Commission H: Waves in Plasmas (November 2010 – October 2013)

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Based on the papers published from November of 2010 to October of 2013, we compiled major achievements in the field of plasma waves and related studies made by Japanese scientists and their collaborators. We categorize the studies into three groups as shown in Contents. Each section provides a specific summary of important scientific achievements rather than a comprehensive report of the whole research activities of Japanese Commission H. On the other hand, the reference list attached at the end is intended to be used as a database of all papers we have collected from the Japanese Commission H members.

Contents

H1. Space Observation and Experiment of Plasma Waves

H1.1 Magnetospheric Plasma Waves

<Akebono>

Natural plasma wave observations by the plasma wave and sounder experiments and thermal ion observations by the suprathermal ion mass spectrometer onboard the Akebono (EXOS-D) satellite at ~9000 km altitude in the polar magnetosphere during the geomagnetic storms showed that ions in the region of enhanced electron density in the polar cap were dominated by very-low-energy O^+ ions with upward velocities of 4-10 km s^{-1}. These signatures are consistent with high-density plasma supplied by the cleft ion fountain mechanism. Trajectory calculations of O^+ ions based on the Akebono observations indicated that the velocities of the very-low-energy upflowing O^+ ions through the dayside polar cap are enough to reach the magnetosphere under strong convection. Thus, the initially very-low-energy O^+ ions can contribute significantly to the ring current formation during geomagnetic storms since some of the O^+ ions were transported into the ring current region with typical energies of ring current ions (several tens of keV) in the trajectory calculations [Kitamura et al., 2010a].

To determine the characteristics and origin of observed storm-time electron density enhancements in the polar cap, and to investigate the spatial extent (noon-midnight direction) of associated O^+ ion outflows, Kitamura et al. [2010b] analyzed nearly simultaneous observations of such electron density enhancements from the Akebono satellite and ion upflows from the Polar satellite during a geomagnetic storm occurring on 6 April 2000. The Akebono satellite observed substantial electron density enhancements by a factor of ~10-90 with a long duration of ~15 h at ~2 R_E in the southern polar region. Velocity filtering of the ion outflow from the cleft ion fountain is identified by the Polar satellite measurements in the polar cap at (~1.8-3.5 and ~7-4 R_E). This coordinated Akebono-Polar observation is consistent with the development of storm-time electron density enhancements in the polar cap as a result of the bulk outflow of low-energy plasma as part of the cleft ion fountain. The large spatial scale, large ion fluxes, and the long duration indicate significant supply of very-low-energy O^+ ions to the magnetosphere through this region.

Kitamura et al. [2011] constructed an empirical model of the electron density profile with solar zenith angle (SZA) dependence in the polar cap during geomagnetically quiet periods using 63 months of Akebono satellite observations at solar maximum. The electron density profile exhibits a transition at ~2000 km altitude only under dark conditions. The electron density and scale height at low altitudes change drastically, by factors of 25 (at 2300 km altitude) and 2.0, respectively, as the SZA increases from 90° to 120°. Comparisons between the present statistical results and modeling studies of the polar wind indicate that the plasma density profile (especially of the O^+ ion density) in the polar cap is strongly controlled by solar radiation onto the ionosphere by changing ion and electron temperatures in the ionosphere during geomagnetically quiet periods.

When the Akebono satellite passed through the plasmasphere, a series of lightning whistlers was often observed by its analogue wideband receiver (WBA). Bayupati et al. [2012] analyzed two typical events representing the clear dispersion characteristics of lightning whistlers along the trajectory of Akebono. The observed trends of whistler dispersion were compared with the ones theoretically derived using a dipole geomagnetic field model and two types of electron density profiles. They showed that the observed trends basically agree with the theoretical results and small deviation between them can be fitted by the optimization of electron density profile. This fact demonstrates that the dispersion analysis of lightning whistlers is a useful technique for reconstructing the electron density profile in the Earth's plasmasphere.

Relativistic electron flux in the outer radiation belt tends to increase during the high-speed solar wind stream (HSS) events. Miyoshi et al. [2013] demonstrate that during HSS events with the southward interplanetary magnetic field (IMF)-dominant HSS (SBz-HSS), relativistic electrons are accelerated by whistler mode waves; however, during HSS events with the northward IMF-dominant HSS, this acceleration mechanism is not effective. The differences in the responses of the outer radiation belt flux variations are caused by the differences in the whistler mode wave-electron interactions associated with a series of substorms. During SBz-HSS events, hot electron injections occur and the thermal plasma density decreases due to the shrinkage of the plasmapause, causing large flux enhancement of relativistic electrons through whistler mode wave excitation. These results explain why large flux enhancement of relativistic electrons tends to occur during SBz-HSS events.

Akebono observed electromagnetic ion cyclotron (EMIC) waves in the deep inner magnetosphere at L = 2.5–5 at altitudes of 3,300–8,700 km. The mode conversion, i.e., L mode (He^+ band) -> R mode (He^+ band) -> L mode (O^+ band) was clearly identified from the equator to high latitudes. In addition, rising tone structures are found, recently identified as EMIC triggered emissions, which could lead to bursty precipitation of relativistic electrons. First, the ion composition ratio (H^+, He^+, O^+) = (83%, 16%, 1%) are estimated from polarization analysis. Second, minimum resonant electron energies with the observed EMIC waves and triggered emissions are estimated to be ~1–10 MeV. The satellite trajectory during the wave observation was primarily through the slot region of electron radiation belts. The collocation implies possible contribution of EMIC waves to formation of the slot region of radiation belts after a magnetic storm [Sakaguchi et al., 2013].

<GEOTAIL>

A terrestrial myriametric radio burst (TMRB) might be a distinct radiation of 12–50 kHz. The TMRB may have a fan beam-like radiation pattern emitted by a discrete, dayside source located along the pole-ward edge of magnetospheric cusp field lines [Fung et al., 2013].

A survey of ULF waves in the Pc 5 frequency range during the six year period (1995–2000) has been made for the field line resonance waves in the outer magnetosphere, using plasma flow and magnetic field measurements with the Geotail spacecraft. On the morning side a series of wave trains often appears during several hours. In contrast such a series of wave trains with a long duration is rarely observed in the afternoon to evening sector. Most of waves in the afternoon sector are isolated, of which duration is approximately one hour. The existence of a set of preferential frequencies and the pronounced dawn-dusk asymmetry of wave occurrence and wave features, which were found in ground-based and ionospheric measurements of geomagnetic ULF pulsations, were statistically confirmed. It is also noted that the background plasma flow is sunward in the evening sector without exception. Transverse waves are generally observed in the condition of plasma β below 1.5. High β cases are mostly associated with events on the dusk side. As for the relation to solar wind conditions, Pc 5 waves tend to occur under the condition of more radial than the average IMF spiral angle, or of low cone angle [Kokubun, 2013].

The cross-shock electrostatic potential at the front of collision-less shocks plays a key role in the distribution of energy at the shock front. Multipoint measurement in space such as by the Cluster II mission has an ability to derive the spatio-temporal variations at the shock front. A statistical study of the cross-shock potential calculated for around 50 crossings of the terrestrial bow shock is presented. The statistical dependency of the normalized cross-shock potential on the upstream Alfven Mach number is in good agreement with analytical results that predict decrease of the cross-shock potential with increasing Mach number [Dimmock et al., 20112].

<CLUSTER, THEMIS>

Electromagnetic ion cyclotron (EMIC) triggered chorus emissions have recently been a subject of several experimental, theoretical and simulation case studies, noting their similarities with whistler-mode chorus. Grison et al. [2013] performed a survey of 8 years of Cluster data in order to increase the database of EMIC triggered emissions. The results of this is that EMIC triggered emissions have been unambiguously observed for only three different days. These three events are studied in detail. All cases have been observed at the plasmapause between 22 and 24 magnetic local time (MLT) and between –15 degrees and 15 degrees of magnetic latitude. Triggered emissions were also observed for the first time below the local helium gyrofrequency. The number of events was too low to produce statistical results, nevertheless they pointed out a variety of common properties of those waves.

A review has been made by Krasnoselskikh et al. [2013] to address a subset of unresolved problems in collisionless shock physics from experimental point of view making use of multi-point observations onboard Cluster satellites. The problems they address are determination of scales of fields and of a scale of electron heating, identification of energy source of precursor wave train, an estimate of the role of anomalous resistivity in energy dissipation process by means of measuring short scale wave fields, and direct observation of reformation process during one single shock front crossing.

The width of the terrestrial collisionless shock front, which is one of the key shock parameters, is reported. The width of the main shock transition layer is related to the nature of the collisionless process that balances nonlinearity and therefore leads to the formation of the shock itself. The shock width determines how the incoming plasma particles interact with the macroscopic fields within the front and, therefore, the processes that result in the energy redistribution at the front. Cluster and Themis measurements at the quasi-perpendicular part of the terrestrial bow shock are used to study the spatial scale of the magnetic ramp [Hobara et al., 2010].

Using waveform data obtained by one of the THEMIS satellites, Kurita et al. [2013] reported properties of rising tone chorus elements without a gap at half the gyrofrequency in a region close to the magnetic equator. The wave normal angle of the chorus elements is typically field-aligned in the entire frequency range of both upper-band and lower-band chorus emissions. They found that the observed frequency sweep rates are consistent with the estimation based on the nonlinear wave growth theory of Omura et al. (2008).

<CRRES, AMPTE, DE-1>

Using the magnetic field and plasma wave data obtained by the Combined Release and Radiation Effects Satellite (CRRES), Nosé et al. [2011] search for enhancements of O^+ ion density in the deep inner magnetosphere known as "the oxygen torus." They examined 4 events on the dayside in which toroidal standing Alfvén waves appear clearly. From the frequency of the toroidal waves, the magnetospheric local mass density is estimated by solving the MHD wave equation for realistic models of the magnetic field and the field line mass distribution.

Nosé et al. [2011] statistically studied the spatial characteristics of Pi2 pulsations using magnetic field observations in the magnetosphere at the equatorial-orbiting Active Magnetospheric Particle Tracer Explorers (AMPTE)/Charge Composition Explorer (CCE) and the polar-orbiting Dynamics Explorer 1 (DE 1) satellites and on the ground at the low-latitude station Kakioka (KAK, L=1.23).

H1.2 Lunar and Planetary Plasma Waves

Tsugawa et al. [2011] performed a statistical analysis of narrowband whistler mode waves in frequencies of near 1 Hz observed by Kaguya around the Moon. The results suggest that the waves are mainly observed in the region of SZA = 40－90 deg with north-south/dawn-dusk asymmetries and are associated with lunar crustal magnetic anomalies.

Broadband whistler mode waves in the frequency range from 0.1 to 10 Hz are frequently observed near the Moon in the solar wind. Their analyses using Kaguya dataset reveal that the waves are mostly observed above lunar magnetic anomalies and are associated with energized electrons and reflected ions. They suggest that narrowband waves which were occasionally observed around the Moon can be formed from the broadband waves [Tsugawa et al., 2012].

The waveform capture (WFC) onboard the KAGUYA spacecraft is designed to measure natural plasma waves generated around the moon and radio emissions which propagate from the sun, the earth and other planets. In order to suppress the artificial noises originated from the instruments onboard KAGUYA, Nishibe et al. [2012] developed a new method to identify the relationship between each interference noise with the noise source and reduce the noise in a systematic way according to the house keeping data of the spacecraft.

Recent observations by KAGUYA revealed that type-II (T2) entry of the solar wind protons into the near-Moon wake occurs when the IMF is dominated by the non-radial components (i.e. BY and/or BZ). Nishino et al. [2013] categorized T2 entry into two cases; T2 entry with magnetic connection to the lunar surface (T2MC) and T2 entry into magnetically detached regions (T2MD). Strong electron acceleration (up to several hundred eV to 1 keV) along the magnetic field associated with the T2 entry is prominent when the field line has its both ends in the solar wind, that is, when the magnetic field is detached from the lunar surface (T2MD). On the other hand, no significant electron acceleration is found in the T2MC cases although an enhancement of the electron flux associated with the T2 proton entry is evident. They also reported that the T2 entry process takes place even under radial (BX-dominated) IMF condition. These results indicate that, while the T2 entry of solar wind protons into the wake itself does not require a special IMF condition but is a rather general phenomenon, the characteristic energy of associated electrons does show a strong dependence on the magnetic connectivity to the lunar surface [Nishino et al., 2013].

H1.3 Ground Observation and Experiment of Plasma Waves

Long-term (1976–2010) variations in reflection heights of tweek atmospherics has been investigated for the first time based on very low frequency (VLF) observations at Kagoshima, Japan. The variations in tweek reflection heights did not show simple correlation with solar activity. Ohya et al. [2011] suggested that these variations in tweek reflection heights could be caused by coupling of several ionization effects at the D and lower E regions.

Daytime tweek atmospherics during the solar eclipse of 22 July 2009 were reported on the basis of VLF/ELF wave measurements at Moshiri and Kagoshima, Japan, where the magnitudes of the solar eclipse were 0.458 and 0.966, respectively. This was the first observation of tweek atmospherics during a low-magnitude eclipse (0.458). The phase variation in the LF transmitter signals were also observed during the eclipse [Ohya et al., 2012].

Goto et al. [2012] examined the accuracy of the global core plasma model (GCPM) in the equatorial region by using long-term total electron content (TEC) data obtained from several GPS tracking stations along the equator and a low Earth orbit satellite. According to the statistical analysis of the GPS TEC, they found a remarkable feature in bias errors in the GCPM-derived TEC. Most of the errors are found to distribute in the topside ionosphere due to the simple representation of the density there.

A high correlation between a pulsating auroral patch and grouped chorus waves was observed at Syowa Station in Antarctica. The generation region of the chorus waves was estimated from the latitude and longitude dependence of the equatorial electron gyrofrequencies using the IGRF geomagnetic field model. The extent of the estimated latitude and longitude was consistent with the spatial distribution of the high-correlation aurora-chorus region. This study supports the hypothesis that pulsating aurora is caused by pitch angle scattering of high-energy electrons by whistler mode chorus waves, via a cyclotron resonance at the equator [Ozaki et al., 2012a].

Using a single-site lightning location technique, a new portable lightning location system was developed. The system incorporated an attitude detection technique using inertial sensors to detect an accurate electromagnetic field vector of sferics by palm-sized electromagnetic sensors which can have arbitrary attitude. The palm-sized system detected the sferics within about several hundred km with the attitude detection technique [Ozaki et al., 2012b].

Sakaguchi et al. [2012a] analyzed Pc5 (1.7–6.7 mHz) oscillations of ionospheric Doppler plasma velocity observed on a westward pointing beam 3 of the SuperDARN King Salmon HF radar in Alaska during the solar maximum in 2002 and the minimum in 2007. Local time distributions of the ionospheric Pc5 oscillations showed peculiar asymmetric characteristics in both years; that is, the occurrence probability had a maximum around the magnetic midnight, whereas backscatter echoes exhibited almost no oscillation on the dayside. They compared these ionospheric Pc5 events with magnetic field variations on the ground under the radar beam at Pebek and King Salmon and the geostationary ETS-8 satellite at almost conjugate longitude. They found only a few nightside events where both the radar and magnetometers detected similar sinusoidal oscillations.

Interaction with EMIC (electromagnetic ion cyclotron) waves is thought to be a key component contributing to the very rapid loss of both ring current and radiation belt particles into the atmosphere. Estimated loss rates are heavily dependent on the assumed spatial distribution of the EMIC wave. Statistical maps of the spatial distribution have been produced using in-situ satellite data. However, with limited satellite data it is impossible to deduce the true spatial distribution. Sakaguchi et al. [2012b] presented ground-based observations using all-sky imager and search coil magnetometer networks, which provide the large-scale distribution and motion of the EMIC wave-particle interaction regions.

Nomura et al. [2012] have investigated the polarization of Pc1 geomagnetic pulsations and related proton auroras at subauroral latitudes, using an induction magnetometer and an all-sky camera at Athabasca, Canada (54.7°N, 246.7°E, magnetic latitude (MLAT) 61.7°N). Isolated proton auroras often appear in association with Pc1 pulsations, because of proton scattering by electromagnetic ion cyclotron (EMIC) waves in the magnetosphere.

The hodograph method enables estimating the latitudinal profile of the field-line resonance (FLR) frequency (fR) using the data from two ground magnetometers. Pilipenko et al. [2013] provides the full details of this method for the first time, and uses a latitudinal chain of ground magnetometers to examine its validity and usefulness. The hodograph method merges the widely-used amplitude-ratio and cross-phase methods in a sense that the hodograph method uses both the amplitude ratio and the phase difference in a unified manner; further than that, the hodograph method provides fR at any latitude near those of the two ground magnetometers. It is accomplished by (1) making a complex number by using the amplitude ratio (phase difference) as its real (imaginary) part; (2) drawing thus obtained complex numbers (one number for one frequency) in the complex plane to make a hodograph; and (3) fitting to thus obtained hodograph a model satisfying the FLR condition, which is a circle with the assumption that the resonance width is independent of the latitude.

Geomagnetic field data with high time resolution (typically 1 s) have recently become more commonly acquired by ground stations. Such high time resolution data enable identifying Pi2 pulsations which have periods of 40–150 s and irregular (damped) waveforms. It is well-known that pulsations of this type are clearly observed at mid- and low-latitude ground stations on the nightside at substorm onset. Therefore, with 1-s data from multiple stations distributed in longitude around the Earth's circumference, substorm onset can be regularly monitored [Nosé et al., 2012].

Tanaka et al. [2012] investigated a relationship between poleward moving auroral arcs (PMAAs), quasi-stationary auroral patches (QSAPs), and Pc 5 geomagnetic pulsations observed at the South Pole Station (74.3 CGLAT) in the interval 0800–1100 MLT. It was demonstrated that the PMAAs, Pc 5 pulsations in the north-south component, and oscillations in the drift of the QSAPs in the east-west direction have similar dominant periods and are well correlated with each other.

H2. Theory and Computer Experiment on Plasma Waves

H2.1 Acceleration and Scattering of Particles

Summers et al. [2011] presented new relativistic formulae for the self-limiting K-P flux. They compared the theoretical K-P limit with observed Radiation Belts fluxes. They include nonlinear wave growth effects in the calculation of extreme Radiation Belts fluxes.

Lee et al. [2011] carried out a series of 2D simulations to study the beam instability and cyclotron maser instability (CMI) with the initial condition that a population of tenuous energetic electrons with a ring-beam distribution is present in a magnetized background plasma. Weakly relativistic cases are discussed with the ring-beam kinetic energy ranging from 25 to 100 keV. The beam component leads to the two-stream or beam instability at an earlier stage, and the beam mode is coupled with Langmuir or whistler mode, leading to excitation of beam-Langmuir or beam-whistler waves.

Lee et al. [2012] demonstrated by a particle simulation that Z-mode waves generated by the cyclotron maser instability can lead to a significant acceleration of energetic electrons. In the particle simulation, the initial electron ring distribution leads to the growth of Z-mode waves, which then accelerate and decelerate the energetic ring electrons. The initial ring distribution evolves into an X-like pattern in momentum space, which can be related to the electron diffusion curves.

Lee et al. [2013] carried out a series of particle simulations to study electron acceleration by Z-mode and whistler-mode waves generated by an electron ring distribution. The electron ring distribution leads to excitations of X-mode waves mainly in the perpendicular direction, Z-mode waves in the perpendicular and parallel directions, and whistler-mode waves mainly in the parallel direction. The parallel Z- and whistler-mode waves can lead to an effective acceleration of ring electrons. The electron acceleration is mainly determined by the wave amplitude and phase velocity, which in turn is affected by the ratio of electron plasma to cyclotron frequencies. For the initial kinetic energy ranging from 100 to 500 keV, the peak energy of the accelerated electrons is found to reach 2–8 times the initial kinetic energy. They further studied the acceleration process by test-particle calculations in which electrons interact with one, two, or four waves. The electron trajectories in the one-wave case are simple diffusion curves. In the multi-wave cases, electrons are accelerated simultaneously by counter-propagating waves and can have a higher final energy.

Nonlinear interaction between EMIC triggered emissions and electrons is studied. Pitch angle scattering depends on rising frequency and magnetic field gradient. Rapid precipitation of electrons by EMIC waves is confirmed by simulations [Omura and Zhao, 2012].

Omura and Zhao [2013] showed that the anomalous cyclotron resonance between relativistic electrons and electromagnetic ion cyclotron (EMIC) triggered emissions takes place very effectively near the magnetic equator because of the variation of the ambient magnetic field. Efficient precipitations are caused by nonlinear trapping of relativistic electrons by electromagnetic wave potentials formed by EMIC triggered emissions. They derived the necessary conditions of the wave amplitude, kinetic energies, and pitch angles that must be satisfied for the nonlinear wave trapping. They have conducted test particle simulations with a large number of relativistic electrons trapped by a parabolic magnetic field near the magnetic equator.

H2.2 Generation and Propagation of Plasma Waves

According to recently developed nonlinear cyclotron resonance theory, the generation of a whistler-mode rising-tone chorus element is determined by a pair of coupled nonlinear ordinary differential equations referred to as "chorus equations." Summers et al. [2012] generalize the chorus equations to an arbitrary energetic electron distribution, and calculate the associated threshold wave amplitude for sustained nonlinear growth.

Chorus emissions grow as an absolute nonlinear instability near the magnetic equator because of the presence of an electromagnetic electron hole in velocity space. The transition process from the linear wave growth at a constant frequency to the nonlinear wave growth with a rising tone frequency is due to formation of a resonant current $-J_B$ antiparallel to the wave magnetic field. The rising-tone frequency introduces a phase shift to the electron hole at the equator and results in a resonant current component antiparallel to the wave electric field $-J_E$, which causes the nonlinear wave growth [Omura and Nunn, 2011].

The frequency and amplitude characteristics of chorus emissions are studied by performing electron hybrid code simulations with different initial number densities of energetic electrons. Chorus emissions with rising tones are generated in all simulation runs except for the simulation assuming the lowest number density. The frequency sweep rates of reproduced chorus vary depending on the variation of the wave amplitude of respective chorus elements. Katoh and Omura [2011] found that the theoretically estimated frequency sweep rates are consistent with the simulation results.

Triggered emissions are excited with triggering wave amplitude above a threshold. The frequency sweep rate of emission does not depend on the triggering amplitude. An electromagnetic electron hole is found in generation of a triggered emission [Hikishima and Omura, 2012].

Katoh and Omura [2013] have conducted numerical experiments with different spatial inhomogeneities to understand properties of the chorus generation process. They assume the same initial condition of energetic electrons at the magnetic equator in all simulation runs. The simulation results reveal that the spectral characteristics of chorus significantly vary depending on the magnetic field inhomogeneity. Whistler-mode emissions are generated and propagate away from the equator in all simulation runs, but distinct chorus elements with rising tones are only reproduced in the cases of small inhomogeneities. In the simulation that had the smallest inhomogeneity, they find excitation of broadband hiss-like emission (BHE) whose amplitudes are comparable to discrete chorus elements found in other simulation runs.

Summers et al. [2013] examined the growth of magnetospheric whistler-mode waves which comprises a linear growth phase followed by a nonlinear growth phase. They constructed time-profiles for the wave amplitude that smoothly match at the transition between linear and nonlinear wave growth. This matching procedure can only take place over a limited "matching region." They constructed this matching region and determined how the matching wave amplitude varies throughout the region.

Recently much progress has been made in the simulation and theoretical understanding of rising frequency triggered emissions and rising chorus. Both PIC and Vlasov VHS codes produce risers in the region downstream from the equator toward which the VLF waves are traveling. The VHS code only produces fallers or downward hooks with difficulty due to the coherent nature of wave particle interaction across the equator. With the VHS code Nunn and Omura [2012] now confine the interaction region to be the region upstream from the equator, where inhomogeneity factor S is positive.

Shoji and Omura [2011] performed hybrid simulations to reproduce the EMIC triggered emissions. They developed a self-consistent one-dimensional hybrid code with a cylindrical geometry of the background magnetic field. They assumed a parabolic magnetic field to model the dipole magnetic field in the equatorial region of the inner magnetosphere. Triggering EMIC waves are driven by a left-handed polarized external current assumed at the magnetic equator in the simulation model.

Shoji et al. [2011] performed a self-consistent hybrid simulation with a one-dimensional cylindrical magnetic flux model approximating the dipole magnetic field of the Earth's inner magnetosphere. In the presence of energetic protons with a sufficient density and temperature anisotropy, multiple EMIC triggered emissions are reproduced due to the nonlinear wave growth mechanism of rising-tone chorus emissions, and a constant frequency wave in the He^+ EMIC branch is subsequently generated.

Shoji and Omura [2012] investigated the generation process of the EMIC triggered emissions in the He^+ branch and associated precipitation of the energetic protons using a one-dimensional hybrid simulation with a cylindrical parabolic magnetic geometry. The simulation results show a good agreement with the nonlinear wave growth theory.

Shoji and Omura [2013] reproduced EMIC triggered emissions in the Earth's magnetosphere by real scale hybrid simulations with cylindrical magnetic geometry. They obtained spontaneously triggered nonlinear EMIC waves with rising frequencies in the H^+ band of the EMIC dispersion relation. The proton holes in the phase space are formed. They have also derived the theoretical optimum wave amplitude for triggering process of the EMIC nonlinear wave growth. The optimum wave amplitude and the nonlinear transition time show a good agreement with the present simulation result. The nonlinear wave growth over a limited time forms a subpacket structure of a rising tone emission. The formation process of a subpacket is repeated because of a new triggering wave generated by the phase-organized protons, which are released from the previous subpacket. Then, the EMIC triggered emission is formed as a train of subpackets generated at different rising frequencies.

Summers et al. [2012] obtained Equations of nonlinear convective growth of a chorus wave. The convective growth of a chorus wave is followed by saturation. The saturation is due to adiabatic effects and the decrease in resonant current.

Using a well-established magnetospheric very-low-frequency (VLF) ray tracing method, Yamaguchi et al. [2013] trace the propagation of individual rising- and falling-frequency elements of VLF chorus from their generation point in the equatorial region of the magnetosphere through to at least one reflection at the lower-hybrid resonance point. They track the motion in the equatorial plane of the whole chorus element, paying particular regard to movement across field lines, rotation, and compression or expansion of the wave pulse. With a generation point for rising chorus at the equator, it was found the element wave pulse remained largely field aligned in the generation regions.

Coalescence of mirror-mode structure results in magnetic peaks and dips. Magnetic dips are generated in 2D low ion beta models. Magnetic peaks are formed in 2D high ion beta models and all 3D models [Shoji et al., 2012].

The fundamental nature of ULF waves in the Pc5 range driven by periodic variation of solar-wind dynamic pressure is studied by using a global MHD simulation. It is shown that a spectrum of the magnetospheric ULF wave induced from the periodic variation has a harmonic structure due to nonlinear behavior of magnetospheric response to the solar wind variation [Fujita et al., 2011].

H2.3 Development of Simulation Codes and Data Analysis Systems

Dimmock et al. [2011] presented comparison of 3 different techniques that can be used to estimate the cross shock potentials. The first technique is the estimate taking only into account the projection of the measured components onto the shock normal. The second uses the ideal MHD condition to estimate the third electric field component. The last method is based on the structure of the electric field in the Normal Incidence Frame (NIF) for which only the potential component along the shock normal and the motional electric field exist. Surprisingly all three methods lead to the same order of magnitude for the cross shock potential. The resulting electrostatic potential appears too high in comparison with the theoretical results for low Mach number shocks. This shows the variability of the potential, interpreted in the frame of the non-stationary shock model.

Photoelectron flows around a spacecraft and a double-probe electric field sensor are studied by means of plasma particle simulations. The stray photoelectron current flowing from a spacecraft into a probe can be reduced by operating the probe nearly at the plasma potential. The analysis also revealed side effects of a guard electrode enhancing a stray photoelectron current from the electrode itself [Miyake et al., 2012].

Umeda et al. [2012] developed a numerical method for analyzing the linear dispersion relation for Maxwellian ring-beam velocity distributions. The obtained linear properties are confirmed by direct comparison with full particle simulation results.

Kakad et al. [2013] performed one-dimensional fluid simulation of ion acoustic (IA) solitons propagating parallel to the magnetic field in electron-ion plasmas by assuming a large system length. To model the initial density perturbations (IDP), they employed a KdV soliton type solution. Their simulation demonstrates that the generation mechanism of IA solitons depends on the wavelength of the IDP. The short wavelength IDP evolve into two oppositely propagating identical IA solitons, whereas the long wavelength IDP develop into two indistinguishable chains of multiple IA solitons through a wave breaking process.

The plasmaspheric virtual resonance (PVR) and the transient Alfven wave bouncing between the ionospheres in both hemispheres (the transient response, TR) are regarded as the possible generation mechanisms of the Pi2 pulsations. However, the global MHD simulation of a substorm [Tanaka et al., 2010] did not reproduce such wave modes because of insufficient ionospheric reflection of the Alfven wave, numerical transfer of the Alfven wave across the field lines, and no plasmasphere. Furthermore, it is noted that the substorm current wedge (SCW) which is a driver of the TR is not reproduced in the global MHD simulation. Fujita and Tanaka [2013] search the sources of the Pi2 pulsations in the global MHD simulation, namely, the compressional wave in the inner magnetosphere for the PVR and the Alfven wave injected to the ionosphere for the TR. In conclusion, there appears a compressional signal in the inner magnetosphere when the high-speed Earthward flow at the substorm onset surges in the inner edge of the plasma sheet.

It is often discussed that the fourth methodology for science research is "informatics." The first methodology is a theoretic approach, the second one is observation and/or experiment, and the third one is computer simulation. Informatics is a new methodology for data intensive science, which is a new concept based on the fact that most scientific data are digitalized and the amount of data is huge. Data-oriented science is considered as the forth paradigm for coming big data science, including polar research. The facilities to support informatics are cloud systems. Herein Murata et al. [2013a] propose a cloud system especially designed for science. The basic concepts, design, resources, implementation, and applications of the "National Institute of Information and Communications Technology (NICT) science cloud" are discussed. The NICT Science Cloud is designed and constructed as a basis for data-oriented science since 2010. They demonstrated information and communication technologies (ICT) designed to transfer, steward, process and publicize large-scale data acquired and analyzed in solar-terrestrial physics. The NICT Science Cloud is a cloud system designed for scientific researches, and expected as a new infrastructure for big data sciences. Not only parallelization of CPU as in super-computers, but I/O and network throughput parallelization are crucial for the big data science. A high-performance visualization system is constructed on the NICT Science Cloud using Gfarm/Pwrake middleware.

Cross-sectional studies have become important for an improved understanding of various Solar-Terrestrial Physics (STP) fields, given the great variety and different types of observations from the Sun to the Earth. In order to better combine, compare, and analyze different types of data together, the Solar-Terrestrial data Analysis, and the Reference System (STARS) has been developed. Cross-sectional study requires cooperative work. STARS has two functions for cooperative work, the "Stars Project List (SPL)" and the "Event Listing." The SPL is used for exchanges of plotting information by cooperating persons. The event list database provides all users of STARS hints for recognizing typical occurrences of STP phenomena [Kunitake et al., 2013].

To optimize space weather research and information services, it is important to establish a comprehensive system that enables us to analyze observation and simulation data in an integrated manner. For this, Watari et al. [2013] recently constructed a new computing environment called the "Space Weather Cloud Computing

System" of NICT. Currently, the Space Weather Cloud contains a high performance computer, a distributed mass storage system using the Grid Data Farm (Gfarm) technology, servers for analysis and visualization of data, a job service based on the RCM (R&D Chain Management) system, servers for the STARS system.

In Watanabe et al. [2013], an outline of a planned system for the global space-weather monitoring network of NICT is given. This system can manage data collection much more easily than our current system by installations of autonomous recovery, periodical state monitoring, and dynamic warning procedures. According to a provisional experiment using a network simulator, the new system will work under limited network conditions, e.g., a 160 msec delay, a 10 % packet loss rate, and a 500 Kbps bandwidth.

For data intensive science on cloud systems, we need development of techniques for DIC (Data-Intensive Computing) as well as HTC (High-Through-put Computing), MTC (Many-Task Computing), and HPC (High-Performance Computing). The DIC is a new concept of large-scale data processing paying attentions to data distribution, data-parallel execution, and harnessing data locality by scheduling of computations close to the data. As the data file size is getting larger, I/O time to read and/or write data is not negligible compared with data processing time. Murata et al. [2013a] herein developed a DIC technique on a science cloud using Gfarm/Pwrake. The Gfarm/Pwrake has been developed as an integrated system of both distributed file system and parallel data processing system. With identifying file system nodes (FSN) and processing client node (CN) and giving higher priority to process files on the local disk than on remote disks, they succeeded in progress of total performance in processing large-scale data files.

Murata et al. [2013b] designed meta-data of the STARS along with the RSS1.0 document. In order to describe the meta-data of the STARS beyond RSS1.0 vocabulary, they defined original vocabularies for the STARS resources using RDF Schema. Their system works as follows. The RSS1.0 documents generated on data sites are automatically collected by a meta-data collection agent. The agent extracts meta-data to store them in an XML database. The XML database provides advanced retrieval processing that has considered property and relation.

Kubota et al. [2013] presented a new concept of analysis using visualization of large quantities of simulation data. The time development of 3D objects with high temporal resolution provides the opportunity for scientific discovery. They visualized large quantities of simulation data using the visualization application "Virtual Aurora" based on AVS (Advanced Visual Systems) and the parallel distributed processing at

"Space Weather Cloud" in NICT based on Gfarm technology. They introduced two results of high temporal resolution visualization: the magnetic flux rope generation process and dayside reconnection using a system of magnetic field line tracing.

Isoda et al. [2013] presented the high time and spatial resolution visualizations in 3D of the global MHD simulations. The Virtual Aurora, a tool designed based on the AVS, is developed on the purpose of adapting to the parallel processing with the distributed file system, Gfarm/Pwrake to process huge amount of simulation data files. The new technique is included, as the tracing of fluid elements. It will helpful for understanding the convection in the magnetosphere.

Nagatsuma et al. [2013] present an operation system to acquire, to transfer and to storage data for world-wide observation networks, which is named as "WONM (Wide-area Observation Network Monitoring) system, developed in NICT. This system provides us with easier management of data collection than legacy systems by means of autonomous system recovery, periodical state monitoring, and dynamic warning procedures. They have equipped world-wide observatories for space weather prediction and research works with this system connected with the NICT Science Cloud. Demonstration and discussion are presented concerning with this challenging system, especially from the viewpoint that they easily operate world-wide observatories on a web application.

H3. New Instruments and Sensors for Plasma Wave Experiments

For future scientific missions, reduction in the resource requirements of plasma wave receivers without loss of performance is important. Fukuhara et al. [2012] introduce a miniaturized on-board instrument for the observation of plasma waves using analogue application-specific integrated circuit (ASIC) techniques. The developed ASIC functions as a system chip to filter and amplify signals detected by plasma wave sensors. Miniaturization of the analogue circuit using the ASIC leads to the realization of a tiny plasma wave receiver. The overall size of the developed plasma wave receiver circuit board is less than 1/20 that of a conventional receiver used in previous scientific missions. The power consumptions of the system chip and the plasma wave receiver are 165 and 525 mW, respectively.

Data processing for plasma wave instrument onboard spacecraft shall be done under quite limited resources of CPU and memory. Matsuda et al. [2012] investigated a signal processing method to derive power spectrum and phase information of plasma wave applicable to onboard data processing. They proposed a more efficient processing method adopting high performance FFT routines according to pre-implemented tables for trigonometric functions and demonstrated that the proposed method is fast enough to apply to the onboard data processing. They also evaluated the accuracy of calculation for phase properties of plasma wave signal even in the low-frequency resolution condition using vector averaging method.

The Energization and Radiation in Geospace (ERG) project for solar cycle 24 will explore how relativistic electrons in the radiation belts are generated during space storms. This geospace exploration project consists of three research teams: the SPRINT-B/ERG satellite observation team, the ground-based network observation team, and the integrated data analysis/simulation team [Miyoshi et al., 2012].

In the upcoming JAXA/ERG satellite mission, Wave Particle Interaction Analyzer (WPIA) will be installed as an onboard software function. Katoh et al. [2013] studied the statistical significance of the WPIA for measurement of the energy transfer process between energetic electrons and whistler-mode chorus emissions in the Earth's inner magnetosphere. The WPIA measures a relative phase angle between the wave vector $\boldsymbol{E}$ and velocity vector $\boldsymbol{v}$ of each electron and computes their inner product W, where W is the time variation of the kinetic energy of energetic electrons interacting with plasma waves. They evaluated the feasibility by applying the WPIA analysis to the simulation results of whistler-mode chorus generation.

A dual-resonant search coil (DRSC) is designed as a wideband magnetometer for natural electromagnetic waves in the near-Earth environment. Since the frequency response of a search coil is determined by its resonant frequency, its bandwidth can be increased by using multiple resonances. Two resonances are obtained by capacitive coupling with negative mutual inductance between two coils. The resulting measurement band of the DRSC is from 10 Hz to 1 MHz for a sensor 100 mm in length, 25 mm in diameter, and 0.11 kg in mass [Ozaki et al., 2013].

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