Relativistic electron precipiations associated with the pulsating aurora

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We investigate the wide energy electron precipiations from keV to MeV associated with the pulsating aurora. The EISCAT observations indicated that a few hundred keV electrons often precipitate into the middle atmosphere during the pulsating aurora. The satellite at the magnetosphere observes that intense rising tone emissions of chorus waves were observed in the magnetosphere. The chorus waves that propagate to the higher latitudes can modulate electrons for the wide energy range, and resultant precipiations take place. Our computer simulation confirmed this process; chorus waves propagating along the field line cause the wide energy electron precipitations. These precipiations have a great impact on the ion chemistory at the mesosphere. In fact, the computer simulation showed that significant enhancement of NOx and decrease of O3 occurs associated with the precipiation of pulsating aurora electrons.

Keywords: Pulsating aurora, radiation belts

Ultra-low-frequency wave-driven diffusion of radiation belt relativistic electrons

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Van Allen radiation belts are typically two zones of energetic particles encircling the Earth separated by the slot region. How the outer radiation belt electrons are accelerated to relativistic energies remains an unanswered question. Recent studies have presented compelling evidence for the local acceleration by Very Low Frequency (VLF) chorus waves. However, there has been a competing theory to the local acceleration, radial diffusion by Ultra Low Frequency (ULF) waves, whose importance has not yet been determined definitively. Here we report a unique radiation belt event with intense ULF waves but no detectable VLF chorus waves. Our results demonstrate that the ULF waves moved the inner edge of the outer radiation belt earthward 0.3 Earth radii and enhanced the relativistic electron fluxes by up to one order of magnitude near the slot region within about 10 hours, providing strong evidence for the radial diffusion of radiation belt relativistic electrons.

Keywords: Van Allen radiation belts, Ultra Low Frequency (ULF) waves, Radial diffusion, Electron acceleration

Excitation of Pc1-3 waves in the magnetosphere by external shear flows

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We present how Pc1-3 wave occurrences are affected by external sources in the magnetosheath. The Doppler shift motion of disturbances in the magnetosheath can continuously generate relatively high frequency component of ULF waves, which includes EMIC band. By adopting a theoretical technique of invariant imbedding method(IIM), it is shown how the solar wind and the IMF control the EMIC activities as well as Pc 1-3 wave occurrences. Our results are found to be very consistent with the observational feature of current statistical studies of EMIC wave events such that dominant occurrences are found at the outer shells, and that there is strong asymmetric distribution between dawn and dusk. In addition, our results are also consistent with Pc2-3 occurrences in the low-latitude ground stations and their relationship with the solar wind speed.

Keywords: magnetosphere, ULF wave

A predictor-corrector schema based upon Boris schema for the integration of the equation of motion of charged particles : Application to the Earth's inner magnetosphere

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A lot of numerical schemes are available for integrating the equations of motion of a charged particle in an electromagnetic field. The schema proposed by Boris (1970) is one of the most remarkable due to its simplicity and accuracy and hence is widely used in numerical plasma physics. Although being not a leap-frog schema due to the dependence of the electromagnetic force upon the velocity, it has a structure reminiscent of the leap-frog which imposes to stop and restart the integration in order to change the time step. Hence the original Boris' schema does not allow a continuous adaptation of the time step. Changing the time step during self-consistent numerical simulations would be difficult, if not practically impossible, but it may be of interest for test particle simulations. We present a predictor-corrector schema making use of the acceleration substep of Boris' algorithm which allows to vary continuously the time step. We have also designed a procedure for the automatic control of the time step. Applications to the motion of energetic particles in the terrestrial magnetosphere will be presented.

Reference

Boris, J.P., ''Relativistic Plasma Simulation - Optimization of a hybrid code'', in Proceedings of the 4th Conference on Numerical Simulation of Plasmas, pp 3-67, NRL, Washington, Nov. 1970.

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Keywords: motion of charged particles in electromagnetic fields, numerical simulation, magnetospheres

Relation between the ionospheric convection observed by the SuperDARN Hokkaido Paif of (HOP) radars and low-latitude auroras

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Recent SuperDARN deployment toward lower latitudes made it possible to study ionospheric convection associated with low-latitude auroras (up to below 50 degrees geomagnetic latitude) with high temporal resolution (1 min). In this paper we report on the relationship between the appearance of low-latitude auroras for a few geomagnetic storm events (such as that on March 17, 2015 and on December 21, 2015) and ionospheric convection observed by the SuperDARN Hokkaido Pair of (HOP) radars. Associated with low-latitude auroral emission in the postmidnight sector, there was a sheared flow structure with westward flow equatorward of eastward flow, with the equatorward boundary of auroral emission embedded in the westward flow region. Such kind of flow distribution was also observed with other events such as that on January 20, 2016. The observations suggest that the presence of electric field distribution plays some roles in keeping low latitude auroral emission. Detailed discussion of the relationship between the low latitude auroras and the electric field distribution will be presented.

Keywords: SuperDARN Hokkaido Pair of (HOP) radars, low-latitude auroras, mid-latitude / subauroral latitude ionospheric convection

Cluster observations of equatorial magnetosonic waves with small inter-satellite separation

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The Cluster mission conducted the Inner Magnetosphere Campaign to probe the emissions that play key roles in the dynamics of energetic electrons in the outer radiation belt. We present the results of this campaign related to the equatorial magnetosonic waves. The wave and plasma data obtained in the wave generation region enabled the validatation of the model for the wave generation. Simultaneous measurements of these waves by the Cluster 3 and 4 spacecraft have been used to identify, directly from data, their dispersion relation. The equatorial magnetosonic waves possess a discrete spectrum, consisting of emissions at harmonics of proton gyro-frequency. It is shown that the resonance overlap criterion is fulfilled, and therefore the discrete wave spectrum can be approximated by the continuous spectrum within the quasilinear approach. The results of the Cluster Inner Magnetosphere Campaign related to other wave modes are also reviewed

Keywords: equatorial magnetosonic waves, radiation belts, wave-particle interaction

Radiation Belt Electrons Observed by Van Allen Probes and MMS

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The loss and rebuilding of the outer radiation belt is observed storm after storm by the Van Allen Probes, both as a result of CME events and high-speed stream events. The post storm enhancement of the outer belt relativistic electrons requires the presence of source (<75 keV) and seed (few hundred keV) electron populations during the main and early recovery phase along with intense VLF chorus waves. In addition, the Van Allen Probes have described the electron content of the slot region and inner radiation zone, which has been seldom studied because of lack of good access and the serious background conditions there. The backgrounds created by the high-energy protons that exist in the inner radiation zone and extending into the lower parts of the slot region made it difficult to obtain good measurements of the electron fluxes there. Similarly, the backgrounds from penetrating Bremsstrahlung x-rays produced by energetic electrons striking the spacecraft caused difficulty for measurements at outer edge of the slot region and inner edge of the outer zone. These difficulties have been remedied for the Van Allen Probes’ MagEIS data set. Now, with the successful launch of MMS there are additional electron seed population measurements taken over a wide altitude range to complement those from the Van Allen Probes. The Van Allen Probe radiation belt observations and preliminary results from the energetic electron sensors on MMS will be reviewed.

Keywords: Inner Magnetosphere, Radiation Belts, Van Allen Probes, Magnetospheric Multiscale

Two types of global poloidal waves in the inner magnetosphere: Satellite observations and implications on wave-particle interaction

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Poloidal waves in the magnetosphere are a unique type of ultra-low-frequency (ULF) waves that can exchange energy with ring current particles. These waves usually come with large azimuthal wavenumbers (*m*), making them difficult to detect from the ground. Here we summarize the recent satellite observations of two types of global poloidal waves that can potentially modulate energetic particles in the inner magnetosphere. The first type is known as the "global poloidal mode" that has a wave frequency independent of *L*. It has recently been found that, by rapidly sweeping through different longitudinal sectors in the low Earth orbit, the ST-5 satellites frequently observed this type of global poloidal waves as the Doppler-shifted high-*m* waves. Furthermore, it is found that this global poloidal mode can last many hours during geomagnetically quiet times. The second type of global poloidal waves is associated with the storm recovery phase. Evidence is demonstrated by an unprecedented combination of satellite observations, including those by five missions with 15 different probes, during the recovery phase of a major magnetic storm in June 2015. The poloidal waves were found at *L*-values between 5 and 10 as well as at all local times covered by these satellites. Observations of *L*-dependent frequencies support the concept of a discrete number of drift-bounce resonance regions across *L*-shells associated with this type of global poloidal waves. We conclude with possible wave excitation mechanisms for these two types of global poloidal waves, as well as their impact on particle energies in the inner magnetosphere.

Keywords: Poloidal ULF waves, Wave-particle interaction, Inner magnetosphere

Van Allen Probes observations of magnetic field dipolarization and its associated O^+ flux variations in the inner magnetosphere at L<6.6

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We investigate magnetic field dipolarization in the inner magnetosphere and its associated ion flux variations, using the magnetic field and energetic ion flux data acquired by the Van Allen Probes. From a study of 74 events that appeared at L=4.5–6.6 between 1 October 2012 and 31 October 2013, we reveal the following characteristics of the dipolarization in the inner magnetosphere: (1) its timescale is approximately 5 min, (2) it is accompanied by strong magnetic fluctuations that have a dominant frequency close to the O^+ gyrofrequency, (3) ion fluxes at 20–50 keV are simultaneously enhanced with larger magnitudes for O^+ than for H^+, (4) after a few minutes of the dipolarization, the flux enhancement at 0.1–5 keV appears with a clear energy-dispersion signature only for O^+, and (5) the energy-dispersed O^+ flux enhancement appears in directions parallel or anti-parallel to the magnetic field. From these characteristics, we argue possible mechanisms that can provide selective acceleration to O^+ ions at >20 keV. We conclude that O^+ ions at L=5.4–6.6 undergo nonadiabatic local acceleration caused by oscillating electric field associated with the magnetic fluctuations and/or adiabatic convective transport from the plasma sheet to the inner magnetosphere by the impulsive electric field. At L=4.5–5.4, however, only the former acceleration is plausible. We also conclude that the field-aligned energy-dispersed O^+ ions at 0.1–5 keV originate in the ionosphere and are extracted nearly simultaneously to the onset of the dipolarization.

Three-step development of the 17 March 2015 storm: Van Allen Probes/RBSPICE observations

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We investigate enhancements and losses of energetic (~10-~500 keV) protons and oxygen ions during an intense storm with Dst_min of -223 nT on 17 March 2015. We use >10 keV proton and oxygen ion data from the RBSPICE instrument onboard the two Van Allen Probes spacecraft.
During the storm event, Van Allen Probes traveled in the pre-midnight sector on the outbound path and around midnight on the inbound path. The orbits of the two spacecraft were in opposite phase. The Dst index displayed a two-step decrease with the first minimum at 9 UT and the second at 22 UT. Enhancements of ring current ions began at RBSPICE-B at ~7 UT, and RBSPICE-A entered the ring current region at ~8 UT. The RBSPICE data show penetration of the lower part of energetic proton populations (mu = 0.01-0.1 keV/nT, 20-80 keV at L~3.5) down to L~3.5 and the higher part (mu = 0.1-0.4 keV/nT, 80-100 keV at L ~ 4) down to L~4 during the first storm development. The protons penetrated more deeply during the second development, with the lower part to L ~ 2.5 and the higher part to L~3. During the storm maximum, the higher part was more enhanced in energy density without further penetration. Protons with mu up to ~0.8 keV/nT, ~300 keV at L ~ 3.5 made a significant contribution to the total energy density. Flux of energetic oxygen ions (>50 keV) was suddenly enhanced at ~9 UT. The oxygen-to-proton energy density ratio for >50 keV, which was below 0.1 prior to the storm, reached ~1 during the first development. Although the ratio remained high between 0.1 to 1.0 during the second and third development phases, it did not increase over unity.
We conclude that the 17 March 2015 storm developed in three phases: penetration of cold plasma sheet population, further penetration of the population and oxygen energization (acceleration and/or transport), and deep penetration of hot plasma sheet population. We will examine the evolution of ion energy spectra to identify how oxygen ions were energized and to determine source plasma sheet population that can make the most contribution to each phase of the ring current buildup.

Keywords: ring current and magnetic storms, transport and acceleration of energetic oxygen ions, injections in the inner magnetosphere

Acceleration of MeV radiation belt electrons through interaction with whistler-mode chorus emissions

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We perform test particle simulations [1] of energetic electrons interacting with whistler mode chorus emissions. We compute trajectories of a large number of electrons forming a delta function with the same energy and equatorial pitch angle. The electrons are launched at different locations along the magnetic field line and different timings with respect to a pair of chorus emissions generated at the magnetic equator. We follow the evolution of the delta function and obtain a distribution function in energy and equatorial pitch angle, which is a numerical Green's function for one cycle of chorus wave-particle interaction. We obtain the Green's functions for the energy range 10 keV-6 MeV and all pitch angles greater than the loss cone angle. By taking the convolution integral of the Green's functions with the distribution function of the injected electrons repeatedly, we follow a long-time evolution of the distribution function. We find that the energetic electrons are accelerated effectively by relativistic turning acceleration [2] and ultra-relativistic acceleration [3] through nonlinear trapping by chorus emissions. Further, these processes result in the rapid formation of a dumbbell distribution of highly relativistic electrons within a few minutes after the onset of the continuous injection of 10-30 keV electrons. We also compare the efficiency of electron acceleration by the cyclotron resonance and that of Landau resonance in oblique propagation [4]. We also study the effects of sub-packet structures found in chorus elements on electron acceleration.

References:

[1] Y. Omura et al., J. Geophys. Res. Space Physics, 120, 9545-9562, (2015).
[2] Y. Omura, N. Furuya, and D. Summers, J. Geophys. Res., 112, A06236, (2007).
[2] D. Summers, and Y. Omura, Geophys. Res. Lett., 34, L24205, (2007).
[4] D. Nunn, and Y. Omura, J. Geophys. Res. Space Physics, 120, 2890-2911, (2015)

Keywords: radiation belts, wave-particle interaction, computer simulations

Nonlinear effect in the pitch angle scattering of energetic electrons by coherent whistler-mode waves

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Coherent whistler-mode waves, such as chorus emissions, are frequently observed by various satellites in the Earth's inner magnetosphere. Coherent whistler-mode waves 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 the generated whistler-mode waves. The pitch angle scattering is closely related to energetic electron precipitation into the ionosphere, contributing to diffuse and/or pulsating aurora. Hikishima et al. (2009, 2010) showed a nonlinear effect in the pitch angle scattering and reproduced the microburst precipitation using a self-consistent full particle simulation, and Saito et al. (2012) and Miyoshi et al. (2015) reproduced the energy spectrum of energetic electrons simultaneously observed with pulsating aurora by a test particle simulation. These results suggest that the significance of investigating the detailed mechanism of pitch angle scattering. We carry out a spatially one dimensional test particle simulation with a coherent whistler-mode wave propagating along the dipole magnetic field, and reproduce the interaction between electrons and coherent whistler-mode waves in the region close to the magnetic equator. In this study, we assume two cases; the case A is pitch angle scattering of electrons with pitch angle around 80 degrees cased by coherent waves of frequency of 0.5 f_{ce0}, where f_{ce0} is the electron cyclotron frequency at the magnetic equator, and the case B is pitch angle scattering of electrons near the loss cone angle (~ 5 degrees) cased by coherent waves of frequency of 0.3 f_{ce0}. In the simulation result of the case A, we reproduce trajectories of trapped/un-trapped electrons as discussed in previous studies (e.g., Omura et al., 2008, 2009) and pitch angle of un-trapped particles is scattered toward the loss cone. In the case B, results indicate that the pitch angle variation due to the nonlinear effect strongly depends on the wave amplitude and the length of the wave packet. In particular, for the case of the large amplitude wave and relatively long wave packet, most of resonant electrons are trapped by the coherent wave and are efficiently scattered away from the loss cone, resulting in less precipitating electrons. In this presentation, we discuss the parameter dependence of the trapping (or un-trapping) in the Poincare diagram and that nonlinear effect for pitch angle scattering of energetic electrons.

Keywords: pitch angle scattering, nonlinear wave-particle interaction, whistler-mode waves

Simulation of interaction between energetic plasmas and EMIC triggered emissions

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Electromagnetic ion cyclotron (EMIC) rising-tone (triggered) emission is known as a fine structure of EMIC waves. Theoretical studies suggest that EMIC triggered emissions can induce significant loss of the relativistic electrons through the nonlinear trapping. We perform test particle simulations of the electrons interacting with the EMIC triggered emissions reproduced by real scale hybrid simulation. Relativistic electrons with a few MeV kinetic energy are scattered in wide pitch angle range. The lower energetic electrons are also scattered since the frequency of the triggered emissions reaches near the proton cyclotron frequency and the helium band waves are also induced close to the helium gyro frequency. Broadband EMIC rising waves generated in the small ambient magnetic field gradient model cause rapid precipitation of the relativistic electrons. Simultaneous precipitations of the energetic protons and relativistic electrons are also reproduced in the hybrid and test particle simulations, respectively.

Keywords: EMIC waves, nonlinear wave particle interaction, computer simulation

Relativistic electron precipitation induced by large amplitude EMIC rising-tone emissions

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We study dynamics of radiation belt electrons interacting with large amplitude EMIC rising-tone emissions by performing test particle simulations. *Engebretson et al.* [JGR, 2015] reported depletion of radiation belt electrons in the distribution took place when EMIC rising-tone emissions peaking above 11 nT were excited outside the plasmapause. In the work of *Omura and Zhao* [JGR, 2012, 2013] and *Kubota et al.* [JGR, 2015], anomalous cyclotron gyroresonance between relativistic electrons and EMIC rising-tone emissions are only tested with plasmaspheric conditions. Therefore, we study both cases; inside and outside the plasmasphere. We set up the EMIC model waves in a localized region in longitude and distribute test electrons all around the Earth corresponding to the radiation belt at L=5.5. The electrons moving eastward encounter the localized EMIC waves and some of the resonant electrons are precipitated into the atmosphere. The wave potential generated by coherent EMIC emissions traps a fraction of the resonant electrons, resulting in efficient decrease of their pitch angles. After the nonlinear wave trapping, some electrons at low pitch angles, however, cannot enter into the loss cone. Based on theoretical and numerical analyses, we find another phenomenon named SLPA (Scatter at Low Pitch Angle). Some of the electrons at low pitch angles are further transported into the loss cone rapidly through SLPA. We obtain time evolution of the electron distribution as functions of equatorial pitch angle and kinetic energy. For comparison with observations of relativistic electron precipitation, we monitor fluxes of electrons being lost into the atmosphere in a narrow longitudinal range. Inside the plasmapause, electrons with energy 0.1-8 MeV are precipitated efficiently. Outside the plasmapause, on the other hand, only highly relativistic electrons with energy >2 MeV are precipitated. Furthermore, we find echos of electron depletion in the distribution because of eastward drift around the Earth.

Keywords: Radiation belt, EMIC , relativistic electrons

Relativistic electron microbursts and local acceleration of MeV electrons by chorus: SAMPEX and Van Allen Probes observations

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It has been suggested that whistler mode chorus is responsible for both acceleration of MeV electrons and relativistic electron microbursts through resonant wave-particle interactions. Relativistic electron microbursts have been considered as an important loss mechanism of radiation belt electrons. Here we report on the observations of relativistic electron microbursts and flux variations of trapped MeV electrons during the 8-9 October 2012 storm, using the SAMPEX and Van Allen Probes satellites. Observations by the satellites show that relativistic electron microbursts correlate well with the rapid enhancement of trapped MeV electron fluxes by chorus wave-particle interactions, indicating that acceleration by chorus is much more efficient than losses by microbursts during the storm. It is also revealed that the strong chorus wave activity without relativistic electron microbursts does not lead to significant flux variations of relativistic electrons. We also find that the microburst occurrence rate during the acceleration event has a peak around which the phase space density peak is identified by the Van Allen Probes satellites. We conclude that effective acceleration of relativistic electrons is caused by chorus that can cause relativistic electron microbursts, and that microbursts can be a proxy of internal acceleration of MeV electrons by whistler-mode chorus.

Keywords: radiation belts, chorus waves

Limitation of energetic ring current ion spectra

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We address the problem of determining the limiting energetic ring current ion spectrum resulting from electromagnetic ion cyclotron (EMIC)-wave-ion-interactions. We solve the problem in a relativistic regime, incorporating a cold background multi-ion plasma component and without assuming a predetermined form for the energy distribution. The limiting spectrum is determined by the condition that the EMIC waves acquire a specified gain over a given convective length scale for all frequencies over which wave growth occurs. We find that the limiting ion spectrum satisfies an integral equation that must be solved numerically. However,at large particle energy E, the limiting spectrum takes the simple form J ~ 1/E . Moreover,this 1/E spectral shape does not depend on the energetic ion in question nor on the background multi-ion plasma composition. We provide numerical solutions for the limiting spectra for Earth-like parameters. In addition, at Earth and four other planets we compare measured ion spectra with corresponding numerical limiting spectra.

Keywords: ring current ion spectra, EMIC waves, limiting ion spectrum

Ground calibration results of Medium-Energy Particle analysers (MEPs) for ERG

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ERG (Exploration of energization and Radiation in Geospace) is the geospace exploration spacecraft, which is planned to be launched in FY2016. The mission goal is to unveil the physics behind the drastic radiation belt variability during space storms. One of key observations is the measurement of ions and electrons in the medium-energy range (10-200 keV), since these particles excite EMIC, magnetosonic, and whistler waves, which are theoretically suggested to play significant roles in the relativistic electron acceleration and loss. In previous space missions, however, the medium-energy range has been the missing region due to the limitation of conventional particle instruments. We present unique techniques, which are essential to challenge this difficult energy range, and report the ground calibration results of the instruments.

Keywords: ERG mission, Medium-Energy Particle analysers

First observation of whistler-mode chorus with wavy tones

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Whistler-mode chorus emissions usually appear as rising tones, falling tones, constant tones, hooks and hiss-like band. Here we report a new type of chorus with “wavy tones” observed by Van Allen Probes. The frequency of chorus rose by up to 500 Hz within ~0.5s and then fell back within ~0.7s. This behavior repeated to give a wavy pattern and the continuous wavy structure lasted for ~10s. At the same time, rising tones and hiss-like band occurred above and below the wavy tones. The generation mechanism of chorus with wavy tones need to be further investigated.

ELF/VLF wave generation associated with magnetospheric compression: conjugated observations from satellite- and subauroral ground-based instruments.

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On February 2012, during the VLF-CHAIN campaign a VLF loop antenna was installed at the Athabasca University Geophysical Observatory in Alberta, Canada. The receiver, located at subauroral latitudes (ATH, 54.7N, 246.7E, L=4.3), has continuously monitored ELF/VLF emissions since September 2012. We found a rare conjugate event of ELF/VLF waves between ATH and the RBSP-B satellite, which was associated with strong magnetic compression.
On December 23, 2014 at 11:17 UT (03:17 MLT), both ATH and RBSP-B observed a chorus-like burst centered at ~2.5 kHz showing discrete elements and lasting approximately 3 minutes. This emission was observed 2 to 3 minutes after an intense sudden commencement (SYM-H amplitude ~63 nT) caused by the enhancement of solar wind speed (~330 to ~420 km/s) and dynamic pressure (~2 to 6 nPa) during northward IMF. The increasing magnetic field on the dayside, caused by the compression of the magnetosphere, lead to betatron acceleration of plasma-sheet electrons and thus enhancement of the temperature anisotropy. This anisotropy regulates electron cyclotron instability and in turn, generates whistler-mode plasma waves.
We use survey and burst mode electric and magnetic field data from RBSP-B, combined with electron fluxes and density, to discuss the characteristics of the waves. We found that wave vectors are highly oblique and frequency dependent (lower k-vector with higher frequencies). We also found that the Poynting vector was anti-parallel to the field line, directed southwards, away from the magnetic equator. Even though this emission was associated with a slight increase of the electron fluxes between 75 to 743 keV (due to the adiabatic compression), it did not cause local relativistic electron acceleration.
All-sky and horizon imagers located at ATH allow investigation of the relationship of the compression with auroras.

Keywords: ELF/VLF, magnetospheric compression, conjugate event, subauroral latitudes

Statistical characteristics of quasi-periodic Pc1/EMIC waves in the magnetosphere and the ionosphere

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Pc1 pearl structure is a quasi-periodic amplitude modulation of Pc1 pulsations with repetition periods of several tens of seconds. In previous studies, Pc1 pearl structures have been frequently observed on the ground, but only sparsely in space. In order to understand the generation and propagation mechanisms of the pearl Pc1 waves, we investigated the statistical characteristics of quasi-periodic (QP) and randomly structured (RS) EMIC/Pc1 waves in the magnetosphere and in the ionosphere, using ground induction magnetometers located at Athabasca (ATH, L = 4.3) in Canada and Magadan (MGD, L = 2.7) in Russia and the Van Allen Probes (RBSP-A and B) satellites located in the inner magnetosphere. From data covering a one-year period from August 2012 to August 2013, we found a total of 590 hours of Pc1 events at ATH, 295.4 hours at MGD, and 73 hours at RBSP-A, 75.8 hours at RBSP-B. By comparing the observations at ATH and MGD, we found that the occurrence of RS Pc1 waves is independent of UT and that QP Pc1 waves occur concurrently with typical Pc1 waves detected at subauroral latitudes. We also found that on the ground QP Pc1 waves are observed more often than RS Pc1 waves (69 % at ATH, and 68 % at MGD). At RBSP-A and B, EMIC waves exhibit a peak occurrence at L~6 and in the morning sector. In space, the QP and RS EMIC waves occurred at similar rates. QP EMIC waves are observed most often in the He^+ band, at L~4.5, and in the morning and dusk sectors. RS EMIC are frequently observed at L~5 from the midnight to morning sector. From these observations we conclude that the L and local time occurrence pattern of QP/RS EMIC differs between space and ground. To understand the source of the difference, we examined the propagation and polarization characteristics of pearl Pc1 waves that were simultaneously detected at magnetically conjugate locations on the ground and in space.

Keywords: Pc1 pearl structures, ground and space observations, conjugate events

A statistical study of EMIC rising and falling tone emissions observed by THEMIS.

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Electromagnetic ion cyclotron (EMIC) waves with rising or falling frequency variations have been studied intensively because of their effects on energetic particles in the Earth’s magnetosphere. We develop an automated classification method of EMIC events based on the characteristics of frequency variations. We report some basic statistical properties of frequency variations in EMIC waves observed by three Time History of Events and Macroscale Interactions during Substorms (THEMIS) probes from January 2012 to December 2014. We clarify whether rising-tones or falling tones are observed in each 20-minute time segment. In the present analysis, we find that the occurrence rate of EMIC rising- or falling tone events is more than 30 % of the total EMIC wave events. The dayside magnetosphere is a preferential region for the EMIC frequency variations. The occurrence rate of rising tone events is slightly greater than that of falling tone events. We examine the relation between the frequency characteristics and the magnetospheric conditions. The solar wind pressure strongly controls the occurrence rates of frequency variations. We also calculate ranges of frequency variations. Large amplitude EMIC waves tend to have wider frequency variations and the range of frequency variation is largest around the pre-noon region. In addition, the fine-structures in wave amplitudes called “sub-packet structures” are found in 70 % of EMIC rising- or falling- tone events in the dayside region. Sub-packet structures appear mainly in large amplitude EMIC rising or falling tones. These features are consistent with nonlinear wave growth theory.

Keywords: EMIC, nonlinear

Ray tracing of mode conversion process from magnetosonic mode waves to EMIC waves inside plasmasphere

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Magnetosonic waves (MSWs) are electromagnetic emissions of X-mode waves, which are typically generated at frequencies between the proton cyclotron frequency and the lower hybrid resonant frequency. Our previous studies using the Van Allen Probes EMFISIS data indicated that MSWs converts to EMIC waves inside the plasmasphere when the frequency of MSWs corresponds to the cross over frequency, so that plasmaspheric MSWs can be an origin of plasmaspheric EMIC waves. In order to investigate the mode conversion process from MSWs to EMIC waves inside the plasmasphere in more detail, we perform the ray tracing simulation for MSWs generated inside plasmaspshere, using the code developed by Kanazawa University. In this simulation, the initial wave normal angle is almost 90 deg. The ray of waves depends on wave frequency if the initial wave azimuthal angle is almost 0 deg, i.e., earthward direction. On the other hand, the ray of waves does not depend on the frequency if the initial wave azimuthal angle is larger than 10 deg. Additionally, we confirm the mode conversion from R-mode to L-mode at lower frequency components of MSWs, while higher frequency components of MSWs remain R-mode. The simulation results are consistent with the Van Allen Probes observations which show the conversion of plasmaspheric MSW to EMIC waves.

Keywords: magnetosonic waves, Van Allen Probes, mode conversion

Energetic Particle Hybrid Simulations on Geomagnetic Pulsations

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It has long been known that geomagnetic pulsations in mHz frequency range may be generated either by the field line resonance mechanism [Southwood, 1974, Chen and Hasegawa, 1974], or by local plasma instabilities [Southwood et al., 1969]. The former is essentially due to mode conversion from fast mode waves into local Alfven eigenmodes. The source of the waves are believed to be external, such as fluctuations in the solar wind and/or waves emitted by the Kelvin-Helmholtz instability at the magnetopause. Generally speaking, such externally driven waves are thought to generate pulsations with small azimuthal wavenumbers m ~ a few, which have been observed on the ground magnetometers. On the other hand, those generated by internal plasma instabilities may have high mode number m ~ 100. Such large wavenumber modes have been primarily observed by satellite measurements during storm times, associated with enhanced injection of ring current ions into the inner magnetosphere. The low-frequency geomagnetic pulsations can be an efficient driver for the radial transport of radiation-belt electrons. The classical drift resonance theory indicates that, despite relatively larger amplitude of internally driven modes, only externally driven modes can contribute to the radial diffusion [Elkington et al., 2003]. However, recent studies have suggested that the internally driven pulsations may also play a role [Ukhorskiy et al., 2009].
It is well known that the so-called drift-bounce resonance of energetic ring-current particles may be responsible for the generation of high mode number ULF waves. Although the idea of drift-bounce resonance is intuitively quite easy to understand, analysis of the instability in reality is much more complicated than this simple picture [Chen and Hasegawa, 1991, Cheng, 1991]. Earlier theoretical studies indicated that it is the inward ring-current pressure gradient that drives the instability via drift-bounce resonance between the fast energetic particles and MHD waves. To the authors knowledge, however, nonlinear simulations of this instability have not been performed so far.
According to the theoretical analysis, kinetic dynamics of the energetic ring current particles is essential for the instability, including finite Larmor radius effect, fast bounce motion along the magnetic field line, as well as finite drift across the magnetic field. On the other hand, a cold dense thermal population that dominates the total mass density but with negligible thermal pressure may well be approximated by MHD. This motivates us to adopt a new simulation model called the energetic particle hybrid simulation, in which the cold ions and electrons are approximated by fluids whereas the energetic population is treated as kinetic particles. By using this newly developed simulation model, we will discuss the internal generation mechanism of geomagnetic pulsations.
We have constructed a two-dimensional pressure-balanced equilibrium by iteratively solving a Grad-Shafranov-like equation for an anisotropic bounce-averaged ring-current pressure distribution in a dipole-like background magnetic field. We adopt this equilibrium as the initial condition for nonlinear simulations. Preliminary three-dimensional simulation results will be presented, focusing on, in particular, the dependence on the plasma beta, the scale length of the pressure gradient, and the temperature anisotropy.

Keywords: magnetosphere, ring current, MHD waves

Study on characteristics of drift resonance between outer radiation belt electrons and a monochromatic Pc5 wave based on GEMSIS-RC and RB simulations

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Outer radiation belt relativistic electrons are accelerated in the inner magnetosphere. The acceleration mechanisms are roughly classified as two categories ; Radial transport and Local acceleration. Radial transport of relativistic electrons due to Ultra Low Frequency (ULF) waves in the Pc5 frequency range (1.67mHz - 6.67mHz) is one of important candidates to accelerate the outer radiation belt electrons. The acceleration is considered as a result of the drift resonant process. This process is a resonant mechanism between the electron drift motion in the dipole-dominated magnetic field configuration and the electromagnetic fluctuations of Pc5 waves in the inner magnetosphere. The resonance violates the third adiabatic invariant of electrons, while it conserves the first and second adiabatic invariants. Recent studies have pointed out that the radial transport due to the drift resonance can produce one or more localized peaks in radial profile of the phase space density (PSD) [Degeling et al., 2008]. Ukhorskiy et al. [2008] indicated that collective motion of outer belt electrons can exhibit large deviations from radial diffusion. Since the peak in PSD is considered as an evidence of local acceleration [e.g., Reeves et al., 2013], these studies have raised fundamental questions in the radiation belt electron acceleration. Thus, in this study, we investigated the fundamental characteristics of radial transport due to the drift resonance between a monochromatic poloidal Pc5 wave and relativistic electrons based on two unique models ; GEMSIS-RC and GEMSIS-RB.
GEMSIS-RC model is a self-consistent and kinetic numerical simulation code solving the five-dimensional drift-kinetic equation for the ring-current ions in the inner-magnetosphere coupled with Maxwell equations [Amano et al., 2011]. The GEMSIS-RB code conducts test particle trajectory tracings of relativistic electrons in arbitrary magnetic and electric field configurations [Saito et al., 2010]. We conducted Pc5 wave simulation with GEMSIS-RC, and then the obtained time variations of the magnetic and electric fields are used as inputs to GEMSIS-RB to calculate the electron transport due to the Pc5 wave. In order to investigate fundamental nonlinear behavior of radial transport, we investigated effects of a monochromatic wave on the radial transport. The result shows that resonant interaction has a finite width due to the nonlinear process and electrons with smaller pitch angle (70°) are transported deeper inside to small L region than 90 degrees electrons. It is considered that the amount of time to come into resonant width becomes longer due to the change of pitch angle while the first and second invariant are conserved.

Keywords: Radiation belt electrons, Drift resonance, GEMSIS-RC and RB

Wave-driven gradual loss of energetic electrons in the slot region

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Resonant pitch angle scattering by plasma waves is one of the important mechanism to the loss of the radiation belt electrons. Based on the observations and simulations, we investigate the detailed variations of the energetic electrons(>100 keV) in the slot region driven by hiss waves and lightning generated whistlers (LGW) during the recovery phase of the magnetic storm on 1 July 2013. The spacecrafts simultaneously detected substantial decreases in fluxes of energetic electrons and intense hiss waves and weak LGW at the region L~3. Correspondingly, using the time-variant wave parameters of those waves, we calculate bounce-averaged diffusion coefficients and solve a 2-D Fokker-Planck diffusion equation, and the hiss-driven simulations of energetic electron evolution show reasonable agreement with the observation data. The results provides further support that the plasmaspheric hiss can be mainly responsible for the loss of the energetic electron in the slot region.

Keywords: slot region, hiss wave, energetic electron

Test particle simulation of energetic electrons interacting with sub-packet chorus emissions in the inner magnetosphere

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A whistler-mode chorus emission is known as a rising tone wave with a smooth amplitude growth in the magnetosphere. Recently there has been a discovery about a new feature of the chorus wave amplitude. When a chorus wave is generated at the equator, the wave amplitude does not show a smooth growth but a gradual growth with multiple peaks. Waves with this feature are called sub-packet waves. The present study includes two attempts. The first attempt is to simulate the generation and development process of the sub-packet wave over the magnetosphere. The sub-packet's unsmooth amplitude growth at the equator is reproduced by suppressing the amplitude growth with the possible maximum amplitude defined as the optimum amplitude, which is calculated by other geophysical factors. Secondly it is aimed to simulate interaction between the sub-packet wave and energetic electrons under the dipole magnetic field. In the simulation results, a distinct wave form of sub-packet is successfully simulated at the equator as theoretically expected, and it has been also verified that the sub-packet's wave form evolves through propagation to higher latitudes depending on the related geophysical factors such as the inhomogeneity of the magnetic field. By simulating the interactions of sub-packet chorus emissions and resonant electrons, we have found notable features in the energetic electron dynamics in the magnetosphere. The details of these effects on electron dynamics are discussed under the various conditions of physical parameters such as particle initial energy and pitch angle.

Void structure of O^+ ion observed by the Van Allen Probes in the inner magnetoshpere

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The Van Allen Probes Helium Oxygen Proton Electron (HOPE) instrument measures charged particles with an energy range from ~eV to ~50 keV. The observation shows that the energy flux of the particles increases inside the geosynchronous orbit during substorms. For some night-side events, the observed H^+ flux and O^+ flux spectrogram showed injections of energetic ions (tens of keV), but only the O^+ flux spectrum has a gap in the low energy range at high-L shells. The purpose of this study is to investigate the generation mechanism of the structure by using numerical simulations. By applying the same simulation model introduced by Nakayama et al. (2015, JGR), we simulated the substorm-time injection of O^+ ions in the global MHD electromagnetic fields and reconstructed the flux in the inner magnetosphere. Our simulation successfully reconstructs the structure of O^+ flux observed by Van Allen Probes. After analysis of test particle simulation, we concluded that the generation mechanisms of the structure are (1) the longitudinally and radially confined flow channel of O^+ ions and (2) the intensive non-adiabatic acceleration of O^+ ions in the nightside tail region.

Keywords: Van Allen Probes Observation, Substorm, Non-adiabatic Acceleration

Periodic Ion Flux Modulation observed by Van Allen Probes in Ring Current Region

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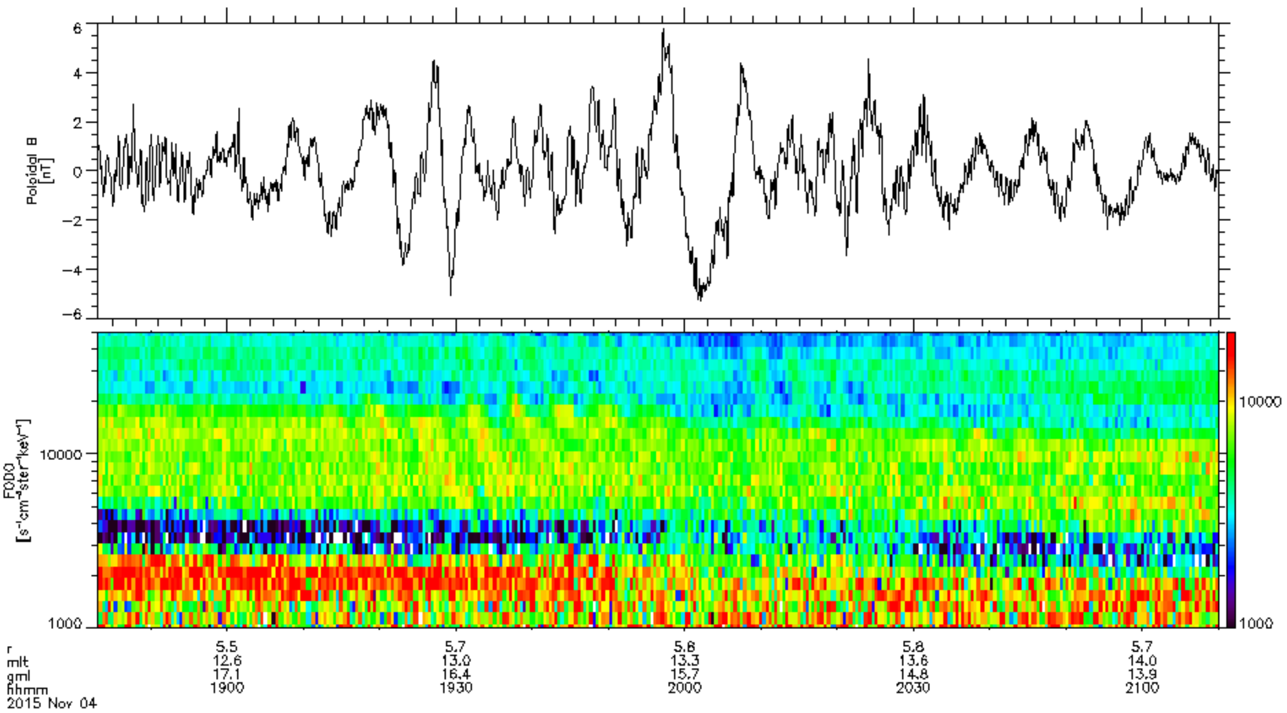
In the drift-bounce resonance that was theoretically introduced by *Southwood et al.* [1969], the interaction is expected between ULF waves and electrons or ions. Through the interaction, charged particles in the ring current can be accelerated or deaccelerated and the population of ring current particles can be changed. There are many observations of drift-bounce resonance for protons [e.g., *Kokubun et al.*, 1977; *Takahashi et al.*, 1990; *Dai et al.*, 2013], whereas only a few observations of drift-bounce resonance are reported for O^+ ions [*Yang et al.*, 2010, 2011].
In this study, we report several events of periodic flux modulation of protons and O^+ ions observed by Van Allen Probes in 2012-2016. We find periodic flux modulation of O^+ ions and Pc5 waves on November 4, 2015 (event A) and November 30, 2015 (event B). In event A, the flux modulation is recognized at 1-50 keV and dispersed in energy. In event B, however, the flux modulation is limited at ~10 keV. We will examine dependence of the flux variations on pitch angles and energies, and discuss if the variations are due to drift-bounce resonance.

Keywords: wave-particle interaction, drift-bounce resonance, geomagnetic pulsations, oxygen ions, ring current, Van Allen Probes



Comparative study of proton and oxygen ion supply into the inner magnetosphere during a geomagnetic storm

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It is observationally known that the contribution of oxygen ions to the ring current increases with increasing size of magnetic storms, although protons are the main component of the ring current ions during small storms. The protons and oxygen ions are considered to have different source and supply mechanisms. The protons mainly come from the solar wind through the plasma sheet, and oxygen ions originate from the terrestrial ionosphere. However, detailed properties of the ion supply and their dependence on ion species (such as depth and timing of ion penetration into the inner magnetosphere) are far from well understood. To characterize the ion supply to the ring current during magnetic storms, here we investigate the properties of energetic proton and oxygen phase space densities (PSDs) during a geomagnetic storm observed by the Van Allen Probes mission. We examine a magnetic storm that occurred during the period from April 23 to 25, 2013. Using energetic ion and magnetic field data obtained by the RBSPICE and EMFISIS instruments onboard Van Allen Probes, we studied the temporal variations of protons and oxygen ions PSD radial profiles.
We calculated the first adiabatic invariant, mu, and PSD for ions with a pitch angle of about 90 degrees (We selected data of a telescope with a pitch angle which is the nearest 90 degrees in all telescopes and is in range of 70 -110 degrees for each time.). Proton and oxygen PSDs for specific mu values (mu= 0.3, 0.5, 0.8, 1.0 keV/nT for proton, mu= 0.5, 0.8, 1.0 keV/nT for oxygen) were obtained as a function of L for each orbit of Van Allen Probes during the storm. The results show that both proton and oxygen ions penetrated directly down to L ~5 during the main phase of the magnetic storm (minimum Dst greater than -65 nT). The penetration boundary of protons were located at smaller L at dusk than at dawn. Protons with smaller mu values (mu= 0.3 and 0.5 keV/nT) penetrated earlier than those with larger mu values (mu= 0.8, 1.0 keV/nT). It seems consistent with the energy dependence of the Alfven layer. In contrast, the timing of O+ penetration is almost the same for all mu values (mu= 0.5, 0.8 and 1.0 keV/nT). The observations also show that O+ ions penetrated more deeply in L and earlier in time than H+ ions.
These results suggest that the source of the transported oxygen ions is located closer to the Earth than that of the protons (i.e., the inner edge of the plasma sheet).
Variations of the oxygen E-t diagram during the second main phase of the storm show enhancement of flux in energy over ~100 keV closer to the Earth than protons inner edges. The magnetic fluctuation with about 0.01 Hz is also enhanced during the second main phase of the storm closer to the Earth than protons inner edges. We suggest that deeper penetrations of oxygen ions are caused by interaction between oxygen ions and Pc5 magnetic fluctuations.
Our results thus demonstrate the importance of the contribution from high energy oxygen ions to the storm-time ring current.

Keywords: Van Allen Probes, Oxygen ion

The impact of interplanetary shock on hydrogen ions in the inner magnetosphere

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An interplanetary (IP) shock is known to redistribute phase space density of magnetosphereic ions. Cluster satellite observations have shown that, soon after arrival of the IP shock, overall intensity of the ions rapidly increases and multiple energy dispersion appears in an energy-time spectrogram of the ions [Zong et al., 2012]. We have performed test particle simulation under the electric and magnetic fields provided by the global magnetohydrodynamics (MHD) simulation. The solar wind speed is 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 propagates tailward in the magnetosphere. The amplitude of the electric field exceeds 20 mV/m. To reconstruct an energy-time spectrogram of the H+ ions at all MLTs at L = 5 ~ 10, we traced trajectories of the ions backward in time. The ions are accelerated nonadiabatically just after arrival of IP shock. Thus, the guiding center approximation is no longer valid. Knowing initial and final positions in 6-dimensional space, we mapped the phase space density, according to Liouville’s theorem. We assumed that the phase space density of the ions is isotropic Maxwellian before the shock arrival. The calculated temperature anisotropy A (=Pperp/Ppara –1) is increased 0.3, which may favor the excitation of electromagnetic ion cyclotron (EMIC) waves. We will discuss the evolution of the temperature anisotropy and possible growth of the EMIC waves.

Keywords: interplanetary shock, inner magnetosphere, hydrogen ion

A pilot study for reconstruction of the inner-magnetosphere by data assimilation of global ENA and EUV measurements

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During these several years, we have developed two data assimilation techniques for the inner magnetosphere. One is for reproducing the temporal evolution of the ring current by assimilation of energetic neutral atom (ENA) imaging data from the IMAGE satellite. The other is for reproducing the evolution of the plasmasphere by assimilation of extreme ultra-violet (EUV) imaging data from the IMAGE satellite. Both of the two techniques uses the data from the same satellite, and both are based on similar frameworks in which the electric field is treated as an unknown quantity. Therefore, it is expected that these two techniques are unified to obtain a comprehensive picture of the evolution of the ring current, the plasmasphere, and the electric field. Since the ring current is located in a different region from the plasmasphere, the ENA and EUV data would provide the information on different regions in the inner magnetosphere. Thus, the use of both the ENA and EUV data could remarkably improve the estimate of the electric field.

We are developing the unified data assimilation technique which incorporates ENA and EUV data into a model of the inner magnetosphere, the comprehensive inner magnetosphere ionosphere model (Fok et al., 2014). We have conducted a pilot study using synthetic ENA and EUV data sets generated from a simulation run under a certain condition. In this study, the distributions of the electric field, the ring current, and the plasmasphere were successfully estimated. The current status of the development of our data assimilation technique will be reported.

Keywords: ring current, plasmasphere, data assimilation

Longitudinally-propagating ionospheric flow structures observed by SuperDARN during March 17-18, 2015 storm

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We study an interesting wavy structure of ionosphere flow at sub-auroral latitudes observed by SuperDARN during a magnetic storm on March 17-18, 2015. The main phase of the storm shows at least two step development in Dst and apparently those two steps are associated with an more or less isolated substorm followed by a series of more intense substorms, respectively. The wavy modulation of ionospheric flow actually occurs during the relatively stagnant period between the two substorms. At sub-auroral latitude, the fast eastward flow prevailing from midnight to early morning during the first substorm ceases and subsequently the mid-latitude SuperDARN radars start to see a series of alternate flow reversals of toward-radar flows and away-from-radar flows. Each of the flow reversal structures has a longitudinal wave length of roughly ~1h magnetic local time (MLT) and fairly large peak-to-peak amplitude of several hundreds of m/s. Interestingly, those flow structures pass by the fields of view of the radars one after another, showing a clear westward propagation over a wide MLT range from early morning all the way to midnight. From the radar observation, the propagation velocity is roughly estimated to be ~2-3 km/s. The large propagation speed with the relatively stagnant background flow (less than ~200 m/s) indicates that the corresponding westward-eastward electric field is not of the ionospheric origin, but is imposed by the magnetosphere. The speed of ~2-3 km/s in the ionosphere corresponds to ~ a few thousands of km/s in the equatorial magnetosphere, comparable with the Alfven velocity. Thus we infer that the westward-traveling modulation of ionospheric electric field could be the footprint of ULF waves propagating in the anti-sunward direction through the dawnside magnetosphere. Further comparison with in situ observations by inner magnetospheric satellites will be made to test this hypothesis as well as to examine how these propagating structure of ionospheric electric field is generated.

Isolated subauroral emissions during a magnetic storm obtained with IMAP/VISI

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We report the SAR arc emission and isolated proton auroral event in the sub-auroral region obtained with IMAP/VISI in a big storm during the period from 21 to 26 July 2015. IMAP/VISI is a visible imaging spectrometer which aims to measures nightglow emissions from ISS (~400 km altitude) covering the wide range from +51 deg. to −50 deg. in geographical latitude. Two slits of VISI point to +45 deg. and -45 deg. to nadir with a scan width (mapped to the E-region altitude) of ~600 km to achieve a stereoscopic measurement of the airglow and aurora emission. In the nominal operation mode, VISI continuously measures airglow and auroral emissions at O2 762 nm, OH or N2 1PG 730 nm and O 630 nm simultaneously with a spatial resolution (plate scale) of ~10 km x 14 km and scan width of ~600 km perpendicular to the orbital track.
A big storm started on June 21, 2015 and Dst index decreased to 195 nT at 5UT on June 23. In the expansion and main phase from 1650 UT on July 22 to 1255 UT on July 23, we identified SAR arc emission at the magnetic latitude of ~50 deg. We will try to estimate the emission height of this SAR arc using the triangulation method with IMAP/VISI data. The dominant emission of SAR arc was O 630 nm with intensity of ~200R. On the other hand, during the recovery phase from 1656 UT on July 24 to 0025 UT on July 25, isolated tail-like or spot-shaped emissions occurred the sub-auroral latitudes, separately from the main auroral oval. These auroral structures are seen in all of the emission data at O630 nm, O2 762 nm and also in N2 1PG. This fact suggests that high-energy (more than 10 keV) particles probably produce these auroral emissions. These appeared almost the same magnetic latitude of ~58 deg, and likely to move with a co-rotation speed in the MLT range of 23-3 MLT. In addition, from 15 −19 UT on July 24 magnetic search coil data at Moshiri showed the Pc1 pulsation at ~2 - 3Hz, which is close to the ion cyclotron frequency in the magnetosphere. Further, POES 19 measured proton precipitation with energy of 30-250 keV existed associated with these isolated auroras. Therefore, these isolated auroras are suggested to be generated by high-energy proton precipitation that is produced by the pitch-angle scattering of ring-current protons by EMIC wave at equator.

Keywords: aurora, inner magnetosphere, IMAP

Transient time scale of poloidal Alfven waves in dipole geometry

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Standing poloidal Alfven waves with high azimuthal wave number (m >> 1) are of interest since they can be excited via bounce-drift resonance with ring current particles of the Earth's magnetosphere. However, the temporal behavior of these transient poloidal waves in realistic dipole geometry has not been demonstrated in detail. We have conducted 2.5-D MHD simulations in a dipole coordinate system that are suited to model high-m ULF waves with high grid resolution. To investigate the time-dependent behavior of local wave fields, we impose fundamental and second harmonic standing poloidal Alfven waves with different azimuthal wave number and follow their evolution in time at different locations. Our results show that the wave energy is initially poloidal and asymptotically transferred to the toroidal mode energy. Such transit time is dependent on the azimuthal wave number; the poloidal mode remains for a longer period of time when the wave has larger mode number. Although our results agree with the tendency from previous theoretical studies that the poloidal mode with higher azimuthal wave number has longer lifetime than that with lower wave number, it is shown that the transit time in dipole geometry is much shorter than that from box models. It suggests that the observations of prolonged poloidal mode waves are likely due to the continuous excitation via wave-particle interaction.

Keywords: Wave particle interaction, Poloidal Alfven wave, MHD simulation

Effects of conductivity asymmetry between the northern and southern latitudes on quarter waves

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Quarter-wave modes are standing shear Alfvén waves in geomagnetic field lines and are generated when the ionosphere has very different conductances between the northern and southern ionosphere. Difference between two conductances is most large when one end of the field line is exposed by sun and the other is in Earth's optical shadow. We study how quarter waves are affected by such north-south asymmetry using three-dimensional dipole wave model. Unlike the previous studies mainly showing resonant frequency of the wave, we consider dipole effect on time histories of electric and magnetic fields at different locations including the equatorial region. To compare with the observation in a realistic manner, we study simulations of time histories and mode structure of quarter-wave mode for various conditions. It is found that dipole effect on time histories is very important in determining amplitude and phase at different locations. In addition, we discuss time-dependent feature of fundamental and second harmonics of quarter-wave mode.

Keywords: Quarter-wave, MHD simulation

