Geospace Exploration Project: Arase (ERG)

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The ERG (Exploration of energization and Radiation in Geospace) is a geospace exploration project. The project focuses on the geospace dynamics in the context of the cross-energy coupling via wave-particle interactions. The project consists of the satellite observation team, the ground-based network observation team, and integrated-data analysis/simulation team. The Arase (ERG) satellite was sucefully launced in December, 2016. Comprehensive instruments for plasma/particles, and field/waves are installed in the ERG satellite to understand the cross-energy coupling system. In the ERG project, several ground-network teams join; magnetometer networks, radar networks, optical imager networks, etc. Moreover, the modeling/simulations play an important role for the quantitative understanding. In this presentation, we will talk about an overview of the Arase (ERG) project.

Keywords: Arase, Geospace, radiation belts

Plasma Wave Experiment (PWE) on board the ARASE (ERG) Satellite (Initial Report)

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The ERG (Exploration of energization and Radiation in Geospace) project is a mission to study acceleration and loss mechanisms of relativistic electrons around the Earth. To achieve comprehensive observations of plasma/particles, fields, and waves, the Plasma Wave Experiment (PWE) is installed on board the ERG satellite to measure electric field in the frequency range from DC to 10 MHz, and magnetic field in the frequency range from a few Hz to 100 kHz. Varieties of operational modes are implemented in the PWE, and the telemetry data consists of several kinds of data such as power spectrum, waveform, spectral matrix and DC E-field. Innovative instruments named S-WPIA (Software-Type Wave Particle Interaction Analyzer) was installed on the satellite to measure energy exchange processes between plasma waves and particles directly, and the PWE will provide raw waveform data to the S-WPIA collaborating with the other scientific instruments.
The PWE will generate two kinds of mission data; nominal data and burst data. The former consists of wave spectra in VLF/HF range and waveforms in ELF range, and will be generated continuously as survey data. The nominal data will be downloaded to the ground. On the other hand, the latter is essentially raw waveform data in VLF range and the data amount is quite huge. They will be once stored in the mission data recorder (MDR) and partial data will be downloaded after data selection. In order to obtain maximum science output, it is very important to check and analyze the nominal data quickly and select valuable data from burst data stored in the MDR.
The ARASE has passed its critical operation phase and we have confirmed successful extension of the wire-probe antennas as well as the masts. The onboard instruments including the PWE are now in the initial check out phase. In the present paper, we introduce the specification of the PWE and its initial data. We also introduce our data processing plan on the ground.

Keywords: Plasma Wave Experiment (PWE), Arase (ERG), Inner Magnetosphere, Chorus, EMIC, Ground data processing

Initial Report of the High Frequency Analyzer (HFA) onboard the ARASE (ERG) Satellite

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The ERG (Exploration of energization and Radiation in Geospace, ARASE) was launched on December 20, 2016. The purpose of the ERG is to explore the dynamics od the Earth’ s radiation belt using electric and magnetic field instruments covering a wide frequency range and electron and ion detectors over a wide energy range. New instruments named S-WPIA (Software-Type Wave Particle Interaction Analyzer) was installed on the satellite to measure energy exchange processes between plasma waves and particles directly.
High Frequency Analyzer (HFA) is a subcomponent of the Plasma Wave Experiment (PWE) for observation of radio and plasma waves in a frequency range from 0.01 to 10 MHz. The bandwidth is 1.2 kHz in 0.01-1 MHz, and 12 kHz in 1-10 MHz. The time
In ERG mission, HFA is expected to perform the following observations:
(1) Observation of upper hybrid resonance (UHR) waves in order to determine the electron number density around the spacecraft and provide it to SWPIA.

Keywords: The ARASE (ERG) satellite, PWE, HFA

Initial results of the magnetic field experiment by the magnetometer (MGF) for the ARASE (ERG) mission

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The acceleration process of the charged particles in the inner magnetosphere is considered to be closely related to the deformation and perturbation of the magnetic field. Accurate measurement of the magnetic field is required to understand the acceleration mechanism of the charged particles, which is one of the major scientific objectives of the ARASE (ERG) mission. We designed a fluxgate magnetometer which is optimized to investigate following topics;
(1) accurate measurement of the background magnetic field - the deformation of the magnetic field and its relationship with the particle acceleration.
(2) MHD waves - measurement of the ULF electromagnetic waves of frequencies about 1mHz (Pc4-5), and investigation of the radiation-belt electrons radially diffused by the resonance with the ULF waves.
(3) EMIC waves - measurement of the electromagnetic ion-cyclotron waves of frequencies about 1Hz, and investigation of the ring-current ions and radiation-belt electrons dissipated by the interaction with the EMIC waves.
A fluxgate magnetometer (MGF) was built for the ARASE satellite to measure DC and low-frequency magnetic field. The design is based on MGF-I, one of the magnetometers for BepiColombo MMO, Mercury orbiter, which would also suffer high radiation on the Mercury orbit.
The requirements to the magnetic field measurements by ARASE was defined as (1) accuracy of the absolute field intensity is within 5 nT (2) angular accuracy of the field direction is within 1 degree (3) measurement frequency range is from DC to 60Hz or wider. MGF measures the vector magnetic field with the original sampling frequency of 256 Hz. The dynamic range is switched between +/-8000nT and +/-60000nT according to the background field intensity.
The MGF initial checkout was carried on January 10th 2017, three weeks after the launch of ARASE. The MGF normal performance and downlinked data were confirmed. The MAST for the sensor was deployed on 17th January.
The initial results of the magnetic field observation and data examination will be shown in the presentation.

Keywords: Geospace, Radiation belt, magnetic field

Preliminary results of the first ERG-ground campaign observation of the inner magnetosphere using the PWING ground network

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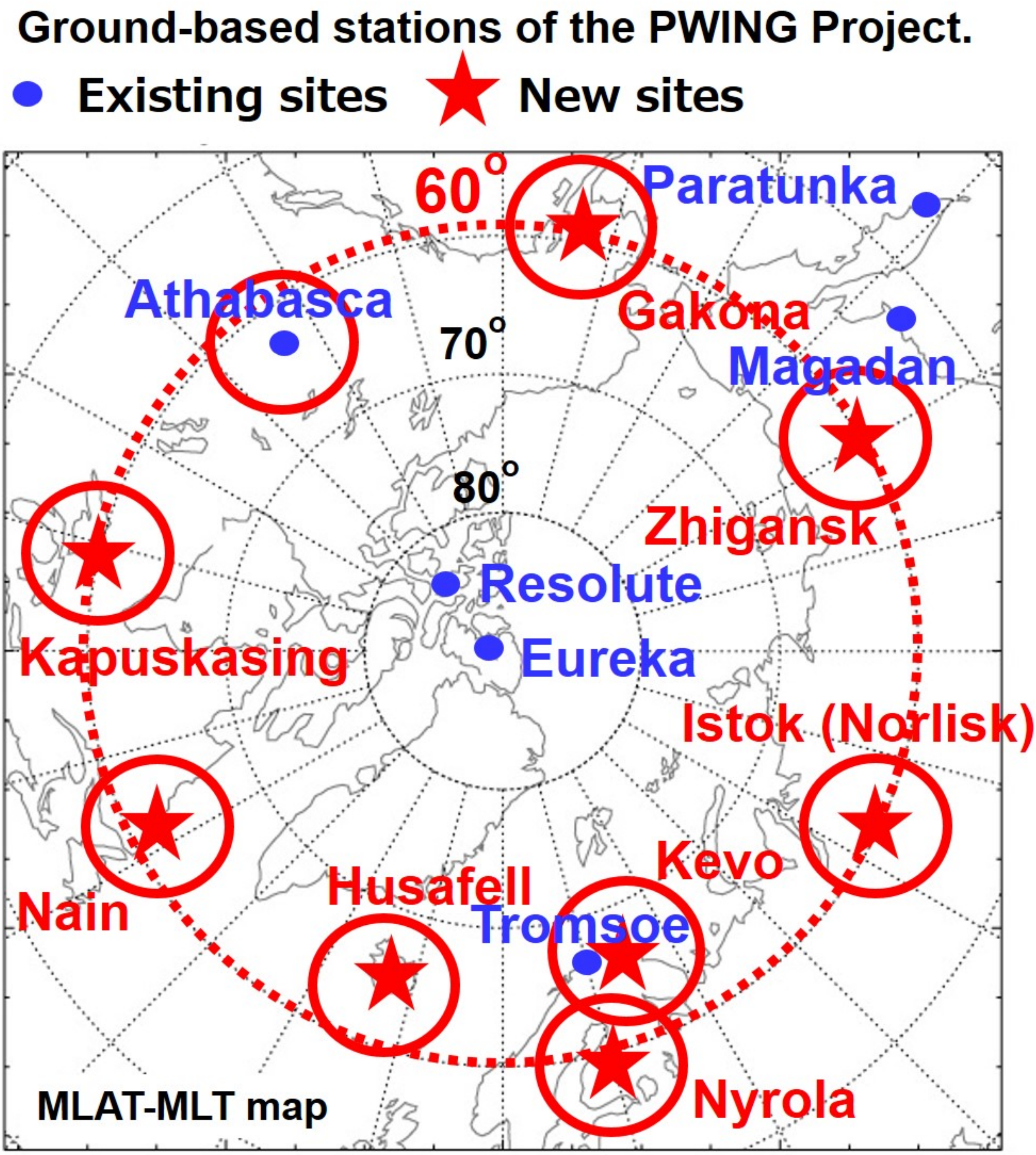
Dynamical variation of particles and waves in the inner magnetosphere is one of the most important research topics in recent space physics. The inner magnetosphere contains plasmas in wide energy ranges from below electron volts to Mega-electron volts. These plasmas (electrons and ions) interact with ULF/ELF/VLF waves at frequencies of 0.1 Hz to 10 kHz to cause their energization in the equatorial plane of the magnetosphere and loss into the ionosphere. In order to provide global distribution and quantitative evaluation of the dynamical variation of plasmas and waves in the inner magnetosphere, we have started PWING Project (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations, http://www.isee.nagoya-u.ac.jp/dimr/PWING/PWING_web_e.htm), which will last for 5 years from April 2016, as a Grant-in-Aid for Specially Promoted Research of the Japan Society for the Promotion of Science (JSPS). In this PWING project, we operate all-sky aurora/airglow imagers, 64-Hz sampling induction magnetometers, 40-kHz sampling ELF/VLF receivers, and 64-Hz sampling riometers at 8 stations at ~60 MLAT around the north pole, as well as two EMCCD cameras at two stations. The stations are distributed in Canada, Iceland, Finland, Russia, and Alaska. We combine these longitudinal network observations with the ERG (Arase) satellite, which was launched on December 20, 2016, and global modeling. The first campaign observation of PWING project with the newly-launched ERG satellite is planned in the second half of March 2017. In this presentation, we show preliminary results obtained from this first campaign observations based on the PWING ground network observations of these instruments.

Keywords: inner magnetosphere, ERG satellite , PWING project , longitudinal network


Ground-based stations of the PWING Project.
Existing sites
New sites
60°
Paratunka
Athabasca
70°
Gakona
Magadan
80°
Zhigansk
Resolute
Kapuskasing
Eureka
Istok (Norlisk)
Kevo
Husafell
Tromsoe
Nain
Nyrola
MLAT-MLT map

Transportation and acceleration of outer belt electrons in the slot region responsible for the formation of new radiation belt during big magnetic storm

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It was reported that relativistic electrons in the outer radiation belt have been transported into the slot region during big magnetic storms (Obara and Matsumoto, 2016 and references therein). Baker et al.(2013) further reported a new radiation belt has been made in some cases.

We have examined electron data in the radiation belt during magnetic storms paying a particular attention to the formation of new radiation belt. Issues, we like to clarify, will be followings: i.e. 1) electrons injected into the slot region will have additional (local) acceleration there ? 2) what is the cause of electron acceleration ? 3) how long electrons will feel acceleration ? and 4) what mechanism will be essential for the formation of new radiation belt ?

We have analyzed two events; one is March 24-th, 1991 event and the other is July 14-th, 2000 event. New radiation belt has been made at round L˜3 in both cases and it persisted for almost two weeks. In both cases, we have confirmed local acceleration. Intense very low frequency (VLF) plasma waves have been observed. We are considering additional acceleration has been made by these waves.

New point of our result will be the identification of local acceleration of electrons in very near Earth region; i.e. L˜3, and it also confirms the results by Baker et al.(2013).

Keywords: New radiation belt, Slot region, Electron acceleration

Results of wave observations during Cluster Inner Magnetospheric Campaign

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The study of the growth and evolution of waves and structure that typically occur within the inner magnetosphere requires multipoint measurements at small separation distances. The Cluster Inner Magnetosphere Campaign was aimed to provide closely spaced (down to separations of the order of 10^1 km) measurements of waves at high temporal resolution. This enables the investigation of composition of the turbulence, its dispersion, linear and nonlinear processes the contribute to the wave field, and interaction with the local plasma populations. Results of Cluster Inner Magnetospheric Campaign related to Equatorial Noise, EMIC waves and other emmisions are reviewed.

Keywords: Magnetosphere, Energetic electrons , wave particle interactions

Coincident Compression Generated EMIC Chorus and Hiss waves

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Electron radiation belt dynamics are controlled by the competition of multiple acceleration and loss mechanisms. Electromagnetic ion cyclotron (EMIC), chorus, and hiss waves have all been implicated as potential loss mechanisms of radiation belt electrons along with Chorus waves proposed as a mechanism for accelerating the lower energy source population to MeV energies. Understanding the relative importance of these waves as well as where and under what conditions they are generated is vital to predicting radiation belt dynamics.

Although the size of the solar wind compression on 9 January 2014 event discussed here was modest, it has given us an opportunity to observe clearly how a magnetospheric compression can lead to the generation of EMIC, chorus, and hiss waves. The ICME generated shock encountered the Earth’s magnetosphere on 9 January 2014 at ~20:11 UT, and the Van Allen Probes observe the coincident excitation of EMIC and Chorus waves outside the plasmasphere, and hiss waves inside the plasmasphere. As the shock encountered the magnetosphere, an electric field impulse was observed to generate an increase in temperature anisotropy for both ions and electrons. This increased temperature anisotropy led to increased wave growth on both the ion and electron cyclotron branches. The simultaneous generation of multiple types of waves may lead to significant impacts on the acceleration and loss of radiation belt electrons, especially during geomagnetic compressions observed during substorms, and the storm sudden commencement and main phases of geomagnetic storms, as well as during quiet time sudden impulse events. For example, the excitation of both EMIC and chorus waves at the same place, and at the same time, may complicate studies seeking a causal connection between specific individual plasma wave bursts and observations of particle precipitation into the atmosphere. During this relatively small event BARREL had three payloads in conjunction with the Van Allen Probes, two of the payloads inferred electron precipitation within the energy range typically associated with chorus wave pitch angle scattering. One can hypothesis that with larger and/or longer lasting ICME-shocks, or with a larger initial population of radiation belt electrons, more electron precipitation, and a larger range of energies, may be observe.

Keywords: Plasma Waves, Geomagnetic compression, Electromagnetic Ion Cyclotron waves, Electromagnetic electron cyclotron waves

Modeling of cavity modes and field line resonances in the inner magnetosphere

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Ultra-low-frequency (ULF) waves are a major means to transport energy through the magnetosphere and play an important role in energization and transport of radiation belt particles. In the inhomogeneous inner magnetosphere, ULF waves frequently are affected by the density structure of the magnetosphere as well as by the ionospheric boundary conditions. We have developed a three-dimensional numerical code in dipole geometry to describe the propagation of ULF waves in the inner magnetosphere. In particular, we model the response of the inner magnetosphere to impulsive compressions that occur on the dayside due to shocks impinging on the magnetosphere and on the nightside due to dipolarization fronts during substorms. These compressions can lead to the development of plasmaspheric cavity modes in the inner magnetosphere that have periods of 1-2 minutes. Furthermore, compressional waves can mode convert to shear Alfvén mode field line resonances that stand on field lines when the compressions contain wave power at the frequency corresponding to harmonics of the fundamental wave period. A special case of field line resonances occurs near the terminator during solstice conditions when one end of the field line is sunlit while the other end is in darkness. Under these circumstances, quarter-wave modes can result in which one end of the field line is a node of the electric field while the other end is an antinode. The model results compare favorably with observations from the Van Allen Probe satellites as well as fields measured by ground magnetometers.

Keywords: ULF Wave Modeling, Radiation Belts, Magnetosphere-Ionosphere Coupling

Rapid Variations of Energetic Electron Pitch Angle Distributions and Associated Wave Emissions

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Injections of energetic electrons into the inner magnetosphere are a common feature of spacecraft observations. The electron flux rises very rapidly and then recovers smoothly to the pre-event level over a period of several hours. Recent high resolution angular measurements by the Magnetic Electron and Ion Spectrometer (MagEIS) instrument on the Van Allen Probes have observed rapid variations in the recovery of the electron pitch angle distributions at energies in range 20-100 keV. These features can take several forms, one of which is peaks in narrow ranges of pitch angle that occur quasiperiodically every few minutes. In many cases, these electron flux bursts appear to correlate with simultaneously detected plasma wave emissions. Fennell et al. [J. Geophys. Res., 2014] reported one such event in which several flux bursts were highly correlated with upper band whistler-mode chorus waves. One difficulty with identifying and cataloging these events is the obscuration of the rapid variations by the slow trends of the background plasma. Algorithms are being developed to detrend the electron flux by subtracting out this slowly varying background and revealing the rapid burst features. Use of this procedure shows that the rapid variations in pitch angle distributions are a common feature of substorm-generated electron injections in the inner magnetosphere. Over 400 such events have been identified with more 3000 individual pitch angle featured detected. The characteristics of the bursts and associated waves are being cataloged, including the energy and pitch angle of the electron bursts, the anisotropy of the background plasma, the wave frequency and mode, the observation location, and the geomagnetic conditions during the events.

Keywords: Plasma waves, Energetic electrons, Substorm particle injections

One year comparison of lighting activity and variations in electron fluxes of the inner radiation belt

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In the radiation belts, energetic electrons with energies above 100 keV undergo cyclotron resonant interactions with whistler-mode plasma waves. These wave-particle interactions lead to either acceleration or loss of particles by energy diffusion or pitch angle scattering. Lightning discharges are known to radiate electromagnetic energy over a wide range of latitudes around their source. Part of this energy propagates in the whistler-mode through the ionospheric plasma and can then interact with electrons in the radiation belts causing whistler-induced electron precipitation. There have been several studies that focus on the effects of these whistler-induced precipitation and their immediate relationship to lightning strikes [Rodger et al. (2004), Clilverd et al. (2004)]. However, there is little research that concentrates on the long-term effects of these electron losses on the population of the inner radiation belts. In this study, we use data from the World Wide Lightning Location Network (WWLLN), continuously monitoring global lightning since 2004, to examine one year of lightning data (January to December 2013) and locate the L-shells with strong lighting activity. Then we use the Energetic Particle, Composition, and Thermal Plasma Suite (ECT) from both Van Allen Probes (RBSP–A and –B) to measure electron fluxes in the inner radiation belt at the L-shells of strong lightning activity. We examine the influence that lightning activity has on long-term electron precipitation using RBSP trapped omnidirectional fluxes, as well as pitch angle distributions, dayside/nightside differences and geomagnetic activity. We use several case studies in order to quantify the loss effects to the radiation belts due to lightning activity.

Keywords: Lightning, Inner radiation belt, whistler induced precipitation, electron loss

Recent Science Highlights of the Van Allen Probes Mission

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The morning of 30 August 2012 saw an Atlas 5 rocket launch NASA's second Living With a Star spacecraft mission, the twin Radiation Belt Storm Probes, into an elliptic orbit cutting through Earth's radiation belts. Renamed the Van Allen Probes soon after launch, the Probes are designed to determine how the highly variable populations of high-energy charged particles within the radiation belts, dangerous to astronauts and satellites, are created, respond to solar variations, and evolve in space environments. The Van Allen Probes mission extends beyond the practical considerations of the hazard's of Earth's space environment. Twentieth century observations of space and astrophysical systems throughout the solar system and out into the observable universe have shown that the processes that generate intense particle radiation within magnetized environments such as Earth's are universal. During its mission the Van Allen Probes verified and quantified previously suggested energization processes, discovered new energization mechanisms, revealed the critical importance of dynamic plasma injections into the innermost magnetosphere, and used uniquely capable instruments to reveal inner radiation belt features that were all but invisible to previous sensors. This paper gives a brief overview of the mission, presents some recent science highlights, and discusses plans for the extended mission.

Keywords: Inner magnetosphere, Radiation belts, Space weather

Multipoint Observations of Cavity Mode Oscillations Excited by an Interplanetary Shock

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Cavity mode oscillations (CMOs) are basic magnetohydrodynamic eigenmodes of the magnetosphere predicted by theory. Excitation of CMOs is expected when an interplanetary shock impulsively compresses the magnetosphere, but observational studies of shock-induced CMOs have been sparse. We present a case study of a dayside ULF wave event that exhibited CMO properties. The event occurred when an interplanetary shock impacted the magnetosphere at 0829 UT on 15 August 2015. The shock was observed in the solar wind by THEMIS-B and -C, and magnetospheric ULF waves were observed by multiple spacecraft including Van Allen Probes-A and -B, THEMIS-D, -E, and -A, GOES-13 and -15, and ETS-VIII. The Van Allen Probes were located in the dayside plasmasphere at L=1.5 and L =2.4, and both spacecraft detected compressional poloidal mode oscillations at ˜13 mHz (fundamental) and ˜26 mHz (second harmonic). At both frequencies, the compressional component of the magnetic field led the azimuthal component of the electric field by ˜90 degrees. The frequencies and the phase delay are in good agreement with CMOs generated in a dipole magnetohydrodynamic simulation that incorporates a realistic plasma mass density distribution and an ionospheric boundary condition. The poloidal oscillations were also detected on the ground by the European quasi-Meridional Magnetometer Array, providing additional evidence for the global nature of the waves.

Keywords: Caviy mode oscillations, Interplanetary shock, Observation and simulation

Occurrence of EMIC waves and plasmaspheric plasmas derived from THEMIS observations in the outer magnetosphere

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We have statistically studied the relationship between electromagnetic ion cyclotron (EMIC) waves and cold plasmaspheric plasma (N_{sp}) in the L range of 6-12 using the Time History of Events and Macroscale Interactions during Substorms (THEMIS) data for 2008-2011. The important observational results are as follows: (1) Under quiet geomagnetic conditions (Kp = 0-1), the maximum occurrence rate of the hydrogen (H) band EMIC waves appears in the early morning sector (0600-0900 MLT) at the outermost region (L = 10-12). (2) Under moderate and disturbed conditions (Kp > 2), the H-band occurrence rate is higher in the morning-to-early afternoon sector for L > 10. (3) The high occurrence region of helium (He) band waves for Kp = 0-1 varies from L = 7 to 12 in radial distances along the local time (i.e., at L ~ 7 near noon and at L = 8-12 near late afternoon). (4) The He-band waves for Kp > 2 are mainly localized between 1200 and 1800 MLT with a peak around 1500-1600 MLT at L = 8-10. (5) N_{sp} is much higher for the He-band intervals than for the H-band intervals by a factor of 10 or more. The He-band high occurrence appears at a steep N_{sp} gradient region. (6) The morning-afternoon asymmetry of the normalized frequency seen both in H and He bands is similar to the asymmetric distribution of Nsp along the local time. These observations indicate that the cold plasma density plays a significant role in determining the spectral properties of EMIC waves. We discuss whether a morning-afternoon asymmetry of the EMIC wave properties can be explained by the spatial distribution of cold plasmaspheric plasma.

Keywords: EMIC waves, Plasmaspheric plasma

Nature's Grand Experiment: Linkage Between Magnetospheric Convection, Substorms, and the Radiation Belts

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The solar minimum of 2007-2010 was unusually deep and long-lived. In the later stages of this period the electron fluxes in the radiation belts dropped to extremely low levels. The flux of relativistic electrons (>1 MeV) was significantly diminished, and at times were below instrument thresholds both for spacecraft located in geostationary orbits and also those in low-Earth orbit. This period has been described as a natural "grand experiment" allowing us to test our understanding of basic radiation belt physics and in particular the acceleration mechanisms which lead to enhancements in outer belt relativistic electron fluxes.

Here we test the hypothesis [1] that processes driven by magnetospheric convection initiate repetitive substorm onsets, which in turn triggers enhancement in whistler mode chorus that accelerates radiation belt electrons to relativistic energies. Conversely, individual substorms would not be associated with radiation belt acceleration. Contrasting observations from multiple satellites of energetic and relativistic electrons with substorm event lists, as well as chorus measurements, shows that the data are consistent with the hypothesis.

We show that repetitive substorms are associated with enhancements in the flux of energetic and relativistic electrons and enhanced whistler mode wave intensities. Our finding is consistent with the recent RBSP case studies [2], which suggested that substorms were the trigger for chorus which lead to acceleration of radiation belt electrons to relativistic energies. However, in our study we see a two stage chorus wave power enhancement, the first starts slightly before the repetitive substorm epoch onset, suggesting that magnetospheric convection leading the chorus activity may be the trigger. This conclusion requires some care, as the second and strongest enhancement in chorus is very slightly after the onset, complicating the picture.

During the 2009/2010 period the only relativistic electron flux enhancements that occurred were preceded by repeated substorm onsets, consistent with enhanced magnetospheric convection and repetitive substorms as a trigger for outer radiation belt electron acceleration. This work has been recently published in JGR [3].

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Rodger, C. J., K. Cresswell-Moorcock, and M. A. Clilverd, *J. Geophys. Res. Space Physics*, 121, 171–189, doi:10.1002/2015JA021537 (2016).

Keywords: outer radiation belt, electron acceleration, coupling processes, whistler mode chorus

Relativistic electron flux dropout due to field line curvature during the storm on 1 June 2013

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A relativistic flux dropout is a sudden and significant decrease in the relativistic electron (> 1 MeV) population of the outer radiation belt occurring over timescales of a few hours. A significant dropout of relativistic electrons was observed by Van Allen Probes during the storm main phase on June 1, 2013. During the same period, MeV electron precipitation with isotropic pitch-angle distribution was also observed from POES but no EMIC waves were detected from either space- or ground-based magnetometers. Based on Tsyganenko empirical magnetic field model, magnetic field lines are highly non-dipolar and stretched at the night side in the inner magnetosphere. This condition can break the first adiabatic invariant (conservation of magnetic moment) and generate pitch-angle scattering of relativistic electron to the loss cone. To understand the relative roles of different physical mechanisms on this dropout event, we simulate flux and phase space density of relativistic electrons with event specific plasma wave intensities using the Comprehensive Inner Magnetosphere and Ionosphere (CIMI) model. We also employ pitch-angle scattering due to field line curvature in the CIMI model. We re-configure magnetic field every minute and update electric field every 20 seconds to capture convective and diffusive radial transport. CIMI-simulation with pitch-angle scattering due to field line curvature shows more depletion of relativistic electron fluxes and better agreement to observation. We conclude that pitch-angle scattering due to field line curvature is one of the dominant processes for the relativistic electron flux dropout.

Keywords: relativistic electron dropout, loss, field line curvature

Van Allen Probes observation of plasmaspheric electron acceleration by ULF waves at the plasmaspheric boundary layer

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In this study, we report the plamsmaspheric electron acceleration caused by drift-bounce resonance with ULF waves at the plasmaspheric boundary layer. Long-lasting ULF waves in the period of about 1 min, identified as second harmonic mode, were observed by Van Allen Probe B during two successive orbits. During ULF wave appearance, both plasmaspheric electrons (<200 eV) and energetic protons (10-20 keV) showed bi-directional pitch angle signature, which is caused by drift-bounce resonance with N=1. And the averaged plasmaspheric electron flux enhanced up to 5 times of that when there were no ULF wves. Based on multi-spacecraft observation using two Van Allen Probes, two GOES satellites (GOES 13 and GOES15) and MMS 1, these ULF waves mainly distributed in the duskside, and MMS 1 observed no external sources when travelling inbound and outbound in the magnetosphere, which suggests that these ULF waves were excited through drift-bounce resonant instability caused by substorm-injected energetic protons.

Keywords: Plasmaspheric electron acceleration, ULF waves, Drift-bounce resonance, Wave exciting mechanism, Multi-spacecraft observation

Spectral structures of energetic electrons in the inner magnetosphere

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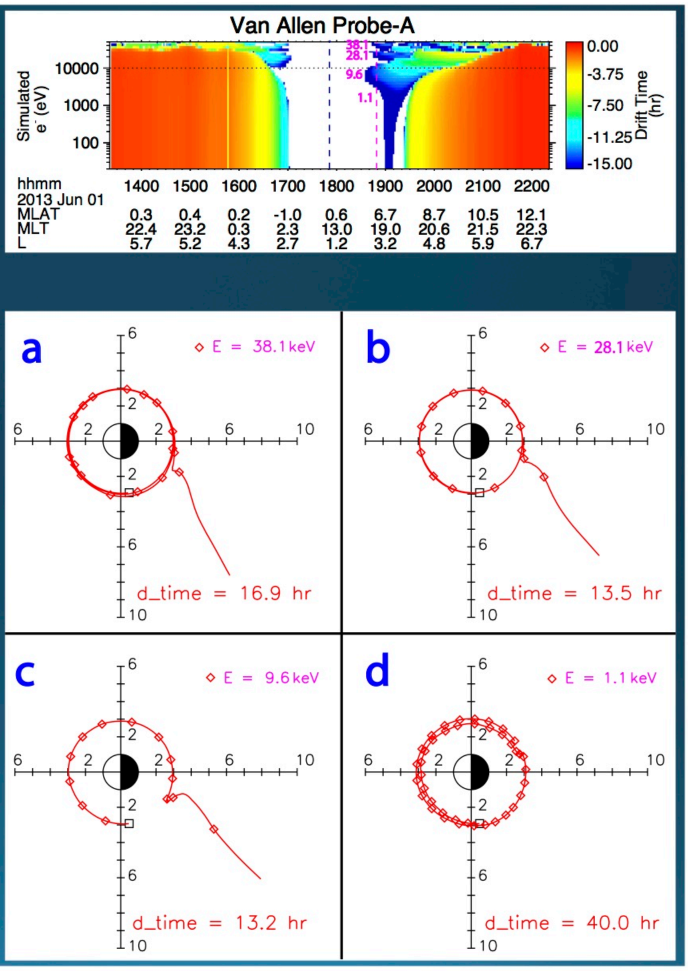
Electron spectral structures in the energy-time flux spectrograms are the observational signatures of electron acceleration, transport, and loss in the global magnetosphere. Combining *in situ* measurements with backward particle drift path simulations, we studied electron spectral structures in the inner magnetosphere before and during the 1 June 2013 storm (min. *Dst* = -119 nT). For the purpose of comparison, proton results were also included. Electron spectral structures were less dynamic during storm time than quiet time, because deeper transport and more enhanced fluxes smeared the spectral structures. Electron injection depth and some spectral features were fairly well reproduced with the Weimer96 electric field and the dipole magnetic field. Although always drifting eastward, electrons could still display multiple spectral structures. Their formation was attributed to “drift resonance”, i.e., electrons with different energies drifting around the Earth by a different number of loops. Pitch angle scattering loss played an important role in the formation of electron spectral features.

Keywords: Magnetospheric configuration and dynamics, Plasma convection , Plasma sheet , Ring current, Solar wind/magnetosphere interactions

Formation of Multiple Electron "Noses"

- Backward Drift Path Tracings at 1850:48 UT:
  - Start at L = 3.0 & MLT = 18.6
  - End at L =10.0 or Drift Time (d_time) > 40 hrs
- Drift Paths:
  - 38.1 keV: (2, 3) loops
  - 28.1 keV: (1, 2) loops
  - 9.6 keV: < 1 loop
  - 1.1 keV: trapped, i.e., no access to the tailward source region



Recent progresses in understanding the contribution of EMIC waves to radiation belt electron scattering

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Resonant wave-particle interactions are long thought as a fundamental cause driving the dynamic variability of Earth's electron radiation belts. In terms of violating one or more adiabatic invariants, magnetospheric waves have been regarded as a necessary agent to transfer energies between different populations of particles. This presentation focuses on some recent progresses in understanding the electron scattering effects of EMIC waves. While cyclotron resonant electron scattering by EMIC waves has been well studied and found to be a potentially crucial electron scattering mechanism, the recent investigation demonstrates that bounce resonant electron scattering may also be very important in a manner to resonate with near-equatorially mirroring electrons over a wide range of L-shells and energies. It is strongly suggested that bounce resonance scattering by EMIC waves should be incorporated into future modeling efforts of radiation belt electron dynamics.

Keywords: Earth's radiation belts, resonant wave-particle interactions, EMIC waves

Observational and numerical studies about frequency chirping of chorus waves

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The underlying physical mechanism of the nonlinear frequency chirping of whistler mode chorus waves has been investigated for more than fifty years; nevertheless, a consensus has yet to be reached. In this talk, we will present some of our recent observational studies about the dependence of the chorus wave frequency chirping rate on both background plasma parameters and wave amplitude. Comparison with different previously published theoretical models will be given. We will also present numerical simulation demonstrating the amplitude modulation of chorus waves that has also been found in observation. With phase space diagnostics, we suggest that the amplitude modulation is caused by phase space trapping of resonant particles.

Keywords: chorus waves, frequency sweep rate

Landau Resonance Acceleration of MeV Electrons by Obliquely Propagating Whistler-mode Chorus Emissions

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A recent analysis of wave and particle data obtained by the Van Allen Probes [Foster et al., 2017] demonstrates highly efficient acceleration of relativistic electrons by whistler-mode chorus emissions. The analysis identified that the acceleration is mostly due to the cyclotron resonance of relativistic electrons with chorus emissions propagating quasi-parallel to the ambient magnetic field. As the energy of an electron becomes relativistic (1 - 2 MeV), the parallel resonance velocity approaches zero near the equator, where nonlinear trapping of resonant electrons becomes possible, resulting in relativistic turning acceleration [Omura et al., 2007]. The detailed subpacket analysis shows that there arises a parallel wave electric field that can trap energetic electrons through Landau resonance. A recent test particle simulation [Hsieh and Omura, 2017], however, shows that the perpendicular wave electric field can also play a significant role in trapping and accelerating relativistic electrons through Landau resonance. We present a theoretical analysis of the Landau resonance acceleration, and verify it by the subpacket analysis of chorus emissions observed by Van Allen Probes. We compare the efficiencies of accelerations by the cyclotron resonance and the Landau resonance.

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Keywords: wave-particle interaction, radiation belts, particle acceleration

Formation process of outer radiation belt electron flux through interaction with lower-band chorus emissions with subpacket structures

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We perform test particle simulations of relativistic acceleration processes of energetic electrons interacting with chorus emissions with sub-packet structures. Recent analyses of whistler-mode chorus emissions observed by spacecraft show that a wave packet of a rising-tone chorus element consists of many sub-packets with gradually increasing frequencies [*Santolik et al.,* JGR, 2014; *Foster et al.,* JGR 2017]. The strong modulation of the wave amplitude affects dynamics of resonant electrons, making them detrapped from the wave potential or entrapped into it. We set up two wave models, i.e., a chorus element with and without subpacket structures. We compare the acceleration efficiencies in the two different wave models by tracing the formation processes through many interactions with the wave packets of chorus emissions based on the Green's function method proposed by *Omura et al.* [JGR 2015]. In both cases, resonant electrons undergoing the cyclotron resonance with the waves are efficiently accelerated by nonlinear wave trapping. In the case of the wave model with the subpacket structure, a larger number of electrons are entrapped into the wave potentials, while the acceleration efficiency in energy is decreased due to shorter interaction. In the case of the wave model without the subpackets, the acceleration efficiency in energy is much higher while the number of electrons undergoing the acceleration is decreased. Eventually the total acceleration efficiencies in forming the relativistic electron flux are not much different in the two different wave models. In both cases, we find formation of butterfly distributions of MeV electrons.

Keywords: radiation belt, chorus, acceleration, relativistic electron

Van Allen Probes Observations of Particle Injections and ULF Waves During Lapping Events

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The twin Van Allen Probes mission provides unique data sets for the studies of radiation belt and ring current dynamics thanks to their orbit configuration and coverage, and state of the art instrumentation with high energy and time resolutions. This study presents mid- to high-energy particle injection and wave events associated with storm and substorm activities when the twin spacecraft were very close to each other (called "lapping event"). The lapping events enable us to investigate the wave-particle interaction on an unprecedented spatial and temporal scale. The events presented here show that mid-energy (a few to hundreds of keV) injected particles provide energy to generate electromagnetic ion cyclotron (EMIC) and ultra low frequency (ULF) waves, resulting in scattering of high-energy (a few MeV) electrons in the radiation belt. Clear one-to-one correspondence between waves and particles with high energy and time resolution is demonstrated. Because of the spacecraft's lapping during multiple consecutive fly-bys, detailed spatial and temporal structures of the wave-particle interaction are revealed.

Keywords: Ring current, ULF waves, injection

Energetic ring current proton spectra measured by the Van Allen Probes

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We examine two geomagnetic storm periods,namely March 17-20,2013 and March 17-20,2015,and analyze proton spectra measured by the Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE) on board the Van Allen Probes. In particular,we consider the most intense proton spectra over the energy range 50 - 600 keV ,for outer-zone L-shells, during these storm periods. Recent theory has been developed to model the limitation of energetic ring current ion spectra resulting from the action of pitch-angle scattering by electromagnetic ion cyclotron (EMIC) waves. The theory suggests that a limiting (extreme) spectrum is achieved when the EMIC waves acquire a certain gain over a given convective length scale for all frequencies over which wave growth occurs. We obtain the theoretical limiting spectrum numerically, and also show that the limiting spectrum varies as 1/E for large kinetic energy E. Comparison of the observed extreme proton spectra with the corresponding numerical limiting spectra provides evidence that the extreme spectra are controlled by EMIC wave scattering.

Keywords: ring current protons, extreme proton spectra, Van Allen Probes

Software-type Wave-Particle Interaction Analyzer on board the ARASE satellite

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The Wave-particle interaction analyzer (WPIA) is a new method of observing wave-particle interactions in space. Based on the cutting-edge of technologies in the onboard instruments, the Software-type WPIA (S-WPIA) is installed in the ARASE satellite, which was successfully launched on December 20, 2016. The present paper introduces the principles of the WPIA and describes the detailed design of the S-WPIA on board the ARASE satellite. Understanding wave-particle interactions is essential in the study on space plasma environments, because space plasmas are collisionless and their kinetic energies are transferred through wave-particle interactions. In the conventional way of the study on wave-particle interactions via satellites, we have compared features of plasma waves with velocity distribution functions. However, that conventional way is not appropriate for identifying wave-particle interactions quantitatively. The nature of wave-particle interactions lies in the phase difference between electric field vectors($\boldsymbol{E}$) and velocity vectors of particles($\boldsymbol{V}$). This appears as the inner product form as $\boldsymbol{E} \cdot \boldsymbol{V}$. The conventional way using velocity distribution functions misses the information of this phase difference, because the velocity distribution function is obtained on the time integration basis. The WPIA overcomes the above problem in the conventional method by handling each detected particle and instant electric field intensity with keeping the enough accuracy in the relative time difference between them. The ARASE satellite and its onboard S-WPIA instrument should be frontiers in the study of wave-particle interactions. The leading edge of the system in the ARASE satellite allows us to collect whole information of particles at every particle detection timing and instant electric fields at every sampling timing. The collected particle and waveform data are stored on the onboard data storage called Mission Data Recorder (MDR). The S-WPIA calculates the phase difference and other quantities onboard reading out the data from the MDR and send the results as well as raw data of particles and plasma waves to the ground.
The main objective of the S-WPIA on board the ARASE satellite is to detect quantitatively the wave-particle interaction related to the generation of the Chorus emissions. The SWPIA also targets the quantitative detection of accelerations of electrons due to plasma waves. The function of the S-WPIA has been already confirmed during the initial operation of the ARASE satellite. The present paper introduces the details of the S-WPIA and discuss the strategy how we meet the objective of the S-WPIA in the operation.

Onboard Processing on PWE OFA/WFC (Onboard Frequency Analyzer/Waveform Capture) aboard the ERG(ARASE) Satellite

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Exploration of energization and Radiation in Geospace (ERG) is a mission for understanding particle acceleration, loss mechanisms, and the dynamic evolution of space storms in the context of cross-energy and cross-regional coupling [Miyoshi et al., 2012]. The ERG (ARASE) satellite was launched on December 20, 2016, and successfully inserted into an orbit.

The Plasma Wave Experiment (PWE) is one of the science instruments on board the ERG satellite to measure electric field and magnetic field in the inner magnetosphere. PWE consists of three sub-components, EFD (Electric Field Detector), OFA/WFC (Onboard Frequency Analyzer and Waveform Capture), and HFA (High Frequency Analyzer). Especially, OFA/WFC measures electric and magnetic field spectrum and waveform from a few Hz to 20 kHz. OFA/WFC processes signals detected by a couple of dipole wire-probe antenna (WPT) and tri-axis magnetic search coils (MSC) installed onboard the satellite. The PWE-OFA subsystem calculates and produces three kind of data; OFA-SPEC (power spectrum), OFA-MATRIX (spectrum matrix), and OFA-COMPLEX (complex spectrum). They are continuously processed 24 hours per day and all data are sent to the ground. OFA-MATRIX and OFA-COMPLEX are used for polarization analyses and direction finding of the plasma waves. The PWE-WFC subsystem measures raw (64 kHz sampled) and down-sampled (1 kHz sampled) burst waveform detected by the WPT and the MSC sensors. It activates by a command, automatic triggering, and scheduling.

The initial check-out process of the PWE successfully completed, and initial data has been obtained. In this presentation, we introduce onboard processing technique on PWE OFA/WFC and its initial results.

Keywords: ERG/ARASE, Plasma wave, Chorus wave, EMIC wave

Charged particle measurements in the radiation belts by ERG

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Radiation belts show mysterious and dynamic variability during geospace storms. The ERG spacecraft aims to observe the cross-energy coupling plasma physics behind the decay and enhancement of the radiation belts. In order to cover the broad energy range from 10 eV up to 20 MeV, ERG is equipped with 6 particle instruments (XEP, HEP, MEP-e, MEP-i, LEP-e, and LEP-i). Here we review the specifications of these sensors.

Observations of low-energy ions with Arase/LEPi

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Arase satellite has been successfully launched into the orbit. The Arase project is focuses on understandings of plasma acceleration / loss / transport mechanisms taking place in the inner magnetosphere. Since energy of particles is ranges over several orders in geospace, Arase carries several particle instruments in order to cover wide energy range, from 10eV/q to 200keV/q (ions), and from 10eV to 10MeV (electrons). LEPi (Low-energy particle experiments - ion mass analyzer) is one of the instruments onboard Arase, which is an energy-mass spectrometer designed to measure the ions with energies from ~0.01keV/q up to 25keV/q. When the instrument passes the initial checkout phase after launch, it will start regular observations.
We will present the current status of LEPi.

Keywords: Arase, low-energy ion, observation

Ground calibration experiments of Magnetic field experiment on the ERG satellite

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The Arase (ERG) satellite was launched on 20 December 2016 to study plasma process in the inner magnetosphere. The Magnetic field experiments (MGF), which is one of the scientific experiments onboard the Arase satellite, observes the background magnetic field and its low frequency fluctuations. The MGF has a set of tri-axis ring-core type fluxgate sensors (MGF-S) to observe the magnetic field in the inner magnetosphere. For accurate measurements of the magnetic field vector along the Arase orbits, ground calibration experiments of MGF-S are needed.
We have been performed in order to determine the sensitivity and alignment via ground calibration experiments. From response of MGF-S to known applied magnetic field, we determined the sensitivity of each axis and found that the error of the sensitivity is less than 0.06%. The axis of the sensor is orthogonal to each other within 0.95 degrees. The estimated error of alignment is within 0.07 degrees. We also have examined the temperature dependence of the sensitivity and offset. The sensitivities relative to the room temperature have linearity with the standard error less than 0.0016, while the offset of the sensors have no clear linearity but reproducibility against temperature. From these ground examinations, the determination accuracies of the amplitude and direction of the magnetic field observed by the MGF will satisfy the science requirements for the Arase observations. In this presentation, we will also evaluate and show measurement error of MGF-S along the Arase orbit.

Keywords: ERG satellite, Magnetic Filed experiment

Modeling energetic particles generated by substorm dipolarizations.

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We describe a novel model of magnetotail which is easily controlled by several adjustable parameters, such as the thickness of the tail and the location of transition from dipole-like to tail-like magnetic field lines. The model is fully three-dimensional and includes the day-night asymmetry of the terrestrial magnetosphere, although the field lines are contained in the meridional planes. This model is well suited to studies of the magnetotail dipolarizations which we consider to be associated with the movements of the transition between dipole-like and tail-like field lines. Induced electric fields generated by this reconfiguration of the magnetotail are capable of energizing electrons and ions. In some cases, the energy of the particles can increase by a factor of 25 or more. These electric fields are also responsible for transport of the energized particles closer to the Earth where they can be observed, either in-situ by the satellites, or indirectly by ground-based instruments, such as riometers. Results of our calculations suggest that this scenario provides a plausible explanation of substorm particles injections.

Keywords: energetic particles in the inner magnetosphere, magnetotail modeling, substorm dipolarizations, substorm particle injections

Relativistic effect on energetic particle injections during the 14 July 2013 Substorm

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Substorm energetic particle injections observed by multiple satellites during a small storm on 14 July 2013 are studied by considering the relativistic effect. We combine the ground observations and in situ magnetic field and particle data from geosynchronous satellites and Van Allen Probes in the inner magnetosphere to investigate the current systems and the energetic particle injections associated with the substorm. Based on a classical electromagnetic field pulse model, we propose a relativistic model to simulate the evolution of energetic particle injections during the particular substorm event. Detailed discussion of the differences in relativistic calculation from non-relativistic ones and satellite observations will be presented.

Keywords: energetic particle injection, inner magnetosphere, substorm

Observations of Electric Fields at Dipolarization Sites from THEMIS mission: Preliminary Results

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The electric fields at diplarization sites in the Earth's tailside have been found to be disturbed when geomagnetic activities occurs (i.e., AL index decreases). These fields can accelerate electrons so that they are possible to be associated with electron injection or changes in electrons' pitch-angles. Therefore, it is essential to understand the variations of these environmental electric fields when dipolarization occurs. In this study, observational data of electric fields from the EFI (Electric Field Instrument) on board of THEMIS mission are analyzed. The database are selected based on dipolarization events around 10 Earth radii identified according to THEMIS observations from year of 2008 to 2011. Both the large-scale and wave-scale features of these dipolarization electric fields will be investigated. The preliminary results of this analysis will be shown in the poster.

Keywords: THEMIS mission, Electric Fields, Dipolarization

Response of relativistic electron microbursts to the arrival of high speed solar wind streams and its relation to flux variation of radiation belt electrons

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Relativistic electron microbursts are short-lived bursty precipitations of relativistic electrons observed by low-altitude satellite in the radiation belt. They are considered as a consequence of pitch angle scattering of radiation belt electrons by discrete whistler-mode emissions known as chorus. Microbursts are frequently observed during geomagnetic storms and previous studies show that atmospheric loss through microbursts appears to contain enough electrons to deplete the radiation belt. They suggest that microburst is an important loss process of radiation belt electrons during the main phase of geomagnetic storms. Microbursts are also frequently observed during high-speed solar wind stream (HSS) events, while important solar wind parameters for the frequent microburst precipitations have not been well understood. We perform a superposed epoch analysis of the microburst occurrence during HSS events, considering the polarity of interplanetary magnetic field (IMF) and solar wind speed according to the method used by Miyoshi and Kataoka (2008). We find the most frequent microburst precipitations during the highest-speed solar wind streams with a southward offset of IMF (SBZ-fast HSS events), indicating that both the southward IMF and fast solar wind are important for enhanced microburst precipitations. We also demonstrate that fluxes of radiation belt electrons with energies from hundreds keV up to 7 MeV preferentially increase during the SBZ-fast HSS events. The result suggests that loss through microbursts is not major loss process of radiation belt during the HSS events. We conclude that relativistic electron microbursts can be a proxy of acceleration of MeV electrons by chorus.

Keywords: radiation belt, high speed solar wind streams, radiation belt dropout

Transport and acceleration of electrons trapped in the inner magnetosphere in response to interplanetary shock

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Interplanetary (IP) shock is known to have a large effect on the electrons trapped in the inner magnetosphere. Observations have shown that the enhancement of the electron flux depends on the pitch angle and energy. It is also proposed that when the IP shock impinges on the magnetosphere, the electrons in the radiation belts are energized not only by induced electric field but also waves excited by low-energy electrons. Therefore, we conduct simulations for acceleration processes of both energized and low-energy electrons by using the global magnetohydrodynamics(MHD) simulation and Comprehensive Inner Magnetosphere-Ionosphere Model (CIMI).In MHD simulation, 12 solar wind conditions are imposed on the upstream boundary condition by changing solar wind velocity, solar wind density and Bz of the Interplanetary magnetic field (IMF). We examine the results of response of the electron flux, temperature anisotropy, the ratio of cyclotron frequency and plasma frequency, the ratio of hot and cold electron density and cold electron density.

We obtained the simulation results as follow. 1) Generally, when the IP shock arrives, energetic electrons (>50 keV) in the dayside magnetosphere are accelerated by the sudden enhancement of the electric field associated with a compressional wave. On the nightside when southward IMF is imposed electrons are transported inward due to E×B drift because the convection electric field is developed. 2) Temperature anisotropy is increased on the nightside by the E×B drift. The value is more than 1 when southward IMF is imposed. 3) Plasmapause is slightly compressed by the compressional wave. Plasmapause is contracted by the convection electricfield when sauthward IMF is imposed. 4) The ratio of plasma frequency and cyclotron frequency is decreased because the magnetic field is increased.

Rapid acceleration of outer radiation belt electrons associated with solar wind pressure pulse : A coupling simulation of GEMSIS-RB and GEMSIS-GM

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Relativistic electron fluxes of the outer radiation belt dynamically change in response to solar wind variations. There are several time scales for the particle acceleration in MeV energy range. One of the shortest acceleration processes is wave-particle interactions between drifting electrons and fast-mode waves induced by compression of the dayside magnetopause through interplanetary shocks (e.g., Li et al., 1993). In order to investigate how relativistic electrons are accelerated by fast-mode waves driven by solar wind pressure pulse, we perform a code-coupling simulation using the GEMSIS-RB test particle simulation (Saito et al., 2010) and the GEMSIS-GM global MHD magnetosphere simulation (Matsumoto et al., 2010). As a case study, the interplanetary pressure pulse with the dynamic pressure of ~ 5 nPa is used as an up-stream condition. In the magnetosphere, the fast mode waves with the azimuthal electric field (negative E_{phi} : $|E_{phi}|$ ~ 10 mV/m) propagates from the dayside and then extends to the entire dayside magnetosphere from 0600 to 1800 MLT. Using the electric/magnetic fields simulated by the GEMSIS-GM, we calculate the electron motion with different initial conditions (energy, and pitch angle). As a result, the increase of electron fluxes occurs for a wide energy range and energy spectrum become hard. The acceleration depends on the initial energy of electrons. We also investigate initial pitch angle dependence of acceleration and find that the fluxes of electron whose initial pitch angle closer to 90°are largely enhanced. The pitch angle dependence may be a result of the latitudinal structure of the induced electric fields and the pich angle dependence of the drift velocity.
The results of investigation for initial energy and pitch angle imply that the acceleration condition of electrons is related to propagation speed of fast-mode waves, drift velocity of electrons and the spatial structure of electric field.

Keywords: radiation belt

Impact of interplanetary shock on ring current ions

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An interplanetary (IP) shock is known to have a large impact on magnetospheric ions. We have performed test particle simulation under the electric and magnetic fields provided by the global magnetohydrodynamics (MHD) simulation developed by Tanaka et al. (2010). In this particular simulation, the solar wind speed was increased from 372 to 500 km/s in order to reproduce the IP shock. The number density in the solar wind was set to a constant to be 5 cm-3, and the Z component of the interplanetary magnetic field (IMF) was turned from +5 to -5 nT. Just after the arrival of the IP shock, a fast mode wave propagated tailward in the magnetosphere. Dawnward electric field comes in first, followed by duskward electric field. The amplitude of the electric field exceeded 20 mV/m. We reconstructed the evolution of phase space density of H+, He+, O+ ions by tracing trajectories of the ions backward on the basis of Liouville's theorem. The trajectory and the phase space density are found to be drastically modified by the fast mode wave in different ways. (1) The ion flux increases at entire energy range. This effect has been traditionally considered. (2) Multiple energy-time dispersion appears in energy-time spectra of the ions with energy less than ~100 keV due to adiabatic acceleration at high latitudes. This is associated with bounce motion (bounce phase bunching), and consistent with the Cluster satellite observation reported by Zong et al. (2012). (3) The ion flux depends on gyro phase due to gyro phase bunching. The gyro phase bunching is prominent for ions with initial speed being comparable to, or less than the ambient ExB drift speed. These results imply that the guiding center approximation is invalid for the ring current ions when large-amplitude fast mode wave is propagating associated with the IP shock. We also calculated temperature anisotropy. The temperature anisotropy increases near the leading edge of the wave where the dawnward electric fields is strong. The increase in the temperature anisotropy may favor the excitation of electromagnetic ion cyclotron (EMIC) waves, and may lead to rapid precipitation of ions and electrons. We evaluated growth of EMIC waves by using KUPDAP (Kyoto University Plasmas Dispersion Analysis Program). We will discuss the effect of IP shock on growing EMIC waves.

Keywords: Ring current, Interplanetary shock

Deeper and earlier penetrations of oxygen ions than protons into the inner magnetosphere observed by Van Allen Probes

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It is observationally known that protons and oxygen ions are the main components of the ring current during magnetic storms and are considered to have different source and supply mechanisms. In order to characterize the ion supply to the ring current during magnetic storms, we study the properties of energetic proton and oxygen ion phase space densities (PSDs) during the 23-25 April 2013 geomagnetic storm observed by the Van Allen Probes spacecraft. We calculated ion PSDs for specific first adiabatic invariants (for proton; for oxygen ion) and the local pitch angles near 90 degrees. The PSD profiles as a function of L show that both proton and oxygen ions penetrated to L < 5 during the main phase of the magnetic storm. The timing of oxygen ion penetration was approximately the same for all values. The observations also show that oxygen ions penetrated more deeply in L and earlier in time than protons for the same value. The early penetration of oxygen ions suggest that the source of the transported oxygen ions was located closer to the Earth than the inner edge of plasma sheet protons. We also discuss the possibility that the interaction between >200 keV oxygen ions and Pc3 ULF waves in the inner magnetosphere causes selective transport of oxygen ions. Our results imply the importance of the contribution from >200 keV oxygen ions to the storm-time ring current.

Keywords: Van Allen Probes, Ring Current, Oxygen ion

Oxygen impulsive energization during the storm main phase and its contribution to the ring current buildup

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We investigate proton and oxygen ion energization during the main phase of magnetic storms. This study addresses one of the unresolved issues: supply, transport, and acceleration of ionospheric oxygen ions in the inner magnetosphere during magnetic storms. It is also yet to be determined whether oxygen ion contribution to the storm-time plasma pressure (and the ring current) is spatially global or localized. Plasma pressure in the inner magnetosphere is dominated by proton and oxygen ions with energies of a few to a few hundreds of keV. It is well known that such energetic oxygen ions increase drastically on a short time scale (< a few tens of minutes). We thus examine impulsive flux enhancements of protons and oxygen ions observed by the RBSPICE and HOPE instruments on board the Van Allen Probes spacecraft.

Van Allen Probes observed oxygen ion enhancements during the main phase of the 17 March 2015 storm. The oxygen energy density showed different temporal variations and radial profile from the proton energy density. It was enhanced during the early main phase (Dst ~ -120 nT) up to the proton energy density level in an L range of 3 to 5. However, it decreased by about an order of magnitude around the beginning of the later main phase. It was increased again during the later phase (Dst ~ -220 nT) particularly at L ~ 3, while it did not reach the early phase level. The radial profile was affected by temporarily impulsive enhancements more significantly than the proton energy density. The difference between the outbound (pre-midnight) and inbound (around midnight) paths is much clearer for oxygen ions than protons.

In this poster, we show the results of multi-event studies on such mass-dependent features during magnetic storms that occurred in 2013 to 2016. Our analysis is particularly focused on changes of energy spectra and pitch angle distributions, and spatial distributions of the oxygen ion contribution to the ring current. We discuss when and where ionospheric oxygen ions are energized to make a significant contribution to the ring current.

Keywords: Magnetic storms, Ring current, Oxygen ion outflow, Plasma transport and acceleration

Modeling Results of the Two Largest Geomagnetic Storms of Solar Cycle 24

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In this paper, radiation belt response to the two largest geomagnetic storms of Solar Cycle 24 (17 March 2015 and the 22 June 2015) is investigated in detail. Even though both storms are primarily CME driven, each has its own complexities [Liu et al., 2015, Kataoka et al., 2015]. Using the CCMC’s run-on-request system, modeling results using the RBE (Radiation Belt Environment) model within the SWMF (Space Weather Modeling Framework) and the RBE model coupled with the SWMF and RCM (Rice Convection Model, which takes the ring current’s contribution into consideration) will be examined. Comparative and comprehensive analyses of the same event from two different models and of two events from the same model/model suite will be provided. Focus will be specially given to impacts of different solar wind drivers on radiation belt dynamics and to the coupling and interactions of different plasma populations/physical processes within the region.

Keywords: radiation belt dynamics, largest geomagnetic storms, coupling

Statistical Analysis of the Spatial Distribution of Low Frequency Magnetosonic Waves and Proton Ring-like Distribution

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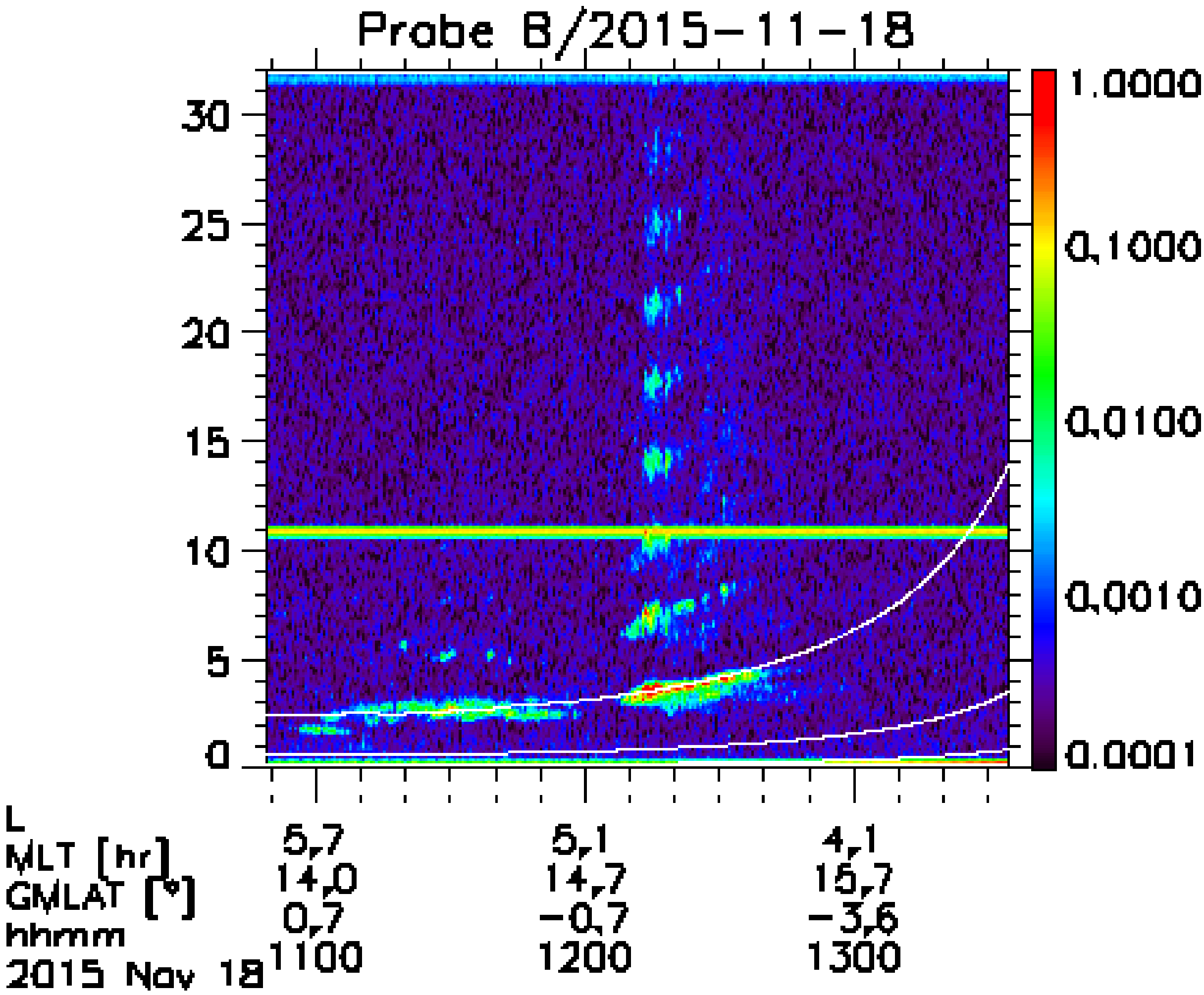
We statistically investigate the spatial distribution of magnetosonic waves at f < 32 Hz and proton ring-like distribution observed by Van Allen Probes from September 2012 to December 2016. The spatial distribution of magnetosonic waves has an occurrence peak at L = 4 –6 and 13 –16 MLT and that of proton ring-like distribution has an occurrence peak at L = 4 –7 and 13 –17 MLT. The coincidence of the occurrence frequency peaks suggests that proton ring-like distribution is likely to be an energy source of magnetosonic waves. We reveals that the proton ring-like distribution with $V_r > 2V_A$ has potential to excite magnetosonic waves at f < 32 Hz, where V_r and V_A are ring velocity and Alfvén velocity, respectively. Case studies of convective growth rate analysis confirms the possibility of wave excitation by the proton ring-like distribution near the frequency of waves observed by satellites in these cases. Under the disturbed magnetospheric condition, the occurrence rate of magnetosonic waves increase up to 10 % and the ring energy increases up to ~20 keV. This is consistent with an idea that and the high ring energy satisfies the wave growth condition of $V_r > 2V_A$. The condition of wave excitation at low frequency is attributed of a weighting function included in the calculation of the convective growth rate. A statistical analysis of the wave frequency reveals that magnetosonic waves in plasma trough are observed around the multiples of local proton cyclotron frequency except the first harmonics and most of them are considered to be excited locally, while some of magnetosonic waves observed inside the plasmapause seems to propagate from the other region.

Keywords: inner magnetosphere, plasma waves, magnetosonic waves, equatorial noise, ring like distribution, Van Allen Probes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Nonlinear generation mechanism of EMIC falling tone emissions

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We have conducted a self-consistent hybrid simulation, successfully reproducing EMIC emissions with falling-tone frequencies. The hybrid simulation is implemented with a parabolic ambient magnetic field. In the simulation, strong oxygen band EMIC emissions are generated through nonlinear wave growth. The cold ion density is modulated by electrostatic structures which are induced by the forward and backward propagating oxygen band EMIC waves. Along with the growth of the oxygen band, the helium band waves also grow because of the linear growth and the nonlinear growth. The nonlinear growth of the helium band waves is affected by the cold plasma density modulation, and there appear short wave packets of helium band emissions. The short wave packets entrap energetic protons efficiently, resulting in electromagnetic proton hills in the velocity phase space. The proton hill forms a nonlinear resonant current causing the falling frequency of the EMIC waves. We find strong deformation of the velocity distribution function of the energetic protons due to the proton hill being guided by the increasing resonance velocity.

A statistical examination of favorable plasma conditions concerning inner magnetosphere EMIC wave excitation

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We examine plasma conditions associated with the excitation of electromagnetic ion cyclotron (EMIC) waves in the inner magnetosphere (L < ˜7). Measurements from the Van Allen Probes (r = 1.1 - 5.8 R_e) are used. EMIC wave events were identified from the polarization analysis of high-resolution magnetic field data from the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) onboard the Van Allen Probes. The time span is from November 2012 to August 2014, which is one complete Van Allen Probes magnetic local time (MLT) precession. Plasma measurements were obtained from the Helium, Oxygen, Proton, Electron (HOPE) instrument. We calculate the observational growth parameter (Σ_h) of the EMIC waves and the theoretical EMIC instability threshold (S_h) to determine if the plasmas are favorable for EMIC wave excitation, i.e., $\Sigma_h - S_h > 0$. Σ_h and S_h are calculated using measurements of the hot (>1 keV) proton anisotropy, parallel hot proton plasma beta, the hot proton density, and the density of electrons. We examine occurrence rates and spatial distributions for the wave-favorable plasma conditions and the ratios of wave vs. non-wave occurrences under these conditions. Plasmas most favorable for EMIC wave generation are primarily observed at the probe apogee (L = ˜6). Peak EMIC wave occurrence is found in the afternoon - midnight (1600 - 0100) MLT sectors. This same region coincides with the enhancements of parallel hot proton plasma beta and hot proton density. Hot proton anisotropy measurements peak in the midnight - noon (0 - 1200) MLT sectors.

Keywords: Plasma waves and instabilities, Wave/particle interactions, Magnetospheric configuration and dynamics, Magnetosphere - inner, Ring current

EMIC waves-driven radiation belt electron precipitation into the atmosphere with ground-based observations in the subauroral region

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Energetic electron losses from the outer radiation belt occur during magnetic storm and substorm. One of the mechanisms is precipitation into the atmosphere and electromagnetic ion cyclotron (EMIC) waves are one of candidates to cause pitch angle scattering of energetic electron. EMIC waves ,which are observed in the Pc1−Pc2 frequency range (0.1−5Hz) are excited by the ion cyclotron instability in the equatorial region of the magnetosphere during the main and the recovery phase of magnetic storms. It has been theoretically studied that EMIC waves play an important role in energetic electron precipitation into the atmosphere, but there have been limited experimental observations to support this idea.
Here, we investigated relation between occurrence of EMIC waves and energetic electron precipitation by means of ground-based magnetometers and low frequency (LF) radio wave propagation observation and confirmed EMIC waves to be driving electron precipitation.
We use induction magnetometer data in North America (ISEE and CARISMA stations) to investigate occurrence of EMIC waves. LF radio wave signals transmitted from WWVB, United States(40.7°N, 255.0°E, L=2.28), are observed at Athabasca, Canada(54.7°N, 246.7°E, L=4.35) to investigate precipitation of energetic electron (>100kev) into the atmosphere. LF radio waves propagate, reflecting between earth's surface and the lower ionospheric boundary (altitude=~70-90km). Ionization caused by precipitating electron in the lower ionosphere changes altitude of the reflection height, resulting in a deviation of the LF wave phase from that in undisturbed conditions.
We detected energetic electron precipitation from the LF radio wave observation in 07:00-09:20 UT on July 7, 2011 and EMIC waves were observed by the induction magnetometer at Athabasca in 05:35-10:55 UT on the same day. At the almost same time, EMIC waves were observed at some CARISMA stations. These observations indicate that EMIC waves are expected to cause detected electron precipitation. Polarization characteristics of EMIC waves which reflect locations where the waves inject into the ionosphere and direction of subsequent horizontal propagation in the F-region were examined by cross-spectrum analysis of EMIC waves.
Based on time variations in intensity, frequency, polarization sense, and angle of the major axis, the period of EMIC appearance could be divided into six sequential events. This suggests that source of the EMIC waves observed in 05:35-10:55UT was not a single but consisted of multiple locations locations.
We found that time variation of the LF wave phase corresponds to that of EMIC waves, and the deviation of the LF wave phase only occurred during the 2nd, 3rd and 4th EMIC events. This result implies that the source locations of the three EMIC events were close to the Athabasca-WWVB radio wave propagation path and the EMIC-driven energetic electron precipitation caused the phase deviation of WWVB signal. Identification of actual source locations of the EMIC events is a future work.

Acknowledgement
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Keywords: EMIC waves, energetic electron precipitation

Polarization characteristics of Pc1 pearl structure observed at Kawatabi, Osaki, Miyagi prefecture

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Pc1 geomagnetic pulsations are often found in the ELF magnetic field data obtained by two sets of induction magnetometers EL-12 constructed by Tierra Technica Co. Ltd, placed in North-South and East-West directions at Kawatabi, Osaki, Miyagi prefecture Japan. The magnetic latitude of the observation site is N30 and the L value is about 1.3.
Although the data coverage was not very good, we have found 7 examples of pearl structures, within the frequency range of 1 to 5 Hz. They showed temporal variation of bandwidth such as 0.3 to 1.2Hz, or 0.9 to 1.8 Hz, forming pearl structures in dynamic spectra. The frequency itself also varied with time: they rose in 3 cases found in pre-midnight, and fall in 4 cases in the pre-midnight region.
Polarization of the magnetic variation was examined by using Fourier components of N-S and E-W magnetic field components. We have 4 evens for which E-W and N-S observations were available. The polarization was steady and right-handed for one event, but for the rest, it was variable. One event showed left-handed polarization at higher frequency and right-handed in the lower. Other two events showed alternative polarizations pearl to pearl.

Keywords: Pc1, pearl, pulsation, ELF, magnetic variation, polarization

Formation of butterfly pitch angle distributions of relativistic electrons in the outer radiation belt due to the drift resonance with a monochromatic Pc5 wave

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Radial transport of relativistic electrons in the inner magnetosphere can be driven by drift resonance with Pc5 Ultra Low Frequency (ULF) waves. The radial transport due to the drift resonance has been considered as one of important acceleration mechanisms of the outer radiation belt electrons. In the course of the radial transport, the energy and equatorial pitch angle of electron change under conservation of the first and second adiabatic invariants. The change in the drift period in the course of radial transport thus depends on the adiabatic process, and it can affect the radial transport rate of the electrons. In other words, the radial transport rate due to the drift resonance depends on the equatorial pitch angle and can form the characteristic pitch angle distributions (PADs). In this study, we investigate the radial transport of relativistic electrons due to the drift resonance with a monochromatic Pc5 wave and focus on formation of PADs of the outer radiation belt electrons.
We use two simulation models of the inner magnetosphere: GEMSIS-Ring Current (RC) and GEMSIS-Radiation Belt (RB). The RC simulation, which is a self-consistent and kinetic numerical simulation code, solves the five-dimensional Boltzmann equation for the ring-current ions coupled with Maxwell equations. The RB simulation calculates trajectories of guiding center of test-particles in arbitrary magnetic and electric field. We used electric and magnetic fields of a monochromatic Pc5 wave in the inner magnetosphere obtained from the RC simulation as background fields in the RB simulations. We traced an order of 10^7 of radiation belt electrons to calculate phase space density of the electrons at each position in the equatorial plane.
Simulation results show formation of characteristic PADs depending on the energy and location (L value), which can be explicable of the pitch angle dependence of resonance conditions. At some fixed location and energy range, the PADs can change from pancake-like to butterfly-like distributions, as the transport by the monochromatic Pc5 wave progresses. These butterfly distributions can be seen when electrons with small (oblique) pitch angles satisfy the resonance condition. It is also found that the small pitch angle electrons can be transported further inward because PA change to larger value through the adiabatic transport enables them to satisfy resonance condition in wider L range compared to the 90-degrees PA electrons.

Keywords: Radiation belt electrons, Drift resonance, Pitch angle distributions

Localtime Dependence of the Pc5 Wave associated with MeV Electron Flux Enhancement Observed by two GOES Satellites

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It is well known that MeV electron flux efficiently increases during the recovery phase of magnetic storms. ULF wave propagating in the magnetosphere is recognized as one of the possible candidates which can accelerate the electron in the radiation belt while various acceleration processes have been widely proposed by many investigators.
In this study, total 20 electron flux enhancement events associated with the CIR (Corotating Interaction Region) driven storms in 2008 have been analyzed using the magnetic field vector data obtained by GOES 10 and 11 satellites. The GOES 10 and 11 were located at 60 deg. and 75 deg. West in geographical longitude, respectively, which corresponds to 1 hour separation in local time. We used the bandpass filtered (150-1000 sec) magnetic data in the ENP coordinate system to investigate the oscillation mode of the field line and the propagation characteristics of Pc5 pulsations in the GEO orbit (6.6 Re).
As a result, following features are observed, that is: both the P (compressional mode) and T (transverse mode) components of the Pc5 strongly enhances at th beginning of the electron flux decreasing in the night side sectors: the Pc5 power is relatively low at the mooning sectors: the dominant frequencies vary from high to low during the electron flux decreasing, which is quite apparent at the afternoon-night sectors. These observational facts indicates that the source region of the Pc5 during the electron flux decreasing can be considered at the evening sectors. The particle injection from night side associated with substorms may generates the ULF wave in the evening sectors. The decreasing of the dominant frequencies also suggests the particle injection from night side associated with substorms from the night to evening sectors.

Keywords: ULF wave, MeV electron flux, Substorm

ULF wave modulation on the generation process of whistler-mode chorus emissions

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We study the modulation of the generation process of whistler-mode chorus emissions under the presence of ULF waves in the inner magnetosphere. Previous studies revealed properties of chorus generation depending on the number density of energetic electrons, temperature anisotropy of velocity distribution function, and spatial gradient of the background magnetic field [Katoh and Omura, 2011, 2013, 2017]. The properties of both energetic electrons and the background magnetic field are also varied by the presence of ULF waves in the inner magnetosphere [e.g., Xia et al., 2016]. The range of parameters controlling chorus generation should be examined by a self-consistent simulation reproducing the generation process of chorus emissions. By referring the range of variations of the background magnetic field for toroidal and poloidal mode ULF waves, we carry out a series of electron hybrid code simulations, changing number density and temperature anisotropy of energetic electrons. Simulation results clarify that the variation of the spatial gradient of the background magnetic field controls whether or not distinct chorus emissions are generated from the magnetic equator. The results of the present study serve useful information in understanding in-situ observation of both chorus and ULF waves and related wave-particle interactions occurring in the inner magnetosphere.

Keywords: whistler-mode chorus, wave-particle interaction, numerical experiments

Van Allen Probes Observations of Modulation of Energetic Ion Fluxes by a Fundamental Poloidal Mode Standing Alfvén Wave

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Magnetospheric ULF waves are known to cause periodic modulations of the flux of ring current ions (energy range ~10-300 keV). Many previous studies reported ion flux modulation events associated with second harmonic poloidal mode standing Alfvén waves. In this study, we report Van Allen Probes observations of an ion flux modulation event associated with a fundamental poloidal wave. The wave (period ~ 100s) was observed on 6 October 2012 in the prenoon and produced a giant pulsation on the ground. The standing wave mode was unambiguously determined from the relationship between the electric and magnetic field perturbations at the spacecraft. The field oscillations were accompanied by oscillations of the flux of ions over an energy range of 100-200 keV. Contrary to previously reported similar ULF wave events with strong modulation of equatorial protons, the flux oscillations in the present event were strongest at pitch angles around 30 degrees. The amplitude and phase of the ion flux oscillations exhibited signatures of drift resonance at 150 keV, from which the wave is inferred to be propagating westward with an azimuthal wave number of 35. This wave number is consistent with the ion finite Larmor radius effects seen in ion fluxes measured at different phases of the spacecraft spin. The ion phase space density exhibits a radial gradient that is consistent with theoretical prediction of an instability involving drift resonance of ring current ions with fundamental poloidal waves.

Keywords: Fundamental standing Alfvén wave, Van Allen Probes, Ring current ions

Landau resonance between electrons and lower-hybrid waves in the inner magnetosphere

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Lower-hybrid waves are frequently observed near the geomagnetic equator in the inner magnetosphere (i.e., equatorial noise). They are in the frequency range between the proton gyrofrequency and the LH frequency, and were found to propagate approximately perpendicular to the background magnetic field with almost linear polarization. We have focused on the capability of the LH waves to scatter electrons, and showed that the diffusions could occur via both cyclotron and Landau resonances. To have the cyclotron resonance to occur, the electron energies should be higher than 1.56 MeV. On the contrary, the Landau resonance occurs even for relatively lower energies from 1.4 keV. Here, the linear resonance condition is assumed under the observed LH wave parameters such as the propagation angle of 85 degree and the frequency of 130 Hz in a plasma environment with the Alfven velocity of 1150 km/s.

In this presentation, we discuss the Landau resonance between electrons and LH waves, by performing test particle simulation. The LH waves are given as a superposition of sinusoidal waves with different frequencies propagating highly perpendicular to the background magnetic field. The given waves obey the cold plasma dispersion relation. We evaluate the pitch-angle diffusion coefficient of electrons with energies from a few eV to 1 MeV. We discuss changes in pitch-angle distributions related to the diffusion processes.

Keywords: pitch-angle diffusion, electron, lower-hybrid wave, inner magnetosphere

Nonlinear pitch angle scattering of low pitch angle electrons caused by whistler mode chorus emissions

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Whistler-mode chorus emissions are defined as coherent emissions with frequency sweep, and are frequently observed by various satellites in the Earth's inner magnetosphere. Chorus emissions are generated by energetic electrons in the kinetic energy range from a few to tens of keV through nonlinear wave-particle interactions, and energetic electrons are scattered their pitch angle by generated chorus emissions. The pitch angle scattering is closely related to energetic electron precipitation into the ionosphere, contributing to diffuse and pulsating aurora. Conventionally, it has been considered that particles satisfying the cyclotron resonance condition are scattered toward the loss cone by whistler mode waves. Li et al. (2015) indicated, however, that low pitch angle particles tend to be scattered away from the loss cone by coherent whistler mode waves. Omura et al. (1991) reviewed the study of the motion of particles under the presence of coherent waves and represented the equation of motion of particle near the resonance condition as a pendulum equation. They assumed in the derivation of the equation that the pitch angle of particles is not small (Nunn, 1974).

In this study, we derive the equation of the motion of particles without the assumption of small pitch angle to consider pitch angle scattering near the loss cone in the velocity phase space. We clarify that electrons near the loss cone satisfying the cyclotron resonant condition are scattered away from the loss cone due to the Lorentz force caused by the wave magnetic field and the parallel velocity component of electrons. In order to reproduce the pitch angle scattering caused by chorus emissions, we carry out a test particle simulation using the simulation system along a dipole magnetic field line and a whistler mode wave model. Results of the test particle simulation are consistently explained by the nonlinear theory we derived, and the pitch angle variation due to the nonlinear effect strongly depends on the wave amplitude. In particular, for the case of the large amplitude wave, most of resonant electrons are trapped by the coherent wave and are efficiently scattered away from the loss cone, resulting in less precipitating electrons. Furthermore, assuming 20 keV electrons uniformly distributed in the pitch angle range from 0 to 90 degrees, we estimate the modulation of pitch angle distribution while electrons encounter one wave packet of chorus emissions. Our results indicate that most of low pitch angle electrons scattered away from the loss cone and build a bump of distribution at the moderate pitch angle satisfying the cyclotron resonant condition. These results suggest that the relation between chorus wave intensity and the flux of auroral electron precipitation is not straightforward and that the nonlinear effect newly proposed by the present study should be taken into account.

Keywords: chorus emissions, pitch angle scattering, wave-particle interaction

Three-Dimensional Forward Modeling of Lightning-Induced Electron Precipitation from the Radiation Belts

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Pitch-angle scattering by radio waves in the VLF (3-30kHz) band is thought to be a major loss mechanism for energetic radiation-belt electrons. Resonant interactions with Whistler-mode VLF waves can alter the reflection altitude of trapped electrons 100keV - 1MeV; when a particle reflects at a low enough altitude, it can be removed from the magnetosphere through collisions with ionospheric constituents. Terres- trial lightning provides a natural and constantly-occurring source of VLF waves. Here we present a three-dimensional forward model of lightning-induced electron precipitation (LEP) due to resonant pitch-angle scattering from a single lightning stroke.

Previous efforts (Lauben 1998, Bortnik 2006) have used two-dimensional raytracing combined with analytical expressions of pitch-angle scattering to forward model precipitation from a single stroke as a function of input and output latitude. However these models are limited in geospatial accuracy by their use of ideal plasmasphere and magnetic field models. We expand on these techniques by incorporating three- dimensional raytracing through a realistic plasmasphere and magnetic field model, to better capture the spatial dependence of LEP.

We then combine our end-to-end model of the LEP process with terrestrial lightning activity data from the GLD360 sensor network to construct a realtime geospatial model of LEP-driven energy deposition into the ionosphere. We explore global and seasonal statistics, provide precipitation estimates across a variety of magnetospheric conditions, and compare the total impact to other magnetospheric loss processes. The completed model is well-suited for comparison with satellite electron flux measurements, such as those from the Arase mission.

Keywords: Wave-Particle Interactions, Radiation Belts, Lightning-Induced Electron Precipitation

Acceleration of energetic electrons by oblique whistler-mode chorus in the radiation belt

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We perform test particle simulations for relativistic electrons interacting with a whistler-mode chorus packet propagating at oblique angles. The properties of group velocity of obliquely propagating whistler mode waves are analyzed. The group velocity of lower band chorus is nearly parallel to the magnetic field, which justify the gyroaveraging method. In the gyroaveraging method, we calculate the equations of motion of electrons averaging the cyclotron motion at gyrocenter and reducing the simulation from two-dimensional system to one-dimensional system. In the simulations, we found that multiple resonances are essential in electron accelerations. We trace evolution of a delta function of relativistic electrons in a phase space of kinetic energy and equatorial pitch angle, and then obtain numerical Green's functions of the chorus wave-particle interactions. The efficiency of the MeV electron acceleration by the Landau resonance is confirmed by examining the Green's functions in a wide range of kinetic energies. We investigate the rate of energy gain of the cyclotron resonance acceleration and the Landau resonance acceleration, and find that the perpendicular component of wave electric field dominates both accelerations for MeV electrons. Furthermore, we find that the efficient acceleration of MeV electrons is contributed by the proximity between the parallel components of V_p and V_g of oblique whistler mode waves. The proximity makes the interaction time of the Landau resonance much longer than that of the cyclotron resonance, resulting in efficient acceleration of MeV electrons.

Keywords: Whistler mode waves, Relativistic electrons, Landau resonance

Nonlinear dynamics of resonant particles interacting with coherent waves and comparison with quasi-linear theory

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We perform test particle simulations of charged particles in an external constant electric field and electrostatic wave fields. We solve equations of motion, which take the same form as the pendulum equation, and we study nonlinear dynamics of particles with different values of inhomogeneity factor S defined as a ratio of the wave amplitude to the background electrostatic field. The target of the present study is to understand nonlinear dynamics of resonant particles interacting with coherent waves in space plasmas. Electromagnetic waves such as whistler-mode chorus, hiss emissions, and electromagnetic ion cyclotron (EMIC) waves in the inner magnetosphere contain structures of coherent waves with various discrete frequencies. Their interaction with resonant particles can be approximated by the nonlinear pendulum equation, or the equations of motion for a charged particle in a one-dimensional electrostatic wave potential. Conventionally, particle scattering and energization are studied as particle diffusion by incoherent waves without any background field causing adiabatic variation of the drift velocity. However, this model, called quasi-linear diffusion model, cannot explain "super diffusion", referring to MeV energization and precipitation of particles in a few minutes, found in observations of chorus, hiss, and EMIC waves. To describe the super diffusion with the simplified electrostatic model, we introduce the external constant field, which corresponds to an inhomogeneous magnetic field causing adiabatic motion such as mirror motion. All particles are accelerated uniformly and constantly as an adiabatic motion, and they are dramatically heated by scattering and/or nonlinear trapping through resonant interaction with the waves. The present simulation model demonstrates the super diffusion due to coherent waves and the external field.

Keywords: wave-particle interaction, nonlinear wave trapping, particle acceleration

Dynamics of energetic electrons interacting with sub-packet chorus emissions in the outer radiation belt

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Our preceding study examined the efficient electrons acceleration processes called Relativistic Turning Acceleration (RTA) and Ultra-relativistic Turning Acceleration (URA), and the mechanism how the outer radiation belt is formed. This time, we undertake an update of the chorus wave model used in the preceding simulation in order to reflect the observational data more precisely. By referring to the latest observations by Van Allen Probes (Foster et al. 2017), we update the chorus wave source model excited around the equator whose amplitude was assumed to grow monotonically in the preceding simulation. The new wave model in the current simulation represents the sub-packet structure in its amplitude variation. Sub-packet amplitude structure is such that when the wave amplitude nonlinearly grows to reach the optimum amplitude, it starts decreasing until crossing the threshold. Once it crosses the threshold, the wave dissipates and a new wave arises to repeat the nonlinear growth and damping in the same manner. The multiple occurrence of these wave generation to dissipation processes forms a saw tooth-like amplitude variation called sub-packet. This sub-packet structure is one of the most distinctive features of chorus waves we can find from the observations and hence should be carefully included in the simulation wave model. Due to the rapid variation of amplitude sub-packet structure, however, the wave frequency as a function of amplitude also undergoes a fluctuation in time variation. This fluctuation is assumed to decrease the duration and efficiency of wave-electron resonance and resultant electron acceleration. We examine the electrons acceleration processes including RTA and URA by the sub-packets and analyze the formation mechanism of a highly energized radiation belt. First we insert 36 test particles assigned with different gyro-phases for 3 different initial energy levels: 500keV, 1MeV and 2MeV with the pitch angle of 85 degrees. The simulation results here are compared with those from the preceding study to well understand the acceleration mechanism of individual electrons. Based on this, we next conduct a statistical analysis how these accelerated electrons collectively form the outer radiation belt. We apply the Green’s function method covering a sufficient number of electrons with the initial energies from 10keV to 2MeV and the initial pitch angles from 10 to 90 degrees. By the overall simulations, we reach a conclusion on how in detail the individual electron is sufficiently accelerated by the sub-packet chorus waves, and how the accelerated electrons collectively form the outer radiation belt.

Two-dimensional Particle Simulations of Oblique Whistler-mode Instability

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We perform two-dimensional electromagnetic particle simulations to study basic characteristics of whistler-mode
wave particle interaction involved in chorus emissions propagating oblique to the static magnetic field. We assume
a simple periodic (x, y) system with the magnetic field taken in the x-direction. Assuming energetic electrons
with an anisotropic bi-Maxwellian velocity distribution function, we first test the linear whistler-mode instability
driven by temperature anisotropy to confirm the numerical property of the simulation code. With the electrostatic
components parallel to the magnetic field, which have been neglected in the previous simulation studies on chorus
emissions, we find the linear phase of the instability is much affected by the Electrostatic thermal fluctuations.
It is necessary to put many super-particles in a grid cell to suppress the thermal fluctuation. With 30,000 particles
per cell, we have confirmed a good agreement of the wave growth in the parallel direction with the linear growth
rate. We next put an array of antennas with obliquely aligned to uniform magnetic field, and oscillate the antenna
current with a variable frequency below the electron cyclotron frequency to excite a large amplitude whistler-mode
wave obliquely propagating to the static magnetic field. In addition to the nonlinear trapping of energetic electrons
through the cyclotron resonance, another nonlinear trapping of electrons by the Landau resonance takes place.
Structures of the nonlinear trapping potentials changes with a varying frequency, affecting the efficiency of
energy transfer between the wave and energetic electrons. We study nonlinear evolution of the wave packet, and
competing processes of both resonances in accelerating the energetic electrons to higher energies.

A statistical investigation of plasmaspheric plasma by using global GPS TEC data

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A statistical analysis of the daily, monthly, yearly and solar cycle variations of plasmaspheric plasma from near earth to the dayside magnetopause is investigated by using the equatorial mapping data of the ground-based global position system (GPS) total electron content (TEC) from the noon meridian for the years of 2003-2015. During the geomagnetic storms, the mapped TEC data often showed clear plume structures in the afternoon sectors, which had been detached from plasmasphere towards sunward and reached the dayside magnetopause. However, the plasma in the plume was exhausted after the main phase of the storms and the plasmasphere needed one day or a few days to be refilled. This exhaustion may be because of the plasmspheric plasma escaping through the dayside magnetopause where the magnetic reconnection or magnetopause shadowing occurred. The mapped TEC plumes and plasmasphere refillings preferred to appear around every afternoon and often reached the dayside magnetopause with different TEC value depending on the solar and geomagnetic conditions, which also preferred to appear in the months from March to May and from October to December and in the years during solar maximum. These results may suggest that the plasma in the plumes escaped away through the magnetopause due to the dayside magnetic reconnection or magnetopause shadowing during the recover phase of the geomagnetic storms, and the polar ionosphere continuously refills plasma into the plasmasphere during the quiet days, which can be stored and partially convected sunward to the dayside magnetopause for forming plumes.

Keywords: Plasmaspheric plasma, Plasmaspheric plume, plasmaspheric refilling

Statistical Analysis of Substorm-Associated SAR arcs at Subauroral Latitudes Based on All-sky Imaging Observations at Athabasca, Canada

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SAR arcs are the optical phenomenon caused by low-energy electron precipitation into the ionospheric F layer from the interaction region between the ring current and the plasmasphere. In the recovery phase of geomagnetic storms, low-energy electrons in the plasmasphere are heated by high-energy plasma in the ring current, and these electrons precipitate into the F layer at subauroral latitude where oxygen atoms are excited at altitudes about 400 km. Thus, SAR arcs have been observed at subauroral latitudes during geomagnetic storms. However, Shiokawa et al. (2009) reported an event of SAR arcs detached from the main oval after substorms, based on observation at Athabasca, Canada (54.7N, 246.7E, magnetic latitude = 61.7N). However, statistical analysis of such substorm-associated SAR arcs have not been done yet. Thus, in this study, we do a statistical analysis of substorm-associated SAR arcs observed at Athabasca. We analyzed all-sky images at wavelengths of 630.0 nm obtained at Athabasca from 3 September, 2005 to 31 December, 2009, and found 98 events. This result indicates that the SAR arcs are often detached from the main oval after substorms at Athabasca. We investigated dependences of these SAR arc appearances and their latitudes and durations on AU/AL indices, SYM-H, X component of magnetic field variation at Yellowknife (YKC), north of Athabasca in the auroral zone, solar wind pressure, and IMF-Bz. We found that when SAR arcs occur, AL and YKC-X component tend to decrease, indicating substorm association of these SAR arcs. We found that the SAR arc occurrence peak is around midnight with a peak rate of ~5 % with decreasing rates in both pre-midnight and post-midnight sectors. We then classified these SAR arcs into 3 types by using simultaneous 557.7-nm images as: 1) 557.7-nm images show weak structures similar to the 630.0-nm SAR arcs (30 %), 2) 557.7-nm images does not show structures similar to the 630.0-nm SAR arcs (55 %), 3) 557.7-nm images show structures different from the 630.0-nm SAR arcs (15 %). In the presentation, we will discuss possible cause of the detachment of SAR arcs from the main oval associated with substorms.

Keywords: SAR arc, substorm, MI coupling

North-south asymmetry of vortex evolution in conjugate aurora

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The influence of the ionosphere on the aurora can be evaluated by examining the asymmetry of conjugate aurora at various time-space scales. We conducted a high-speed imaging observation of aurora at Tjornes/Iceland and Syowa/Antarctica for the time interval from 2 September 2016 to 7 September 2016 when high aurora activity continued for several days, which was driven by high-speed solar wind from a large coronal hole. It is found that an overall conjugacy is not good as we originally expected, even considering the modeled conjugate points. For example, vortex evolution from small scale (so called folds, a few ten km) to large scale (spirals, a few hundred km) occurred over whole field of view at Syowa, while such vortex structures themselves are hard to recognize at Tjornes at the same time. In this talk we discuss the conjugate morphology in more detail. Further we present the current situation and future development of the high-speed conjugate imaging observations.

Keywords: Aurora, Conjugacy, High-speed imaging

