auroral arcs is to identify the magnetospheric domain and changes therein that lead to the equatorward detachment of the arc from the main auroral oval. The coordinated ground - and space-based measurement at the time of arc detachment might shed some light on the series of processes occurring in the magnetosphere that causes the detachment. In this context, we present observations of an equatorward detachment of auroral arc from the main oval and magnetically conjugate measurements made by the Arase satellite in the inner magnetosphere. The all-sky imager at Gakona (magnetic latitude = 63.6°N), Alaska, shows the detachment of auroral arc in both red- and green-line at local midnight (~01-02 MLT) on 30 March 2017. The electron density derived from the Arase in-situ observations shows that this arc occurred outside the plasmapause. Associated with a substorm, the electron flux of energies ~0.1-10 keV locally enhanced at L~4.1 at the arc crossing. We estimated auroral intensities for both red- and green-line by using the Arase low-energy electron (0.1-19 keV) flux data. The peak latitude of the estimated intensity shows reasonably good correspondence with the observed intensity mapped at the ionospheric footprints of the Arase satellite. Further, we employ the simulation results of the Community Coordinated Modeling Center (CCMC), the BATS-R-US–CIMI 3D MHD code to understand the connection between magnetospheric dynamics and the auroral arc detachment. Simulations successfully show the substorm triggered earthward injection of plasma and the buildup of lower energy electrons (<20 keV) at the lower radial distance (R) ($R \leq 4$) around the time of arc detachment. These findings indicate that the observed arc detachment at Gakona was associated with the substorm induced localized enhancement of 0.1-10 keV electron flux at the inner edge of the electron plasma sheet.

Evening side EMIC waves and related proton precipitation induced by a substorm

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We present the results of a multi-point and multi-instrument study of EMIC waves and related energetic proton precipitation during a substorm. We analyze the data from Arase (ERG) and Van Allen Probes (VAP) A and B spacecraft for an event of 16-17 UT on 01 December 2018. VAP-A detected an almost dispersionless injection of energetic protons related to the substorm onset in the night sector. Then the proton injection was detected by VAP-B and further by Arase, as a dispersive enhancement of energetic proton flux. The proton flux enhancement at every spacecraft coincided with the EMIC wave enhancement or appearance at the same spacecraft. This data shows the excitation of EMIC waves first inside an expanding substorm wedge and then by a drifting cloud of injected protons. Low-orbiting NOAA/POES and MetOp satellites observed precipitation of energetic protons nearly conjugate with the EMIC wave observations in the magnetosphere. The coefficient of proton pitch-angle diffusion and the strong diffusion regime index were calculated based on the observed wave, plasma and magnetic field parameters. The diffusion coefficient maximum corresponded well to the energy range of the observed proton precipitation. The diffusion coefficient values indicated the strong diffusion regime, in agreement with the equality of the trapped and precipitating proton flux at the low-Earth orbit. The growth rate calculations based on the plasma and magnetic field data from both VAP and Arase spacecraft indicated that the detected EMIC waves could be generated in the region of their observation or in its close vicinity.

Excitation mechanisms of the storm-time Pc5 ULF waves by the drift-bounce resonance with ring current ions based on the drift-kinetic model

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Storm-time Pc5 ULF waves can be excited by ring current ions injected from the magnetotail during substorms. The excitation mechanism of Pc5 waves is a key to understand dynamic variation of radiation belt, since they can drive radial diffusion of radiation belt electrons [e.g. Elkington et al., 2003]. The drift-bounce resonance [Southwood, 1976] is considered to be the candidate excitation mechanism. However, the excitation mechanism and global distribution of storm-time Pc5 waves are far from understood due to the difficulty of non-linear global simulations. This study aims to investigate the excitation of internally driven ULF waves based on the global drift-kinetic model.

We performed a kinetic simulation for ring current ions using GEMSIS-RC model [Amano et al., 2011], in which 5D drift-kinetic equation for PSD of ions and Maxwell equations are solved self-consistently. In order to simulate ion injection from the plasma sheet, we set a localized high pressure region around midnight consisting of protons. We compare two cases of the initial velocity distribution; the Maxwellian distribution with the temperature of 16 keV (Case a) and the butterfly-like velocity distribution with asymmetry in pitch angle direction (Case b). In Case a, the simulation results show the drift resonance excitation of poloidal and toroidal Pc5 waves in the dayside dusk sector. Global distribution of the excited Pc5 waves indicates that they are excited where the local growth rate resultant from the positive PSD gradient in energy is positive [Yamakawa et al., 2019]. In Case b, excitation of the 2nd harmonic poloidal Pc3 ULF waves due to the drift-bounce resonance was also identified in addition to Pc5 ULF waves. Ions contributing to the growth of poloidal mode ULF waves tend to have the pitch angle of about 90 degrees for Pc5 waves and oblique pitch angle for Pc3 waves [Yamakawa et al., 2020]. We will also report on characteristics of excited ULF waves with a focus of the relative contribution of the drift and drift-bounce resonances.

Multiple Boris integrators for particle-in-cell simulation

S. Zenitani (Kobe U) and T. N. Kato (NAOJ)

We propose a family of numerical schemes for integrating the motion of charged particles in particle-in-cell (PIC) simulation. It subcycles the Boris-type 2-step procedure arbitrary n times. Numerical tests of the new solvers are presented.

Stormer regions in paleomagnetospheres

Bruno S. Zossi, Alvaro R. Gutierrez Falcón, and Ana G. Elias

Determining charged particle's motion in a magnetic field is an old and challenging problem due, mainly, to the equations which describe this motion that are generally nonlinear and an analytical solution is not possible. Stormer, at the beginning of the 20th century, described global aspects of charged particle motion in a dipole field looking at qualitative solutions, whereby space was partitioned into allowed and forbidden regions. Based on the results of two works, one by Shebalin in 2004 and the other by Tsareva in 2019, and analyzing Stormer's two dimensional topological solutions, instead of finding particles trajectories, allowed regions for non-dipolar magnetic fields are analyzed. We consider these idealized field configurations as plausible plaeomagnetospheres during a polarity transition, which are periods of drastic consequences for the Earth's magnetosphere and its shielding capacity.

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