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Magnetospheric Physics in China: 2008–2010

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Abstract In the past two years, most of the works on magnetospheric physics were made by using the data of Double Star Program and Cluster missions. However some works were still conducted by computer simulation or using the data from other space missions and ground geomagnetic observations. This paper briefly review these previous works based on papers selected from the 28 publications from April 2008 to April 2010. The subjects covered various sub-branches of magnetospheric physics, including geomagnetic storm, magnetospheric substorm and *etc.*

Keywords Geomagnetic storm, Magnetospheric substorms, Space plasma

1 Geomagnetic Storms

Similar to the *Dst* index, the SYM-H index may also serve as an indicator of magnetic storm intensity, but having distinct advantage of higher time-resolution. Cai *et al.*[1] for the first time used the NARX neural network to predict SYM-H index from Solar Wind (SW) and IMF parameters. Total 73 time intervals of great storm events with IMF/SW data available from ACE satellite during 1998 to 2006 were used to establish the ANN model. Out of them, 67 were used to train the network and the other 6 samples for test. Additionally, the NARX prediction model was also validated using IMF/SW data from WIND satellite for 7 great storms during 1995–1997 and 2005, as well as for the July 2000 Bastille day storm and November 2001 super-storm using Geotail and OMNI data at 1 AU, respectively. Five interplanetary parameters of IMF B_z, B_y and total B components along with proton density and velocity of solar wind were used as the original external inputs of the neural network to predict the SYM-H index about one hour ahead. For the 6 test storms registered by ACE including two super-storms of minute. SYM-$H < -200$ nT, the correlation coefficient between observed and NARX network predicted SYM-H is 0.95 as a whole, even as high as 0.95 and 0.98 with average relative variance of 13.2% and 7.4%, respectively, for the two super-storms. The prediction for the 7 storms with WIND data is also satisfactory, showing averaged correlation coefficient about 0.91 and RMSE of 14.2 nT. The newly developed NARX model shows much better capability than Elman network for SYM-H prediction, which can partly be attributed to a key feedback to the input layer from the output neuron with a suitable length (about 120 min). This feedback means that nearly real information of the ring current status is effectively directed to take part in the prediction of SYM-H index by ANN. The proper history length of the output-feedback may mainly reflect on average the characteristic time of ring current decay which involves various decay mechanisms with ion lifetimes from tens of minutes to tens of hours. The Elman network makes feedback from hidden layer to input only one step, which is of 5 min for SYM-H index in this work and thus insufficient to catch the characteristic time length.

Xu *et al.*[2] studied the statistical relationship be-

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tween solar wind conditions and geomagnetic storms in 1998–2008. They used the ACE data and pressure-corrected Dst index (Dst*) to display the correlations between solar wind structures and geomagnetic storms. It was found that, within the Earth's upstream solar wind, the dominant feature was Interplanetary Coronal Mass Ejections (ICMEs), primarily magnetic clouds, during solar maximum period but Corotating Interaction Regions (CIRs) at solar minimum. During rising and declining phases, solar wind features became unstable for the complicated solar corona transition processes between the maximum and minimum phases, and there was a high CIR occurrence rate in 2003, the early period of the declining phase, for the Earth's upstream solar wind was dominated by high-speed southern coronal-hole outflows at that time. The occurrence rate of Sector Boundary Crossing (SBC) events was evidently higher at the late half of declining phase and minimum period. ICMEs mainly centered on the maximum period but CIRs on all the declining phase. The occurrence rate of ICMEs was 1.3 times of that of CIRs, and more than half of ICMEs were Magnetic Clouds (MCs). Half of magnetic clouds could drive interplanetary shock and played a crucial role for geomagnetic storms generation, especially intense storms ($Dst^* \leqslant 100$ nT), in which 45% were jointly induced by sheath region and driving MC structure. Sixty percent of intense storms were totally induced by shock-driving MCs; moreover, 74% of intense storms were driven by magnetic clouds, 81% of them driven by ICMEs. Shock-driving MC was the most geoeffective interplanetary source for four fifths of it able to lead to storms and more than one-third to intense storms. The rest of intense storms (19%) were induced just by 3% of all detected CIRs, and most of CIRs (53%) were corresponding to nearly 40% moderate and small storms ($-100 < Dst^* \leqslant 30$ nT). The true Sector Boundary Crossing (SBC) events actually had no obvious geoeffectiveness, just 6% of them corresponding to small storms.

2 Magnetospheric Substorms

On February 26, 2008, the THEMIS satellites observed two substorms that occurred at about 04:05 UT and 04:55 UT, respectively. Pu *et al.*[3] display detailed features of the two substorms with emphasis on the first. In both substorms a distinct auroral intensification occurred during the earliest stage of onset, about 1 to 2 min after midtail reconnection began. This initial intensification was weak and localized and thus had the signatures of a pseudo breakup. In both substorms, a second, major intensification occurred next in the substorm onset sequence, followed by rapid and extensive poleward expansion. This second intensification had the features of the major expansion onset and was nearly co-incident with observations of earthward flows and magnetic dipolarization in the near-Earth tail. During the growth phase of the two substorms, open magnetic flux accumulated in the polar cap; in the expansion/recovery phase the polar cap open flux was quickly reduced. These observations are in agreement with the assertion that tail reconnection initiates the initial pseudo breakup and the ensuing major expansion and releases and transports energy to eventually cause near-Earth dipolarization and the expansion phase onset of these two substorms.

Zhang *et al.*[4] introduce an effective processing method to acquire the time derivative of the AE index as a coefficient. Using this coefficient, the AE index can be divided into the four stages: quiet, ascending, descending and active stage. The statistical results show that the ascending and descending stages of the AE index are dominant and occupy two thirds of the whole period. An analysis of the relationship between the occurrence frequency of the Dst index and AE index in solar cycle 23 shows that the monthly variation of the occurrence frequency of the ascending stage of AE is closely related to the Dst index.

A substorm event has been simulated for the first time by using SWMF (Space Weather Modeling Framework) developed by the University of Michigan in Wang *et al.*[5]. The model results have been validated using Geotail and Cluster satellite observations. The substorm onset occurred at 22:08 UT on 28 September, 2004, as identified from FUV WIC observations on the NASA IMAGE spacecraft. SWMF can couple effectively the magnetosphere, inner magnetosphere and ionosphere processes and is driven by the solar wind and IMF (Interplanetary Magnetic

Field) parameters, which are measured by ACE satellite and time delayed to the upstream boundary of the model. It shows that (1) SWMF can predict well the large-scale variations of the magnetospheric magnetic field and ionospheric currents during the substorm event; and (2) the accuracy of the time delay of the solar wind from ACE to the outer boundary of the model has great effects on the model results. Finally, the substorm trigger mechanism has been discussed and the way of improvement of the model has been pointed out.

Tang *et al.*[6] present observations of a substorm on 13 March 2008 by Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft in the near-Earth tail during the plasma sheet expansion evidenced by increase in the plasma density and temperature. The main features of the event are as follows: (1) Cross-tail current reduction or Current Disruption (CD) was observed in the near-Earth tail at $x = -8.0\,R_{\rm e}$ and $y = -2.0\,R_{\rm e}$, marked by a sharp drop of $|B_x|$ and accompanied by sharp increases in the plasma density and temperature, manifesting a rapid expansion (recovery) of the local plasma sheet. During the course of the plasma sheet expansion, the propagation speed of the dipolarization is -48 km/s in tailward direction and -35 km/s in azimuthal direction. (2) In the inner edge of the plasma sheet, slow flux pileup is observed. The magnetic flux pileup is characterized by continuous enhancement of B_z and $B_{\rm t}$ and a reduction of the plasma density, pressure $P_{\rm th}$, and b in the flow-braking region. The tailward moving plasma sheet expansion (CD) is also passing across the flow-braking region. In short, the dipolarization in the inner edge of the plasma sheet can be attributed to CD, while the tailward progression of dipolarization in the flow-braking region can be attributed to magnetic flux pileup. (3) A sharp decrease in the magnitude of B_x at P_1 ($-13.1\,R_{\rm e}$, $2.5\,R_{\rm e}$, $-0.56\,R_{\rm e}$) prior to the dipolarization at P_5 is difficult to explain as part of the outward evolution of the CD. The rapid change in the magnetic field topology, and signatures of earthward flows and dipolarization observed at P_1 prior to Pi2 onset may be caused by inward motion of flux from magnetic reconnection in the midtail (20–30 $R_{\rm e}$). Tail reconnection prior to substorm expansion can result in a sudden change of the near-Earth configuration, which may result in instabilities related to the onset of CD.

Wei *et al.*[7] studied the westward ionospheric electric field perturbations on the dayside associated with substorm processes. The case presented by them suggests that some substorms can produce strong westward electric field perturbations and drive westward equatorial electrojets on the dayside ionosphere. This westward electric field is created by an overshielding-like imbalance state of Field-Aligned Currents (FACs), Region 2 (R_2) FAC greater than Region 1 (R_1) FAC, which is built up through R_2 FAC enhancement rather than R_1 FAC reduction due to IMF northward turning. The substorm processes should be responsible for the westward electric field especially through polar cap shrinkage and magnetic field dipolarization.

A comparison between substorm onset times identified by geomagnetic westward electric jet AL index, substorm electric jet AE index and field-aligned current AF index and auroral breakup were conducted by Ding *et al.*[8]. They found that if auroral onsets are chosen as zero time, then AL and AE onsets are mainly distributed between $[-5, +6]$ min, with just several events between $[-9, +9]$. Field-aligned current AF onsets are relatively widely distributed, that is $[-8, +7]$ min. The average AL, AE, AF onsets are 0.5, 0.5, and -0.1 min. The most possible AL onset is at the same time as auroral onset, but that is 1 min before for AE and AF onsets. The substorm onsets got by geomagnetic indices get closer to auroral onset with more intense substorm activities. For the 5 super substorms, AL and AE onsets are both before auroral onset. It is indicated that for intense substorm, electric jet will increase before auroral breakup.

3 Solar Wind-magnetosphere-ionosphere Interaction

The quasiperiodic variations of the Interplanetary Magnetic Field (IMF) sector structure at the ACE satellite (L_1) were investigated using power spectrum analysis by Du *et al.*[9]. It appears that the two-sector structure of the IMF dominates during the solar ma-

ximum, lasting 3 years from 2000 through 2003, and the four-sector structure dominates during the solar activity minimum. A possible explanation is introduced for this phenomenon in which the IMF sector structures vary with the tilt angle of the Heliospheric Current Sheet (HCS) with respect to the solar rotation axis. During the solar activity maximum, the HCS is perpendicular to the ecliptic plane. Therefore the spacecrafts at L_1 point are expected to pass through the HCS only twice in one solar rotation, which gives rise to the observed two-sector structure of the IMF. On the other hand, during the solar activity minimum, the HCS is nearly parallel to the ecliptic plane, and the polarity of IMF B_x changes several times in one solar rotation due to the wavy nature of the HCS, which may lead to the observed four-sector structure.

Wei *et al.*[10] studied the unusually long lasting multiple penetration of interplanetary electric field to equatorial ionosphere under oscillating IMF B_z. During November 11–16, 2003, the Interplanetary Magnetic Field (IMF) B_z oscillated between northward and southward directions, which suggests discontinuous magnetic reconnection associated with the multiple pulses-like reconnection electric field. The Jicamarca Incoherent Scatter Radar (ISR) measurements of ionospheric zonal electric field showed similar fluctuations during this period. The high correlation coefficient of 0.71 between the reconnection electric field and equatorial zonal electric field during 125 hours suggests that the Interplanetary Electric Field (IEF) pulsively penetrated into the equatorial ionosphere due to the discontinuous magnetic reconnection. It is implied that the short lifetime (< 3 hours) dawn-dusk IEF pulses can penetrate into ionosphere without shielding, in other words, they may exhibit the "shielding immunity". The averaged penetration efficiency is about 0.136 and highly local time-dependent. Furthermore, the intense *AU* and *AL* indices imply that the multiple electric field penetration is associated with a "High-Intensity Long-Duration Continuous *AE* Activity (HILDCAA)".

Han *et al.*[11] present the first evidence for particle injection in the dawn-side equatorial plane caused by a sudden enhancement of the solar wind dynamic pressure ($P_{\mathrm{SE,dyn}}$). The observational results demonstrate that the $P_{\mathrm{SE,dyn}}$ caused two effects: (1) instantaneous particle energization in the dayside, and (2) particle injection in the dawn side at approximately 7 min later. The former effect has been suggested to be energization of the preexisting particles by the sudden compression of the magnetosphere. They argue that the latter effect was due to acceleration of relatively hot ions in the dawn-side plasma sheet by a bipolar electric field caused by the $P_{\mathrm{SE,dyn}}$.

Yue *et al.*[12] used the magnetic field data of GOES satellites from 1997 to 2007 and the plasma data of MPA on the LANL satellites from 1997 to 2004 to study the properties of magnetic field and plasma (0.03–45 keV) at the geosynchronous orbit ($6.6\,R_{\mathrm{e}}$) within 3 hours before and after the arrival of shock front at the geosynchronous orbit through both case study and superposed epoch analysis. It is found that following the arrival of shock front at the geosynchronous orbit, the magnetic field magnitude, as well as GSM B_z component increases significantly on the day-side (08:00–16:00 LT), while the B_y component has almost no change before and after shock impacts. In response to the interplanetary shock, the proton becomes much denser with a peak number density of $1.2\,\mathrm{cm}^{-3}$, compared to the typical number density of $0.7\,\mathrm{cm}^{-3}$. The proton temperature increases sharply, predominantly on the dusk and night side. The electron, density increases dramatically on the night side with a peak number density of $2.0\,\mathrm{cm}^{-3}$. The inferred ionospheric O^+ density after the interplanetary shock impact reaches the maximum value of $1.2\,\mathrm{cm}^{-3}$ on the dusk side and exhibits the clear dawn-dusk asymmetry. The peak of the anisotropy of proton's temperature is located at the noon sector, and the anisotropy decreases towards the dawn and dusk side. The minimum of temperature anisotropy is on the night side. It is suggested that the Electromagnetic Ion Cyclotron (EMIC) wave and whistler wave can be stimulated by the proton and electron temperature anisotropy respectively. The computed Electromagnetic Ion Cyclotron Wave (EMIC) intense on the day side (08:00 LT–16:00 LT) with a frequency value of 0.8 Hz, and the wave intensity decreases towards the dawn and dusk side, the minimum value can be found on the night side. The computed electron whistler wave locates on the day side (08:00 LT–

16:00 LT) with a value of 2 kHz.

Zhang *et al.*[13] carried out numerical simulations to study the magnetospheric Ultra Low Frequency (ULF) waves excited by positive and negative impulses of solar wind dynamic pressure. The sources of ULF waves in the magnetosphere are generally believed to be either the external solar wind perturbations or the internal plasma instabilities. When a sudden impulse of the solar wind dynamic pressure impinges on the magnetopause, ULF waves might be excited and thus the solar wind energy is transported into the Earth's magnetosphere. In this paper, we study the ULF waves excited by different kinds of sudden solar wind pressure impulses through an MHD simulation. We primarily focus on the responses of the Earth's magnetosphere to positive/negative impulses of solar wind dynamic pressure, and positive-negative impulse pairs. The simulation results show that the ULF waves excited by positive and negative impulse have the same amplitude and frequency, with 180A degrees difference in phase, if the amplitude and durations of the input impulses are the same. In addition, it is found that Field Line Resonances (FLRs) occur at certain L-shell regions of the Earth's magnetosphere after the impact of different positive-negative impulse pairs, which appear to be related to the duration of the impulses and the time interval between the sequential impulses. Another result is that the energy from the solar wind could be transported deeper into the inner magnetosphere by an impulse pair than by a single pulse impact. The results presented in this paper could help us to better understand how energy is transported from solar wind to the Earth's magnetosphere via ULF waves. Also, these results provide some new clues to understanding of how energetic particles in the inner magnetosphere response to different kinds of solar wind pressure impulse impacts including interplanetary shocks.

4 Radiation Belt, Ring Current and Plasmasphere

Li *et al.*[14] proposed the total flux variation of the entire outer zone relativistic electrons to describe the final effects of storms/substorms on changing the entire outer zone relativistic electron population. The total flux of the relativistic electrons is the summation of their omnidirectional integral fluxes over the entire outer zone. By analyzing the total flux variations of relativistic electrons in the entire outer zone during about 18 storms from August 1990 to March 1991, this paper investigates the statistical relationships between the total flux variations of the entire outer zone relativistic electrons and the intensities of storms/substorms. The statistical results indicate that the primary impact of a storm development is the net loss of relativistic electrons from the entire outer zone via the main phase losses of relativistic electrons, whereas the continuous intense substorm activity (average $AE > 200$ nT) can lead to the net increases of the relativistic electrons in the entire outer zone. Furthermore, the more intense the substorm activity, the larger the increases of the relativistic electrons, indicating that the continuous intense substorm activity can effectively supply relativistic electrons for the entire outer zone. Since the net increases of the relativistic electrons usually occur during the continuous intense substorm activity, the effective acceleration of the relativistic electron is correlated with the continuous intense substorm activity, *e.g.*, the stochastic acceleration of electron by whistler mode chorus waves.

Xiao *et al.*[15] utilized a recently introduced relativistic Kappa-Type (KT) distribution function to model the omnidirectional differential flux of energetic electrons observed by the SOPA instrument on board the 1989-046 and LANL-01A satellites at geosynchronous orbit. They derive a useful correlation between the differential flux and the distribution of particles which can directly offer those best fitting parameters (*e.g.*, the number density N, the thermal characteristic speed q and the spectral index k) strongly associated with evaluation of the electromagnetic wave instability. They adopt the assumption of a nearly isotropic Pitch Angle Distribution (PAD) and the typical LMFIT function in the program IDL to perform a non-linear least squared fitting, and find that the new KT distribution fits well with the observed data during different universal times both in the lower and higher energies. They also carry out the direct comparisons with the generalized Lorentzian (Kappa) distribution and find that kappa distribu-

tion fits well with observational data at the relatively lower energies but display deviations at higher energies, typically above hundreds of keV. Furthermore, the fitting spectral index k basically takes 4, 5 or 6 while the fitting parameters N and q are quite different due to different differential fluxes of electrons at different universal times. These results, which are applied to the case of a nearly isotropic PAD, demonstrate that the particle flux satisfies the power law not only at the lower energies but also at the relativistic energies, and the new KT distribution may present valuable insights into the dynamical features in those space plasmas (*e.g.*, the Earth's outer radiation belts and the inner Jovian magnetosphere) where highly energetic particles exist.

Fu *et al.*[16] investigated the nightside to dayside evolution of the inner magnetosphere: Imager for Magnetopause to Aurora Global Exploration Radio Plasma Imager observations. It took about 12 h for the IMAGE satellite to fly from the outbound pass to inbound pass of every inner magnetosphere crossing. This provides a unique opportunity to study the nightside to dayside evolution of the corotating inner magnetosphere when the outbound pass is in the nighttime while the inbound pass is in the daytime because a flux tube observed on the nightside may be observed again on the dayside in such situation. The differences between the two observations may be caused by the evolution of the flux tube. By analyzing both the passive and active sounding measurements from the IMAGE Radio Plasma Imager, they study two cases concerning this evolution. One, under a quiet geomagnetic condition, shows a typical evolution process during which the plasmapause was observed on both the nightside and the dayside. The other, during the recovery phase of a magnetic storm, shows a different inner magnetospheric structure in which the distinct plasmapause observed on the nightside becomes unidentifiable on the dayside as the density in the nearly empty nightside plasma trough increases to a level similar to that of the plasmasphere. It is shown that the evolutions of the inner magnetosphere in both cases were primarily controlled by the fast plasma refilling of the flux tubes from the ionosphere as the flux tubes drift from the nightside to the dayside. In the former case the fast refilling was confined inside $L = 6.3$, while in the latter case the fast refilling extended to at least $L = 10$. The present observations provide an example for fast refilling as a possible cause of the smooth density transition from the plasmasphere to the subauroral region and demonstrate the importance of the plasmasphere-ionosphere coupling in controlling the structures of the inner magnetosphere.

Li *et al.*[17] tried to establish a global quasi-linear diffusion model of electrons by using the whistler-mode wave amplitude distribution model, the electron density distribution model and the IGRF10 magnetic field model in $1 < L < 7$ region. The numerical results reveal that the variation of plasmapause location changes the electron loss region controlled by whistler-mode hiss and acceleration region controlled by whistler-mode chorus through changing electron density and wave intensity under different geomagnetic conditions. The variation of the electron loss region is consistent with the variation of the slot region, and meanwhile the variation of the electron acceleration region is consistent with the variation of the outer radiation belt, suggesting that variations of electron diffusion regions by whistler-mode waves cause the structure-variations (including size and spatial location) of the slot region and the outer radiation belt. During the recovery phase of a great storm, for electrons with certain energy, as their loss region controlled by hiss disappears, the inner radiation belt may connect with the outer radiation belt together completely.

Su *et al.*[18] constructed a three-dimensional realistic plasma trough electron density model (particularly a field-aligned density variation model) following the previous works. They examine the evolution of energetic electrons in the outer radiation belt at locations $L = 4.5$ and $L = 6.0$ with and without incorporation of electron density variation along magnetic field lines. Numerical calculation shows that neglect of the density variation along magnetic field lines generally results in overestimates of relativistic electrons Phase Space Density (PSD) due to an underestimate of the plasma parameter $f_{\rm pe}/f_{\rm ce}$ along the field lines. Particularly, the overestimates of PSDs due to neglecting field-aligned density variation are found to increase with kinetic energy E_k and L increasing. At

$L = 4.5$, maximum overestimates of PSDs over all the pitch angles are found to be by a factor of −1.5, 2.1, and 4.7 for energies of 1.0, 2.0, and 3.0 MeV in 2 days. At $L = 6.0$, maximum overestimates of PSDs over all the pitch angles are found to be by a factor of −1.5, 18, and 47 for energies of 1.0, 2.0, and 3.0 MeV in 2 days. This result suggests that incorporation of a field-aligned density variation model is very important to evaluate cyclotron wave-particle interaction in the outer radiation belt.

Xiao *et al.*[19] develop a new code which uses a hybrid finite difference (HFD) method to solve a 2-D bounce-averaged energy pitch angle diffusion equation in the outer radiation belts. They implement the numerical algorithm by adopting a split operator technique, an implicit scheme for dealing with diagonal diffusion coefficients, and an alternative direction implicit scheme for off-diagonal (or cross) diffusion coefficients. They show that their code HFD can successfully overcome the unstable problem when the large and rapidly varying cross diffusion coefficients are included. Particularly, they examine whether resonant interactions with obliquely propagated whistler mode chorus and hiss waves result in a net acceleration or loss of relativistic electrons in the outer radiation belt $L = 4.5$. Numerical simulations show that chorus waves can yield significant acceleration of relativistic electrons, while hiss waves are primarily responsible for scattering equatorially mirroring electrons toward the loss cone.

5 Magnetic Structure and Current System in the Magnetosphere

The equivalent ionospheric electric currents in the polar region mainly consist of the DP1 and DP2 systems. The former involves a westward electrojet around midnight, while the later involves a two-cell system with foci on the morningside and eveningside, respectively. In space weather prediction and nowcasting, sophisticated models of the polar currents are needed, but concise and convenient models are also useful to predict or nowcast the principal characteristics of the current systems, such as intensity and position. Xu *et al.*[20] propose a "key points model" for outlining the basic features of the polar region current system for different disturbance levels. The "Key Points model" (or KP model) includes six key points of the current system: the centers of two DP2 cells, the maximum densities of the eastward and westward electrojets, and the maximum densities of the northward and southward currents. Each of six key points is described by three parameters: intensity, local time, and latitude. The *AE*-dependences of the 18 parameters are deduced from the equivalent current systems for every 5 min during a 2-d period (18–19 March 1978). The KP model reveals systematic variations of the current systems. When *AE* increases, the currents and the current densities are simultaneously enhanced linearly, and most of the key points concentrate towards midnight. In addition, when *AE* increases, the key points K_2 and K_4 for the evening current cell move equatorward, while the key points K_1 and K_3 for morning cell move poleward.

Wang *et al.*[21] performed field-aligned currents in the varying northward and dusk ward IMF with nonzero dipole tilt by SWMF simulation. Their study concentrates on the FACs distribution for the varying northward and duskward Interplanetary Magnetic Field (IMF) conditions when the dipole tilt is nonzero. A global MHD simulation (the Space Weather Modeling Framework, SWMF) has been used to perform this study. Hemispheric asymmetry of the time evolution of northward IMF B_z (NBZ) FACs is found. As the IMF changes from strictly northward to duskward, NBZ FACs shift counterclockwise in both summer and winter hemispheres. However, in the winter hemisphere, the counterclockwise rotation prohibits the duskward NBZ FACs from evolving into the midday R_1 FACs. The midday R_1 FACs seem to be an intrusion of dawnside R_1 FACs. In the summer hemisphere, the NBZ FACs can evolve into the DPY FACs, consisting of the midday R_0 and R_1 FACs, after the counterclockwise rotation. The hemispheric asymmetry is due to the fact that the dipole tilt favors more reconnection between the IMF and the summer magnetosphere. When mapping the NBZ and DPY FACs into the magnetosphere it is found that the NBZ currents are located on both open and closed field lines, irrespective of the IMF direction. For the DPY FACs the hemispheric asymmetry

emerges: the midday R_1 FACs and a small part of R_0 FACs are on closed field lines in the winter hemisphere, while a small part of the midday R_1 FACs and all the R_0 FACs are on open field lines in the summer hemisphere. Both IMF By and dipole tilt cause the polar cap hemispheric and local time asymmetric. When the IMF is northward, the summer polar cap is closed on the nightside while the winter polar cap is open. The polar cap boundary tends to move equatorward as the IMF rotates from northward to duskward, except in the summer hemisphere, the polar cap on the dawnside shifts poleward when the clock angle is less than 10°. The further poleward displacement of the polar cap boundary on one oval side is caused by the twist of the tail plasma sheet, which is in accordance with the changing open field lines topology in the magnetotail.

6 Geomagnetic Field and Auroras

Han *et al.*[22] took advantage of high time-resolution (1 s) geomagnetic field measurements obtained at low-latitude stations to investigate frequency differences of Pi2 pulsations between the dayside and the nightside. Firstly, they examined two Pi2 cases globally observed by multiple ground stations and found that the dominant frequency peaks at the dayside showed latitudinal dependence, *i.e.*, the higher (lower) frequency peak was predominant at lower (higher) latitude. They also noticed that the dominant Pi2 frequency on the nightside was apparently higher than that on the dayside. They argue that the multiple frequency peaks observed on the ground are harmonics of a plasmaspheric Cavity Resonance Mode (CRM) and that the latitudinal dependence of the dominant frequency peaks may result from the energy coupling between the CRM and Field Line Resonance (FLR) occurred in the near Earth space. They also argue that the frequency difference between the dayside and the nightside could be caused by the reason that a higher harmonic was observed in the nightside plasmasphere but was not effectively observed in the dayside. In addition, they statistically examined 829 Pi2 events that were simultaneously re-corded at Kakioka (KAK, Maglat=27.2°) and Jicamarca (JIC, Maglat=0.0°), the two stations separated by about 10 h in Local Time (LT) and one of them (JIC) is located at the dip equator. They found that the Pi2 frequency observed at KAK on the nightside was higher than that observed at JIC on the dayside on average. After investigating the occurrence histogram of the frequency difference ($\Delta f = f_{\mathrm{JIC}} - f_{\mathrm{KAK}}$) for the events simultaneously observed at KAK and JIC, they found that close to half of the events had the identical frequency ($|\Delta f| < 1.0$ mHz). The statistical results are consistent with the facts reflected by case studies.

The waveform of geomagnetic Sudden Commencement (SC) on the ground depends on both latitude and Local Time (LT). Using high-resolution (1 s) geomagnetic field measurements obtained at Jicamarca (JIC, Maglat = 0.0°) from 1998 to 2005, Han *et al.*[23] examined the waveforms of 188 SC events and found that some of the SCs observed at nighttime (approx. 22:00–05:00 LT) and dawn time (approx. 05:00–07:00 LT) had a common observational feature, *i.e.*, a positive impulse always appeared at the beginning of the main impulse of the SC, which led to these events show Preliminary Positive Impulse (PPI) or 'Stepwise' structure in the waveforms. In particular, the occurrence rate of the PPI/Stepwise events at the dawn time was clearly higher than that at the nighttime. This is the first complete report of this observational feature for the SCs observed at the dip equator. Based on a comparison of our observations with the previously proposed model calculation of Kikuchi *et al.*[30], they suggest that the PPI/Stepwise events observed at the dawn-time dip equator reflect the effects of the Ionospheric Currents (ICs) and Field-Aligned Currents (FACs). They therefore argue that this observational result provides evidence for the validity of the model calculation.

Hu *et al.*[24] used the data acquired from three-wavelength (427.8, 557.7 and 630.0 nm) all-sky imagers (ASIs) at Yellow River Station (YRS) in Ny-Ålesund, Svalbard, to examine the synoptic distribution of dayside aurora. The results demonstrate that the Maximum Emission Regions (MERs) at each wavelength are all located in the postnoon sector, but have rather different Magnetic Local Time (MLT) distributions from each other. The so-called 15 MLT "hot spot" is the overlapping region of the MERs at

three wavelengths, and the prenoon "warm spot" is characterized uniquely by an increase of emissions at the 557.7 nm wavelength. The detailed dayside auroral spectra and morphology as a function of MLT are discussed.

7 Space Plasma

Previous multi-dimensional particle simulations have shown that electron phase-holes can be formed during the nonlinear evolution of bi-stream instability. In these holes, the parallel cut of the parallel electric field ($E_\parallel$) has bipolar structures while the parallel cut of the perpendicular electric field ($E_\perp$) has unipolar structures. Lu *et al.*[25], two-dimensional (2D) electrostatic particle-in-cell simulations are performed to investigate the evolution of $E_\parallel$ in such electron holes for different plasma conditions, and the generation mechanism of the unipolar structures of $E_\perp$ is also discussed. The electrons trapped in electron holes bounce in the parallel direction, which leads to transverse instability. At the same time, they gyrate in the background magnetic field, which tends to stabilize electron holes. In this way, the trapped electrons are forced to accumulate locally, and the charge density has variations along the perpendicular direction inside the electron holes. The balance between these two effects leads to the following results: in weakly magnetized plasma ($\Omega_\mathrm{e} < \omega_\mathrm{pe}$, but Ω_e is comparable to ω_pe Where Ω_e and ω_pe are the electron cyclotron frequency and electron plasma frequency, respectively), electron holes have two-dimensional structures (isolated along both the parallel and perpendicular directions). Within such holes the parallel cut of $E_\perp$ has unipolar structures. In strongly magnetized plasma ($\Omega_\mathrm{e} > \omega_\mathrm{pe}$), electron holes have one-dimensional structures along the direction perpendicular to the background magnetic field within which a series of islands (with alternate positive and negative $E_\perp$) develop because of the variations of the charge density along the perpendicular direction. Therefore one recovers that a parallel cut of $E_\perp$ has unipolar structures at the location of the holes. Present results show that the unipolar structure of $E_\perp$ in electron holes is attributed to the balance between the electron transverse instability and the stabilization of the background magnetic field. The unipolar structures of $E_\perp$ in electron holes last for hundreds to thousands of electron plasma periods. They are destroyed and the streaked structures are formed in the whole simulation domain after the electrostatic whistler waves are excited and have sufficiently large amplitude. The influences of the initial perpendicular thermal velocity of electrons (*via* temperature anisotropy) and the drift speed of electron beam on the structures of $E_\perp$ are also analyzed in details. At last, the relevance between our simulation results and the unipolar structures of the parallel cut of $E_\perp$ observed in the auroral region is discussed.

Particle-in-cell simulations evidenced that supercritical, quasi-perpendicular shocks are non-stationary and may suffer a self-reformation on the ion gyro scale. Yang *et al.*[26] investigate the evolution of the electric field at a non-stationary, supercritical perpendicular shock. The contributions of the ion Lorentz, Hall, and electron pressure terms to the electric field are analyzed. During the evolution of the perpendicular shock, a new ramp may be formed in front of the old ramp, and its amplitude becomes larger and larger. At last, the new ramp exceeds the old one, and such a non-stationary process can be formed periodically. When the new ramp begins to be formed in front of the old ramp, the Hall term becomes more and more important. The electric field E_x is dominated by the Hall term when the new ramp exceeds the old one. The significance of the evolution of the electric field on shock acceleration is also discussed.

Satellite observations clearly reveal that superthermal electrons in space plasma generally possess a pronounced non-Maxwellian distribution that can be well modeled by a κ distribution. Lu *et al.* [27] performed one-dimensional (1-D) particle-in-cell simulations to investigate the evolution of whistler waves driven by superthermal electrons with a typical κ distribution in the presence of a cold plasma population. The results obtained from the linear theory are first confirmed: with the increase of the spectral index κ for the κ distribution, the linear growth rate of the excited waves increases and instability threshold for the temperature anisotropy ($A = T_\perp/T_\parallel - 1$) decreases. Then they further find that with the increase of κ,

the fluctuating magnetic field energy density at the saturation stage also increases. Therefore, from both the linear growth rate and the fluctuating magnetic field energy density at the saturation stage, they can find that a bi-Maxwellian distribution ($\kappa \to \infty$) overestimates the importance of whistler waves, since the observed value of κ lies in the range $2 \leqslant \kappa \leqslant 6$. They also find that the κ values of the electron distributions become smaller with the excitation of the whistler waves.

Driven by a waveform inflow, multiple X line reconnection is initiated in a long current layer, and the plasmoids are bound between two neighboring reconnection sites. Liu *et al.*[28] investigate the behaviors of the plasmoid-like structures in the absence and presence of an initial guide field B_{y0} normalized by B_0 (B_0 is the initial intensity of B_x field at the top and bottom boundaries of the simulation domain) using a Hall Magnetohydrodynamic (MHD) code. For the case with $B_{y0} = 0$ the profiles of the out-of-plane B_y component are the bipolar signature or the bipolar wavelike signature which is caused by Hall effect and independent of the external mechanism. Such B_y features are in line with the observed signature of a closed-loop-like plasmoid in the magnetotail. The bipolar and fluctuation signatures of B_y have an asymmetric feature in the presence of a small $B_{y0}(= 0.1)$, and the B_y profile becomes a positive signature as B_{y0} reaches or exceeds 0.3. In the case of $B_{y0} = 0.5$, B_y a bulge appears in the B_y signature when the enhanced B_y regions caused by Hall effect take place in the plasmoid. The B_y bulge evolves into a peaking signature, whose maximum is quickly raised and approaches the lobe magnetic field strength. Such a significant enhancement of the B_y component in the central region of the plasmoid might be representative of the observed strong core field in the magnetic flux rope. The present results indicate the following implications: (1) Hall effect and a preexisting cross-tail component B_y are two important factors controlling the occurrence of various plasmoid-like structures in the magnetotail. (2) In the later phase the nonlinear interaction between Hall effect and the B_y flux added by the plasma inflow makes a most important contribution to the growth of the core B_y field.

A three dimensional Hall MHD simulation is carried out by Zhang *et al.*[29] to study roles of initial current carrier on the topology of magnetic field, on the generation and distribution of FACs (Field Aligned Currents) and on the appearance of Alfvén waves. With consideration of contribution of ions on initial current, the topology of resulted magnetic fields turns to more complex. In some cases, it is found that not only the traditional B_y quadrupole structure but also a reversal B_y quadrupole structure is presented in the simulation box, which can explain the satellite observed features near the diffusion region that is inconsistent to the Hall MHD theory with the total initial current carried by electrons. Several other interesting features are also emerged. First, motions of electrons and ions are decoupled from each other in the small plasma region (Hall effect region) with a scale comparable with the ion inertial length or ion skin depth $d_{\rm i} = c/\Omega_{\rm p}$. In the non-Hall effect region, the global magnetic structure is shifted in $+y$ direction under the influence of ions with initial y directional motion. However, in the Hall effect region, magnetic field lines are bent in $-y$ direction, mainly controlled by the motion of electrons and B_y is generated. Second, FACs $\left(J_{||} = \left[-B_y\dfrac{\partial B_z}{\partial x} + B_z\dfrac{\partial B_y}{\partial x} + O(\varepsilon^2)\right]\Big/B\right)$ emerge as a result of B_y. Compared with the prior Hall MHD simulation results, the generated FACs shift in $+y$ direction as well as the dawn-dusk symmetry is broken. Third, electron and ion Walén relation in Hall plasma is $A_{\rm e} \times A_{\rm i} = 1$. Here, $A_{\rm e} \equiv \Omega_{\rm e||}/\Omega_{\rm A||}$ and $A_i \equiv \Omega_{\rm i||}/\Omega_{\rm A||}$ are the Walén coefficients of ions and electrons, respectively, $\Omega_{\rm e\|}$, $\Omega_{\rm i||}$ and $\Omega_{\rm A||}$ are the electron, ion and Alfven parallel vorticities. In our simulation, $A_{\rm i} \approx 0.76$, $A_{\rm e} \approx 1.36$, $A_{\rm i} \times A_{\rm e} \approx 1.03$, which is consistent with the Walén relation in Hall plasma, indicate the presence of Alfvén wave.

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