Observations of a viable process for the loss to space of terrestrial atmospheric matter

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Earth’s atmosphere is protected from direct solar wind erosion by the geomagnetic field. Escape of atmospheric atoms to interplanetary space requires photoionization and subsequent upward ion acceleration to overcome Earth’s gravity. However, these ionospheric ions have not yet escaped the terrestrial environment because the Dungey circulation (convection) keeps most within the inner magnetosphere where they either remain or precipitate back into the atmosphere. Key problems in estimating isotopic loss rates on geological scales are quantifying the fluxes of source upflows and evaluating the fraction that subsequently returns to Earth. We present direct evidence of ionospheric ions making their way, via detached regions from the dusk plasmasphere, into the accelerated flows along the magnetopause generated by magnetic reconnection. Using recently developed techniques to find the transit time of open flux tubes across the polar cap, we show that they gain enough energy to escape from the terrestrial environment into interplanetary space.

Keywords: Plasmaspheric plume, Dayside magnetic reconnection, Particle acceleration

Identifying Vortex Core and Extremum Lines using four Satellites based on Field Topology

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Identifying vortices are the key to understanding the turbulence in plasma shear layers. Here, the term 'vortex' **or** 'vortex core' is associated with a region of Galilean invariance [*Jeong and Hussain*, 1995]. Unfortunately, no single precise definition of a vortex is currently universally accepted, despite the fact that many space plasma authors claim that many observations have detected "vortices" (**as** Kelvin-Helmholtz vortices at/around the magnetopause). By using the four satellite velocity data, and Taylor series, we expand the velocity data around the satellites, calculate its first order tensor, and linearly approximate the field. We can identify the vortex structures by using various vortex identification criteria as follows: (i) The first criterion is Q-criterion that defines vortices as regions in which the vorticity energy prevails other energies; (ii) the second criterion is the lambda2-criterion that is related to the minus of the Hessian matrix of the pressure related term; and (iii) the third criterion requires the existence of vortex-core-lines that is the Galilean invariance inside the four satellite tetrahedral region. Using these methods, we can identify and analyze more precisely the 3D vortex using tetrahedral satellite configuration. In the field topology theory, the extremum lines (X-lines) that are other manifolds corresponds to different eigenvalues also can be identified using the same method.

Keywords: vortex, x-line

Global MHD simulation study of the vortex at the magnetopause boundary for the southward IMF and steady solar wind conditions

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We have used a high-resolution and three-dimensional global magnetohydrodynamic (MHD) simulation to study the interaction between the steady solar wind and Earth’s magnetosphere during the weak southward IMF. The simulation results show that the vortex like is generated at about = 11.7R_E region (1600LT-1700LT) with a vortex size of about 2.9 R_E at the inner boundary of magnetosphere. The vortices are propagating tailward with a velocity of 55 km/s up to 86 km/s. Moreover, the quasi-periodic fluctuations of magnetic field and plasma properties clearly show 8-10 min variations across the vortex. The total magnetic field and density are enhanced in center of the vortex with a bipolar magnetic field perturbation in the field component normal to the magnetopause. Also the velocity is low in the center of the vortex and V_x and V_y components have an opposite polarity across the vortex. Magnetic reconnection favorably occurs in anti-parallel field region with slower shear velocity in the magnetosheath. The magnetic field lines are highly bent by parallel vorticity in the flanks of the magnetopause boundary. We suggest that the reconnection is a mechanism of generating vortex with a periodicity in the dayside during the southward IMF.

Keywords: MHD simulation, vortex, reconnection, magnetopause

Particle dynamics in the electron current layer in collisionless magnetic reconnection

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Particle dynamics in the electron current layer in collisionless magnetic reconnection is investigated by using particle-in-cell simulations. Electron motions and velocity distribution functions are studied by directly tracking self-consistent particle trajectories. New classes of electron orbits are discovered: a figure-eight-shaped regular orbit inside the electron jet, another regular orbit on the jet flank boundaries, a Speiser-like noncrossing orbit, and nongyrotropic electrons in the downstream of the jet termination region (a remagnetization front). Based on these discoveries, we will discuss the composition of electron velocity distribution functions, fluid properties of a super-Alfvenic outflow jet, and implications for upcoming MMS observation in the magnetotail.

Keywords: Magnetic reconnection, PIC simulation, Particle dynamics

Near-Earth magnetotail and auroral arc development associated with substorm onset: A new interpretation of substorm triggering

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Using data from Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft and ground-based observatories at high temporal and spatial resolutions, we studied the time sequence of near-Earth magnetotail and auroral arc development associated with a substorm onset. We discuss four steps of auroral development, auroral fading, initial brightening of an auroral onset arc, enhancement of the arc's wave-like structure, and poleward expansion, and link them to magnetotail changes. A case study shows that near-Earth magnetic reconnection began at X ~ -17 Re at least ~1 min before auroral fading and ~3 min before initial auroral brightening. Large-scale ionospheric convection was also enhanced just before auroral fading and before initial auroral brightening. Then low-frequency waves were amplified in the plasma sheet at X ~ -10 Re, with the pressure increase likely due to arrival of an earthward flow from the near-Earth reconnection site ~4 min after initial auroral brightening and ~50 s before enhancement of the wave-like auroral structure. Dipolarization began ~7 min after initial auroral brightening and ~30 s before auroral poleward expansion. On the basis of these observations, we suggest that near-Earth magnetic reconnection plays two roles in substorm triggering. First, it generates a fast earthward flow and Alfven waves. When the Alfven waves, which propagate much faster than the fast flow, reach the ionosphere, large-scale ionospheric convection is enhanced, leading to auroral fading, initial brightening, and gradual growth of the wave-like auroral structure. Second, when the reconnection-initiated fast flow reaches the near-Earth magnetotail, it promotes rapid growth of an instability, such as a ballooning instability, and the wave-like auroral structure is further enhanced. When the instability has grown sufficiently, dipolarization and auroral poleward expansion are initiated.

Keywords: substorm, auroral arc, auroral breakup, magnetotail, magnetic reconnection, substorm triggering

Response of the incompressible ionosphere to the compression of the magnetosphere during the geomagnetic sudden commencements

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The ionospheric plasma in midlatitude moves upward/downward during the geomagnetic sudden commencement causing the HF Doppler frequency changes; SCF (+ -) and (- +) on the day- and night-sides, respectively, except for the SCF (+ -) in the evening as found by Kikuchi et al.[1985]. Although the preliminary and main frequency deviations (PFD, MFD) of the SCF have been attributed to the dusk-to-dawn and dawn-to-dusk potential electric fields, there still remain questions if the positive PFD can be caused by the compressional magnetohydrodynamic (MHD) wave and what causes the evening anomaly of the SCF. With the HF Doppler sounder, we show that the dayside ionosphere moves upward toward the sun during the main impulse (MI) of the SC, when the compressional wave is supposed to push the ionosphere downward. The motion of the ionosphere is shown to be correlated with the equatorial electrojet (EEJ), matching the potential electric field transmitted with the ionospheric currents from the polar ionosphere. We confirmed that the electric field of the compressional wave is severely suppressed by the conducting ionosphere and reproduced the SC electric fields using the global MHD simulation in which the potential solver is employed. The model calculations well reproduced the PI and MI electric fields and their evening anomaly. It is suggested that the electric potential is transmitted from the polar ionosphere to the equator by the TM_0 mode waves in the Earth-ionosphere waveguide. The near-instantaneous transmission of the electric potential leads to instantaneous global response of the incompressible ionosphere.

Keywords: Incompressible ionosphere, geomagnetic sudden commencement, TM0 mode wave, ionospheric current, potential electric field

Magnetosphere-Ionosphere Coupling by Alfvén waves during Geomagnetic Storms

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We present observations from the Van Allen probes which show the coincident occurrence of Alfvénic fluctuations in the equatorial plane, field-aligned electrons and outflowing energized ionospheric ions during geomagnetic storms. Based on these observations we build a model for the observed wave-fields and the particle acceleration that occurs within them. It is shown how Alfvén waves extract ions from the topside ionosphere and through the action of trapping and stochastic acceleration drive the acceleration of these ions to energies which may exceed 100 keV in the equatorial plane. The agreement in the form and evolution of the observed and simulated ion distributions provides confidence in the veracity of the modelling and simulation results. It is estimated for observed wave amplitudes and ion densities that this process may make a significant contribution to magnetospheric ion energy density. This is supported by statistical results which reveal an inverse correlation between the time rate of change of Dst and Alfvén wave spectral energy density.

Keywords: Alfven waves, ionosphere, ring current

Ballooning instability with the magnetosphere-ionosphere feedback coupling

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The ballooning instability has been investigated as a possible mechanism for triggering the substorm in the magnetosphere. The ballooning mode is destabilized, when the interchange term provided with the pressure gradient and the magnetic curvature overcomes the line bending term causing the shear Alfven waves. In the magnetosphere-ionosphere (M-I) coupling system in polar regions, on the other hand, the shear Alfven waves (or the kinetic Alfven waves) can also be destabilized by the magnetospheric convection, if the ionospheric density change is taken into account with the feedback mechanism [1-3].
In the present study, we have investigated the ballooning and the feedback instabilities in the same theoretical framework. Our linear analysis demonstrates that, as the interchange term increases, the "unstable" shear Alfven waves with the opposite sign of the real eigenvalues in their lowest harmonic branch collide with each other and transit to the ballooning mode. It implies that competitions and/or interactions between the two instabilities may provide a plausible explanation of auroral breakup triggered through the M-I coupling.
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[3] T.-H. Watanabe, Geophys. Res. Lett., 41, doi:10.1002/2014GL061166 (2014).

Keywords: aurora, magnetosphere-ionosphere coupling, instability

What if the evolution of auroral forms does not reflect magnetospheric processes?

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We often find auroral images very helpful for diagnosing magnetospheric processes, especially from a global point of view, supplementing spatially sparse satellite observations. The assumption that is very often made, if not explicitly, is that the temporal and spatial development of auroral forms reflects that of the corresponding magnetospheric processes. Although this assumption may be reasonable in many cases, caution needs to be exercised since the aurora is a manifestation of complex coupling between the magnetosphere and ionosphere, and the ionosphere does not always respond passively. In this presentation I shall discuss, with an actual example, how our perspective would change if the foundation of this assumption is not as solid as we generally consider.

Keywords: Magnetosphere-ionosphere coupling, Aurora, Field-aligned currents

Complex and fast motion of the afterglow of aurora

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Afterglow of aurora at 732 nm can be used to track the plasma flow in the topside ionosphere at 300 km altitude (Dahlgren et al., 2009). From ground-based high-speed (50 fps and 200 fps) imaging observations made by Kataoka et al. (2015) at Poker Flat Research Range in Alaska, we found two interesting afterglow events on January 7 and January 28 2015, in which the speed of the brightest arc is suddenly accelerated within the field-of-view (15 deg by 15 deg). Both events occurred near the substorm onset. The existence of the afterglow is confirmed at wavelength range of >665 nm, and any contributions from major forbidden lines at 557.7 and 630.0 nm are rejected. The lifetime of the afterglow is an order of 5 s, which is consistent with the expected emissions from metastable O+ ions at 300 km altitude. The motion of afterglow is complicated and contains counterclockwise rotation. The maximum speed of the motion is more than an order of magnitude faster than those previously reported by Dahlgren et al. (2009). We report the results of the analysis of the optical flow to investigate the motion of afterglow, combined with the ionospheric conditions obtained by Poker Flat Incoherent Scatter Radar, and discuss the possibility of such a fast and complex plasma flow in the topside ionosphere. In addition, we have started our high-speed observation for this season in January. The accurate timing measurement of the imaging system has been realized by installing a newly developed GNSS timing board. That makes it possible to perform a synchronized observation with multiple cameras in different places. We also report our newly developed system in this presentation.

Keywords: Aurora, Afterglow, High-speed imaging

Fine scale morphology of flickering aurora

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The generation mechanism of flickering auroras has been considered as Landau resonance between electrons and electromagnetic ion cyclotron (EMIC) waves. The typical frequencies of the flickering aurora are 3-15Hz which correspond to oxygen ion cyclotron frequency at altitudes of 3000-10000 km. The necessary condition of the appearance of the flickering aurora remains unsolved. Recent cameras enable us to see the extreme situation and the moments when the flickering aurora appears or disappears. An sCMOS camera we used in this study has two advantages: a high spatial resolution and a high sampling rate. Observations taken the former advantage were already conducted during two winter seasons. The camera captures fine images at 50 frames per second (fps). The field of view and the spatial resolution at the 100 km altitude is 26.6 x 26.6 km and 52 m, respectively. We found that the modulation of small flickering patches less than 1 km occur in narrow frequency variations while the modulation of large flickering patches with a few kilometers scale occur in broad frequencies. Such a tendency is consistent with the dispersion relation of O+ EMIC waves. On the subject of the auroral intensity, the camera is capable of detecting extremely bright auroras without causing a saturation. The flickering aurora occur in the bright and extremely bright auroras. The ranges of the auroral intensity are roughly estimated approximately 10-100 kR at 557.7 nm by comparison with a keogram obtained from a meridian spectrograph at PFRR. We also found that the frequency ranges of the flickering aurora are constant, but the ratio of the flickering amplitude to the steady auroral intensity systematically increases with the decreasing of the steady auroral intensity . The result may suggest the slightly energetic electrons tend not to fulfill the resonance condition of EMIC waves. We also found some flickering auroras coincidentally occur with an isolated magnetic impulse in the Pc5 ULF range observed by magnetometer nearby PFRR. Such a tendency may indicate that mesoscale (of the order of 100 km) traveling current vortices are one of the necessary conditions to generate the flickering aurora. We will discuss on the relation between the excitation of EMIC waves and the traveling auroral arcs with the current centralization. To verify the possibility of EMIC waves as the generation mechanisms, we are now challenging a high-speed imaging at 320 fps which is taken the latter advantage. It has the potential to capture faster modulations by H+ and He+ EMIC waves. We will collect the data in April 2016, and will report initial results in this talk.

Preliminary results of auroral tomography analysis of discrete arcs observed on March 14, 2015

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We conducted a campaign of auroral tomography observation using multi-point imager network and the EISCAT UHF radar in Northern Europe in March, 2015. During this campaign, an auroral breakup was observed at 23:15 UT on March 14 by three all-sky EMCCD imagers and three wide-view CCD imagers. Wavy structure of discrete arcs was often observed around the magnetic zenith at Tromso from 22 to 23 UT and pulsating aurora was observed after the breakup. The monochromatic (427.8 nm) images were taken at a sampling interval of 2 seconds by the three EMCCD imagers and at an interval of 10 seconds by all the six imagers. The EISCAT UHF radar at Tromso measured the ionospheric parameters along the field line at the magnetic zenith from 20 to 24 UT.
We apply the auroral tomography method to these data set to reconstruct reliable three-dimensional distribution of the 427.8 nm emission, that will allow us to investigate quantitatively the following subjects; (1) relation between the 427.8 nm emission and electron density enhancement along the field line, (2) spatial distribution of energy of precipitating electrons in the wavy structure, in particular, relation between the energy of precipitating electrons and thickness of discrete arc, (3) relation between motion of the wavy structure and spatial distribution of the ionospheric conductivity, and (4) spatial and temporal variations of energy distribution of precipitating electrons at the auroral breakup. We present preliminary results from the auroral tomography analysis of the discrete arcs.

Keywords: aurora, tomography analysis, 3D distribution, ionosphere, EISCAT radar

Ionospheric variation during pulsating aurora

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We have statistically analyzed data from the European Incoherent SCATter (EISCAT) UHF/VHF radars in Tromsoe (69.60N, 19.20E), Norway to reveal how the occurrence of pulsating aurora (PsA) modifies the electron density profile in the ionosphere. By checking 5 winter seasons (2007-2012) observations of all-sky aurora cameras of National Institute of Polar Research (NIPR) in Tromsoe, we have extracted 21 cases of PsA. During these PsA events, either UHF or VHF radar of EISCAT was operative and the electron density profiles were obtained along the field-aligned or vertical direction near the zenith. From these electron density measurements, we calculated hmE (E region peak height) and NmE (E region peak density), which are proxies for the energy and flux of the precipitating PsA electrons, respectively. Then, we examined how these two parameters changed during the evolution of 21 PsA events in a statistical fashion. The results can be summarized as follows: (1) hmE is lower (the energy of precipitation electrons is higher) during the periods of PsA than that in the surrounding interval, (2) When NmE is higher (flux of PsA electrons is larger), hmE tends to be lower (precipitation is harder), (3) hmE is lower and NmE is larger in the later magnetic local time, (4) When the AE index during the preceding substorm is larger, hmE is lower and NmE is larger. These tendencies are discussed in terms of the characteristics of particles and plasma waves in the source of PsA in the magnetosphere. In addition to the statistics of the EISCAT data, we carried out several detailed case studies, in which the altitude profiles of the electron density were derived by separating the ON and OFF phases of PsA. This allows us to estimate the true altitude profiles of the PsA ionization, which can be used for estimating the characteristic energy of the PsA electrons and better understanding the wave-particle interaction process in the magnetosphere.

Keywords: Pulsating Aurora, Ionosphere, Magnetosphere

A quantification method for the properties of diffuse and pulsating aurorae based on auroral image data

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The auroral images provide much information on the state of the magnetosphere-ionosphere system. However, since the variations of aurorae are highly complicated, it was difficult to quantify the dynamical properties of the aurorae. We are developing a technique for obtaining quantitative metrics about various auroral properties by analyzing a sequence of auroral images taken with high temporal resolution. We introduce a state space model to describe the translational motion of diffuse aurorae, and estimate the translational velocity by using an algorithm which approximates the Kalman filter. We also extract the features of pulsatingaurora, patches of pulsating aurora by using a technique based on a sparse modelling. We will report some results of our analyses.

Keywords: pulsating aurora, kalman filter, sparse modelling

Statistical feature of Omega band aurora observed by THEMIS all-sky imager network

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We examine morphological and statistical characteristics of Omega band auroras. In order to study statistical feature of Omega band aurora we used the THEMIS ground-based all-sky imager network data for 8 years from January 2007 to December 2014. Omega band auroras show their own distinctive behavior on shape and movement, so we could easily pick up an Omega band auroral event from the THEMIS summary plot database on keogram and all-sky image. Consequently, we could identify ~330 events of Omega band type auroras.

In this study we examine statistical features for the following parameters when Omega aurora observed; 1) magnetic local time (MLT), 2) seasonal variations, 3) annual variations, 4) life time, 5) drift speed, 6) scale size, 7) Kp and AE index dependence, 8) solar wind speed and pressure, 9) IMF By and Bz dependence. Then we will discuss their signature.

Keywords: aurora, omega band aurora, magnetosphere, ionosphere, magnetosphere-ionosphere coupling, polar region

Precipitation of high-energy particles at high latitudes and impact on middle atmosphere

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When trying to understand the role of precipitating high-energy particles in variations of atmospheric properties, we are still facing the fact that accurate measurements throughout the chain from the origin of the particles, their acceleration and interactions in the magnetosphere-ionosphere system down to details of final atmospheric effects are limited. Similarily models mostly cover only specific regions and a consistent holistic model is not available. However, recent individual studies have shown for example evidence of energetic electron precipitation causing statistically significant decrease of upper stratospheric and mesospheric ozone during extended periods of time. Indeed, we need to include energertic electron precipitation as a process in general atmospheric circulation models, if we want to understand our atmosphere as a whole. Here we first review shortly the impact of energetic particles in atmosphere in general, and present the current status of knowledge in chemical variations of atmosphere caused by these particles, including galactic cosmic rays, solar protons and electrons of magnetospheric origin. The effects are both direct and indirect by first generating chemically active minor constituents of the atmosphere, such as odd nitrogen and odd hydrogen, which in turn can affect atmospheric ozone via catalytic reactions either directly in-situ, or after transport in atmosphere to lower altitudes and lower laitudes. Then we discuss recent advance in studying the effects of high-energy electron precipitation in atmosphere. In order to assses the role of precipitating particles in atmospheric variations one needs new measurements which characterize more accurately the energy and flux, as well as spatial and temporal variations of the energetic electron precipitation, both at high and subauroral latitudes, such as given for example by the Japanese ERG satellite mission, so that combined studies using advanced ground-based and satellite measurements together with theoretical modeling would be possible.

Keywords: high-energy particle precipitation, coupling of atmospheric regions, chemical variations

Plasmaspheric modeling using the new Ionosphere-Plasmasphere-Electrodynamics (IPE) model

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Cold plasma in the plasmasphere and plumes plays an important role in wave-particle interactions in the inner magnetosphere. Plumes regulate the excitation of electromagnetic ion cyclotron (EMIC) waves. Plumes modulate the resonant EMIC wave-particle interactions by energization of cold ions and the pitch angle scattering of the ring current hot ions and the radiation belt relativistic electrons. Furthermore, a remarkable correlation has been observed between the inner edge of the outer radiation belt electrons and the innermost plasmapause location. Very recent observations show that plasmaspheric plumes can influence the dayside magnetic reconnection rate.
A newly developed global three-dimensional ionosphere-plasmasphere-electrodynamics (IPE) model is used to understand the dynamical redistribution of the cold plasma in the plasmasphere and it's coupling to the ionosphere-thermosphere system. The IPE model reproduces the ionospheric Storm Enhanced Density (SED) plumes as frequently observed in TEC during geomagnetically active conditions. The SED plumes are transported into the cusp and over the pole due to the high latitude convection, which is characterized as Tongues of Ionization (TOIs). The model captures the corresponding formation of the plasmaspheric drainage plume-like structure in the magnetospheric equatorial plane as reported in previous studies. The plumes gradually start to rotate around the earth, and the plasmasphere gradually refills from the ionosphere as the storm time convection weakens. In this presentation, the temporal and spatial evolution of the redistribution of cold plasma between the plasmasphere and ionosphere is examined depending on the types of the solar wind driving conditions. Furthermore, the role of the Sub-Auroral Polarization Streams (SAPS) electric field is evaluated in draining the plasmaspheric plasma and plumes, as SAPS field penetrates into the plasmasphere due to enhanced convection. An example of how the ERG spacecraft will measure the dynamical evolution of the plasmasphere and plumes is demonstrated.

Keywords: plasmasphere, Modeling and forecasting, coupling to ionosphere-thermosphere, ERG mission

Data assimilation of low-altitude magnetic perturbations into a global magnetosphere model

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The ionosphere is the only region of the terrestrial magnetosphere-ionosphere system where in situ observations with high temporal resolution and approaching global spatial scale are possible. Ionospheric measurements of magnetic fields with such spatio-temporal coverage have become available from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE), combining data from the Iridium satellites. Motivated by the emergence of this dataset, we report here on the first results of assimilation of low-altitude ionospheric magnetic perturbations into the Lyon-Fedder-Mobarry (LFM) global magnetospheric model coupled with the Rice Convection Model (RCM). Our assimilation approach relies on the assumption of a quasi-steady, linear approximate relation between equatorial magnetospheric pressure and ionospheric field-aligned currents. This approximation is implemented numerically by perturbing the coupled LFM-RCM model and considering only large-scale modes from the Fourier decomposition of the ionospheric magnetic field and equatorial magnetospheric pressure. This methodology was validated by using model-based assimilation tests of the so-called ”fraternal-twins” type. In this approach, the LFM-RCM model with one set of parameters is used to generate synthetic observations, while a model version with a different parameters is used to assimilate the ionospheric observations and calculate the magnetospheric pressure corrections which are then applied to reproduce the synthetic observations. The model with assimilated synthetic data responded correctly by modifying ionospheric currents and magnetic perturbations in the expected way. We thus found the approach proposed herein to be promising for future assimilation of real data.

Latitudinal distribution of the Field Aligned Current estimated from SWARM constellation

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We make use of the estimated Field Aligned Current (FAC) data provided by SWARM constellation A/B/C, we study the FAC footprint and strength in the northern hemisphere region. Through 398 day of good FAC data of SWARM-A, we got a profile not only of the FAC intensity footprint at the subaurotral region but also a profile of the FAC intensity in the northern geographic from the equator until the polar cap region at different Magnetic Local Time (MLT).
Results showed that the maximum and minimum dayside FAC intensities shifted to higher latitudes, while the nightside FAC shifted to lower latitudes. The latitudinal difference between the dayside and nightside FAC intensity is approximately 3 degrees. Near the duskside the minimum FAC intensity is stronger than the maximum FAC intensity.
The mean absolute FAC value each 10^o latitude in the northern geographic hemisphere 0^o-80^o showed that; close to the equator [0^o,40^o] latitude] the mean absolute FAC increases within [1000-1600] MLT increases. This daytime enhancement decreases at latitudes >40^o, and reverses its signature at the sub-auroral region [50^o, 60^o] where the nightside FAC intensity increases dramatically in comparison to dayside FAC. Again Dayside FAC intensity maintains its strength at latitudes >70^o. The largest FAC intensity is observed at latitudes larger than 60^o which is comparable at all longitudes. The seasonal FAC variations showed the same behavior as the longitudinal variations. It has small amplitude within latitudes [20^o, 50^o], but dramatically jumps at latitudes larger than 50^o . The seasonal FAC showed two crests at spring and autumn. The latitudinal profile of the FAC at different MLT showed that dayside FAC is stronger than nightside FAC intensity within latitude [0^o -50^o] and >70^o and nightside FAC intensity is stronger than dayside FAC within latitudes [50^o-70^o], while the duskside and dwanside FAC showed a parallel correlation.

Keywords: Ionosphere, Field Aligned Current (FAC)

Stagnant Transpolar Arc and Its Intensification during Dual Cusp and Magnetotail Magnetic Reconnections

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We present that TransPolar Arc (TPA), which was observed during magnetic reconnections at the cusp regions in northern/southern hemispheres and in the magnetotail, intensified when the magnetic flux at geosynchronous altitudes slightly piled up. The B_y component of Interplanetary Magnetic Field (IMF) during this TPA interval was dominantly negative (dawnward), and associated IMF-B_z component turned from negative (southward) to positive (northward) directions. We refer to the solar wind conditions four hours before the TPA interval because they correlate with the TPA's location and motion stronger than "current condition" which is estimated with the time delay between the solar wind and magnetospheric observational time. In this presentation, we also show how "current condition" IMF and associated plasmas were changing. Further discussion on the relation between the TPA brightening, intensification and two cases ("current"/"four hours before") of IMF condition will be made. One of the most interesting points in this event was that TPA's location has been biased and stagnant in post-midnight and dawn region for one hour of its duration.
On September 16th, 2001, Cluster made in-situ observation of the cusp reconnection in northern hemisphere, and detected strong acceleration of the solar wind electrons at the electron edge as formed by this cusp reconnection during TPA's appearance (On the details of this northern cusp reconnection event, see Nowada et al. "Cluster Observation of Electron Accelerations at the Electron Edges Formed by Localized Magnetic Reconnection at Cusp/Entry Region", submitted to J. Geophys. Res., 2016). On the ground, SuperDARN radar in the southern hemisphere simultaneously observed the ionospheric plasma flows whose velocity was faster than 0.6 km/s around the cusp footpoint region. These flows, which were faster than the background plasma velocity, suggest that magnetic reconnection occurred also at the cusp in the southern hemisphere. Adding these dual cusp magnetic reconnections, east-westward and west-eastward flows faster than 0.5 km/s were also observed over the region from pre- to post-midnight along the main auroral oval. These fast ionospheric flows support that the magnetotail reconnection also would occur. During this TPA's appearance, we found that the TPA's luminosity had intensified for 23 minutes, when GOES 10 observed slight enhancements of the B_z component and associated magnetic inclination angle between B_x and B_z components at geosynchronous altitudes. These magnetic field variations seen by the geosynchronous satellite suggest that the magnetic flux pileup in near-earth magnetotail plays a significant role in the intensification of the TPA's luminosity even though its amount is small.
In this presentation, we will discuss further feasibility of the constellation study including the MMS fleet under this topic. In-situ magnetic reconnection signatures at northern cusp can be observed by Cluster in this event, but no satellites detected direct evidence for simultaneous reconnection process in the magnetotail, which was estimated and speculated by the ionospheric plasma flow patterns by SuparDARN radars on the ground.
In general, it has been believed that high energy source electrons for which TPA was formed are

generated by magnetic reconnection in the magnetotail or “twisted” plasma sheet due to an influence of the IMF-B_y component. However, the observations of TPA during which simultaneous magnetotail reconnection evidently occurs and/or those of the whole TPA formation process from the stage of energetic electron generation by the magnetotail reconnection to the transport process of the TPA’s source electrons to the ionosphere has not been conducted. We can understand the TPA’s physics more, if we could reveal a global view of TPA’s formation from both space- and ground-based observations.

Keywords: Transpolar Arc, Cusp and Tail Reconnections, Ionospheric Flows

Nonlinear resonant scattering of radiation belt relativistic electrons by oblique EMIC waves

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Resonant scattering by EMIC waves has long been proposed as a candidate loss mechanisms for radiation belt relativistic electrons. Such resonant interaction process has been found to be in the nonlinear (rather than quasi-linear) regime. However, previous works are usually limited to the parallel EMIC waves, and the nonlinear scattering process by oblique EMIC waves remains to be investigated in detail. In this study, we perform test-particle simulations to examine the dependence of nonlinear characteristics on wave normal angle and resonance order. Our results provide in-depth understanding of the nonlinear loss of radiation belt relativistic electrons induced by EMIC waves.

Keywords: EMIC wave, non-linear, resonant

Interactions of energetic electrons with low-m number ULF waves in the inner magnetosphere during a storm recovery phase

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A number of previous studies have suggested that ULF waves, which occur during a recovery phase of a geomagnetic storm, are associated with the enhancement of electron flux in the outer radiation belt. ULF waves accelerate electrons whose drift velocities match the azimuthal phase velocities of ULF waves via drift resonance. Elkington et al., (1999 and 2003) proposed a simple model for the drift resonance effect on energetic electrons due to ULF toroidal and poloidal modes with large azimuthal wavelengths (low m numbers). Although some observational studies (Tan et al.,2004 and 2011) reported effects of low-m number ULF waves on electron acceleration, the interaction between low-m number ULF waves and energetic electrons is still incompletely understood.
In this study, we investigate interaction between low-m number ULF and energetic electron observed in the inner magnetosphere, using data from the multiple satellites, GOES 13, 15 and Van Allen probes. A Pc5 pulsation occurring at 6:00-8:00 UT on 13 September 2014 during a storm recovery phase are focused on. These Pc5 pulsations are dominated by the toroidal component with the frequency of a 3 mHz and a large amplitude of 30 nT when Van Allen Probes were located on the morning side (MLT~5) at L~6. Estimating m number from the phase difference of Pc5 pulsations and azimuthal separation between Van Allen Probes A and B, the Pc5 has an m number of 3 with westward propagation. Perturbations corresponding to the Pc5 pulsation are observed in the electron flux data. In this presentation, we discuss weather Pc5 pulsations accelerate the energetic electron via the drift resonant interaction.

Magnetospheric dynamo driving the nightside Region 2 field-aligned current system

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The importance of field-aligned currents connecting the magnetosphere and ionosphere is widely recognized. In order to stimulate steady-state plasma convection in the ionosphere, energy must be supplied continuously from the magnetosphere to the ionosphere by field-aligned currents. In the magnetosphere side of the current system, there exists a "dynamo" in which electromagnetic energy is produced from other sources. In spite of this recognition, it was not until the advent of global magnetohydrodynamic (MHD) simulation that we started to gradually understand the physical processes of the magnetospheric dynamo. Global numerical simulations revealed that in the magnetosphere plasma thermal energy is much higher than flow kinetic energy, indicating that the energy source of the field-aligned currents is mainly plasma thermal energy. Recently, we have learned that one dynamo process is the "expanding slow mode" disturbances (Watanabe et al., 2014), and we now have a consensus that the Region 1 field-aligned current system can be interpreted in terms of the expanding slow mode. However, this mechanism seems not applicable to the nightside Region 2 FAC system. The purpose of this study is, using MHD formulation, to interpret the physical processes of the Region 2 dynamo on the nightside, in prospect of generalizing the theory of the magnetospheric dynamo. The magnetospheric dynamo is defined as the region in which the dot product of the current density vector (J) and the electric field vector (E) is negative (J.E < 0). Using Poynting's law, Faraday's law, and Ohm's law (with no use of equation of motion), the dynamo condition can be expressed in terms of the spatial variation of the magnetic field. Keeping in mind that we are considering a high beta region in which the magnetic field is relatively strong, the spatial structure of the magnetic field is assumed to determine the physics in the system. For formation of a dynamo, either (1) the magnetic pressure increases in the convection frame, or (2) the magnetic tension and plasma convection are in opposite directions. By considering the equation of motion separately, condition (1) indicates that the plasma pressure is sustained by the magnetic pressure, which is interpreted by the expanding slow mode disturbances mentioned above. This mechanism applies to the Region 1 system. Meanwhile, condition (2) indicates that the plasma pressure is sustained by the magnetic tension, which is considered to be applicable to the nightside Region 2 system. The latter process has never been focused in the past, and in this study we describe physical processes of this tension-driven dynamo.

Keywords: field-aligned current, dynamo, Region 2

Multi-event analysis for chorus waves and pulsating aurora at sub-auroral latitudes

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Pulsating aurora is a kind of luminous phenomena, which shows a luminous modulation on timescales from several hundred milliseconds to tens of seconds. It is generated by interaction between high-energy electrons and chorus waves. It is expected that spatial and temporal variations of pulsating aurora show a close relationship with those for chorus waves. In order to investigate their relationships, we have been analyzing simultaneous ground observations of pulsating aurora and chorus waves at Athabasca in Canada (L=4.3). VLF waveform is sampled at 100 kHz and all-sky EMCCD camera for pulsating aurora is sampled at 110 Hz. In this study, we analyzed 11 events of simultaneously observed pulsating aurora and chorus waves from Dec., 2014 to May, 2015. In each event, the auroral luminosity had a correlation with the chorus intensity, which also showed a correlation with AE index. These results show that high-energy electrons resonate efficiently with the chorus waves during a high auroral activity. Next, we have performed a statistical analysis of internal modulations of the pulsating aurora observed at different latitudes in the FOV of the all-sky EMCCD camera. The occurrence distributions of the internal modulation showed different trends above and below a modulation frequency of 4 Hz. In the case of less than 4 Hz, the internal modulation frequency had a correlation with its luminosity. This is the same result reported by Nishiyama et al. [2014] based on the nonlinear wave growth theory. Pulsating aurora having the internal modulation below 4 Hz frequently appeared at low latitudes. This would be caused by the effect of a small geomagnetic inhomogeneity at the equatorial region based on the nonlinear wave growth theory. On the other hand, pulsating aurora exhibiting internal modulations above 4 Hz had a weak intensity in comparison with that with less than 4 Hz. This would suggest that the flux of energetic electrons causing the high modulation frequency was low, or the internal modulation above 4 Hz was generated by high-energy electrons, which could not contribute to the auroral emissions. The occurrence of pulsating aurora showing a high modulation frequency (4~10 Hz) was mainly distributed at high latitudes. This would be caused by the effect of hiss-like emissions generated with a high ratio of plasma frequency and electron cyclotron frequency. Thus, the spatial and temporal features of pulsating aurora can be expected to vary with the conditions of chorus generation depending on the L-value.
In this presentation, we will discuss the relationship between high-energy electrons causing pulsating aurora and chorus waves in detail.

Keywords: Pulsating aurora, Chorus waves, A few Hz modulation

Cold heavy ion composition in the lower plasmasphere estimated from lightning induced EMIC waves

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Ion cyclotron whistler waves are electromagnetic ion cyclotron (EMIC) mode waves induced by lightning discharge. Propagation properties of ion cyclotron whistler waves strongly depend on the local cold heavy-ion composition. Crossover frequency is an important frequency for the ion cyclotron whistlers, which is a function of the ion composition. In this study, we examine the variation in the crossover frequency of heavy ion band ion cyclotron whistler waves observed by the Van Allen probes and the Akebono satellites. We found that the crossover frequencies of the observed events decreased with increasing altitude. This suggests the total heavy-ion composition is high at low altitudes and decreases with increasing altitude around lower plasmasphere. We can determine the composition of three species of ions by measuring two crossover frequencies. We focus on H^+ band and He^+ band ion cyclotron whistler waves, and estimate proton-helium ion ratio ($n(He^+)/n(H^+)$) and proton-oxygen ion ratio ($n(O^+)/n(H^+)$) in the lower plasmasphere. This wave-based approach used in this study can also be a useful means of estimating unknown cold-ion distributions in the inner magnetosphere.

Keywords: Ion cyclotron whistler, EMIC wave, heavy ion

Frequency structure and polarization of MF/HF auroral radio emissions observed in the topside ionosphere

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Auroral radio emissions are generated at ionospheric F-region altitudes in the medium and high frequency bands (MF/HF) and propagate towards the ground and outward into space. Satellite-level MF/HF auroral radio emissions, which were termed terrestrial hectometric radiation (THR), are band-limited signals like ground-level auroral roar. We report on the statistical properties of frequency structure and polarization of THR emissions using a long-term data set obtained from the Plasma Waves and Sounder (PWS) experiment mounted on the Akebono satellite in the polarization (PL) mode operation. The PL mode observation provides the power spectra of right- and left-handed polarized components (I_R and I_L), whose rotation is viewed from the normal direction of the antenna plane. We analyzed multi events where THR emissions appeared simultaneously in two discrete frequency ranges (THR-L and THR-H). THR-H was about twice the frequency of THR-L, as in the case of minor ground-level event of simultaneous $2f_{ce}$ and $4f_{ce}$ roars. The sign of axial ratio ($(I_L - I_R)/(I_L + I_R)$) of THR-L was opposite to that of the simultaneously detected THR-H. The axial ratio is applied to identify the propagation mode of the electromagnetic waves with the assumption that the source of the waves is in an altitude region lower than the satellite position in the night-side auroral latitude. The observed axial ratio is consistent with the hypothesis that THR-L and THR-H respectively correspond to O- and X-mode electromagnetic waves. The observed harmonic frequency structure and polarization feature support the idea that O-mode THR-L results from linear conversion of upper hybrid waves generated under the condition of $f_{UH} \sim 2f_{ce}$, and harmonic X-mode THR-H is attributed to the nonlinear wave–wave coalescence of two upper hybrid waves generated under the same matching condition. However, we also found that the upper limit frequency of THR-H was slightly higher than twice the upper limit frequency of THR-L, and the normalized frequency bandwidth of THR ($\Delta f/f$) was often more than 0.1, unlike ground-level auroral roar. The explanation of these observed features should involve other factors related to the excitation of upper hybrid waves and mode conversion processes.

Cowling conductance estimated from the equatorial electrojet and midlatitude ionospheric drift velocity during the Halloween storm PC5 events

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During the stormtime PC5 magnetic pulsations on 31 October 2003, we detected large amplitude oscillations in the ionospheric drift velocity with the HF Doppler sounder at midlatitude for 10 hours from 11 to 21 MLT. We estimated the electric field (E) from the HF Doppler frequency (HFD) under an assumption that the vertical motion of the reflection height is caused by the ExB drift of the ionospheric plasma. Similar oscillations were recorded on the magnetometer data at high-to-equatorial latitudes with significant amplitude enhancement at the dayside equator. We estimated the equatorial electrojet (EEJ) as a deflection of the equatorial PC5 from the low latitude PC5 and found that the midlatitude E is well correlated with the EEJ with correlation coefficients (0.80-0.95) calculated in each 60-min time interval over the 10 hour period, suggesting that the midlatitude E is associated with the ionospheric currents transmitted from high latitude to the equator. Taking the geometrical attenuation of the transmitted electric field into the estimation of the electric field at the equator, we estimated the ionospheric conductance enhanced by the Cowling effect at the equator as ranging from 140 mho at 11 MLT, 50 mho at 16 MLT, and 3 mho in the night after 18 MLT. The conductance depends on the solar zenith angle in a function of $\cos^{0.6}$(zenith angle), roughly matching the Chapman layer formation due to the solar radiation. It is remarkable that the nighttime Cowling conductance is large enough to drive the EEJ with the transmitted electric field, although the magnetic effects of the nighttime EEJ are overcome by the PC5 propagated directly from the magnetosphere. We point out that the usage of the PC5 enables us to obtain the LT/solar zenith angle dependence of the ionospheric conductivity and to improve the capability of the HFD which would be less sensitive to longer period disturbances such as the DP2, substorms and so on.

Keywords: Cowling conductance, PC5 magnetic pulsation, equatorial electrojet, ionospheric electric field, Halloween storm event

The Harang Reversal Generated by Ionospheric Polarization Field by Hall Current Divergence

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The ionospheric electric potential shows various asymmetries, localized structures, and so on. Whereas these structures have been mainly interpreted by the IMF polarity and/or magnetospheric convection structure, we have proposed that they can be also recognized purely by the ionospheric effect, the generation of polarization field due to conductivity inhomogeneities. Our study has been based on a part of the M-I coupling theory [e.g., Yoshikawa et al, JGR, 2013a, b] including the idea of Pedersen/Hall divergence/polarization effect [e.g., Yoshikawa et al., JpGU, 2009]. Although the possibility of ionospheric effect had been reported [Wolf, 1970; Atkinson and Hutchison, 1978], we have for the first time addressed and visualized the underlying physics.
By applying a simplified version of 'Hall-conjugate method [Yoshikawa et al., JpGU, 2008]' to a 2D ionospheric potential solver (so-called thin shell model), we separate the total field (Φ, ionospheric total potential) into the primary field (Φ0, including the background and Pedersen polarization field) and secondary field (δΦHall, the polarization field generated by Hall current divergence).
In the previous meetings [Nakamizo et al., SGEPSS, 2012-2014], we have specified one-to-one correspondence between characteristic spatial gradients of conductivity and characteristic deformations of potential, as follows; (a) For simplicity we consider dawn-dusk symmetric R1-FAC as the driving source. As the reference field, we calculate the potential with the uniform conductivity distribution. This reference field is symmetric with respect to both the noon-midnight and dawn-dusk axes. From this condition we gradually add spatial structures on the conductivity distribution. (b) Equatorward latitudinal conductivity gradient generates positive/negative Hall polarization field (δΦHall,eq) around pre-noon/pre-midnight sectors. As the result the total field (Φ) rotates clockwise. (c) Day-night conductivity difference not only shifts the potential centers toward night due to Pedersen polarization effect (in other words, current continuity), but also generates Hall polarization fields (δΦHall,t) along day-night terminators due to sharp conductivity gradients there, resulting in the convex/concave of total field (Φ) along terminators. (d) Auroral conductivity enhancement generates Hall polarization fields (δΦHall,a) around edges of conductivity band. Thus in the total field (Φ) a conspicuous structure appears around the midnight oval, resembling 'Harang reversal.'
This presentation mainly discusses the point (d). Important point is that we get Harang-like structure with simplified distribution of FAC (dawn-dusk symmetric R1-FAC) noted above. Moreover Harang-like structure located in pre-midnight sector, as the same as the observations, where we placed no input FAC. We suggest the possibility of two-ways of the ionospheric control of magnetosphere-ionosphere convection based on the characteristics of the solver used in this study (physically it can be called as 'perfect current confinement solver') and the advanced M-I coupling theory [Yoshikawa et al., JGR, 2013a,b].

Keywords: Hall current divergence and Hall polarization field, Conductivity gradient, Deformation of ionospheric potential, Harang reversal, Magnetosphere-Ionosphere coupling, Ionospheric control on magnetosphere-ionosphere convection

