Magnetospheric Physics in China: 2010—2011

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Abstract

In the past two years, many progresses are made in magnetospheric physics by using either the data of Double Star Program, Cluster and THEMIS missions, or by computer simulations. This paper briefly reviews these works based on papers selected from the 80 publications from April 2010 to April 2011. The subjects covered various sub-branches of magnetospheric physics, including geomagnetic storm, magnetospheric substorm, *etc*.

1 Geomagnetic Storms

Lu *et al*. compared ion distributions retrieved from ENA images of the ring current and contemporaneous, multipoint ion measurements recorded in situ during the major magnetic storm of 15 May, 2005[1]. On 20 January 2005, a coronal mass ejection arrived at the magnetopause at 17:12 UT, 21 January, and produced a strong compression pressure pulse. Enhanced magnetospheric activity was stimulated. A magnetic storm from ~17:12 UT, 21 January, reached minimum *Dst* ≈−101 nT at 06:00 UT, 22 January, and its recovery phase endured until 27 January. ENA data from DSP and THEMIS indicate that the ring current experienced a deep injection of H^+ and O^+ ions at 18:30 UT when IMF B_z was oriented southward. At this time, the ring current was strongly asymmetric, although later it became more symmetric. The B_z turned northward at 19:46 UT. From 02:24 to 06:12 UT on 22 January, B_z fluctuated such that it intermittently pointed southward (±10 nT). The moderate but extended response of the magnetosphere to the strong pressure pulse is explained by a slow evolution in the orientation of B_z under conditions of enhanced plasma sheet density. Modeling of dynamical parameters that represent various current systems that contributed to *Dst* revealed their individual characteristics. The changing geomagnetic field was also modeled. Comparisons with ENA data show that early asymmetric enhancements recorded in hydrogen and oxygen were accompanied by intensified external current systems that produced a magnetic field related compression of the magnetosphere. The gradual reduction in ring current asymmetry was complemented by the largely symmetrical configuration displayed by the corresponding, still intensified, modeled magnetic field.

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*. use the NARX neural network for the first time to predict SYM-*H* index from Solar Wind (SW) and IMF parameters[2]. In 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 are used to train the network and the other 6 samples for test. Additionally, the NARX prediction model is 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 superstorm using Geotail and OMNI data at 1AU, respectively. Five interplanetary parameters of IMF B_z, B_y and total B components along with proton density and velocity of solar wind are 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 min. 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.

Geomagnetic storm intensity, as measured by the *Dst* (SYM-*H*) index, shows no limit as the solar wind dawn-to-dusk electric field increases. Li *et al*. show that the magnetopause around noon erodes earthward with increasing storm intensity[3]. The panoramic geosynchronous B_z signatures for the magnetic storm groups with different intensity are differ significantly from each other. For superstorms with SYM-*H*⩽−300 nT, the magnetopause around noon erodes to inside the geosynchronous orbit, which causes the B_z reversal near local noon. The necessary conditions for superstorms with SYM-*H*⩽−300 nT to occur include the following: (1) interplanetary magnetic field (IMF) $B_z < -27$ nT lasts for at least about 1 h; (2) solar wind dynamic pressure, P_d>12 nPa; (3) the projected interplanetary electric field, $E_{K\text{-}L}$>30 mV·m^{-1}.

To identify which magnetospheric current system contributes the most to the SYM-*H* index during magnetic storms, Li *et al*.[4] perform a statistical analysis of 299 magnetic storms from 1996 to 2006 and investigated the distribution of the *H* depressions with Magnetic Local times (MLT), by using data from 25 geomagnetic stations distributed almost uniformly in magnetic longitudes over magnetic latitudes ranging from 9° to 45°. As expected, a significant dawn-dusk asymmetry of *H* depression during the storm main phase and early recovery phase reveals the importance of the partial ring current during magnetic storm processes. The location, evolution, and quantitative contribution of the partial ring current during magnetic storms with different intensities are all further obtained. The partial ring current locates in the dusk sector, peaking in 18:00–20:00 MLT. It forms in the early main phase, increases gradually until the SYM-*H* index reaches its minimum, and then quickly decreases in the recovery phase. The contribution of the partial ring current weakens gradually as the storm intensity increases. For moderate (−100 <SYM-*H*⩽−50 nT) and intense (−300 < SYM-*H*⩽ −100 nT) storms, the partial ring current is the predominant contributor during the main phase. However, the partial ring current is no longer the predominant contributor for the super storms with SYM-*H*⩽−300 nT, which may suggest the saturation of the partial ring current under extreme solar wind conditions.

Yuan *et al*.[5] present the precipitation characteristic of energetic particles and the influence on the sub-ionosphere in the Storm Enhanced Density (SED) plume in the event of the geomagnetic storm during March 31, 2001. With observations of the NOAA16 satellite, the peak of precipitating electron flux was located near the TEC peak in region of a SED plume recognized on two dimensional GPS TEC maps. On the other hand, the peak of precipitating energetic proton flux was observed in the outer boundary of the SED plume. Those precipitations were associated with energetic ions/electrons injected into Ring Currents (RC) caused by a sequence of substorms. When the Digisonde at Millstone Hill was located in the SED plume, the minimum frequency of ionogram echoes (f_{min}) was observed to keep a high level. Considering the SED plume as a signature of a plasmaspheric drainage plume, the precipitation of energetic electrons is attributed to the RC-ELF hiss interaction in the plasmaspheric plume. Calculations of a simple sub-ionospheric model demonstrate that those energetic electrons can precipitate into the sub-ionosphere and cause sub-ionospheric ionization enhancements in the SED plume. As a result, the f_{min} observed by the Digisonde in the SED plume was kept at a high level. Therefore, the paper provides direct evidences that precipitating energetic RC electrons play a significant role in the coupling between magnetosphere and sub-ionosphere in SED plumes.

2 Magnetospheric Substorms

Cao *et al*.[6] use the plasma data from Cluster and TC-1 and geomagnetic data to study the geomagnetic signatures of the current wedge produced by fast-flow braking in the plasma sheet. The three fast flows studied occurred in a very quiet background and were accompanied by no or weak particle injections, thus avoiding the influences from other disturbances. All the geomagnetic signatures of a substorm current wedge can be found in the geomagnetic signatures of a current system produced by the braking of fast flows, indicating that the fast flows can produce a complete current wedge which contains post-midnight downward and pre-midnight upward field-aligned currents, as well as a westward electrojet. The Pi2 precursors exist not only at high latitudes but also at midlatitudes. The starting times of midlatitude Pi2 precursors can be identified more precisely than those of high-latitude Pi2 precursors, providing a possible method to determine the starting time of fast flows in their source regions. The *AL* drop that a bursty bulk flow produces is proportional to its velocity and duration. In three cases, the *AL* drops are <100 nT. Because the *AE* increase of a typical substorm is >200 nT, whether a substorm can be triggered depends mainly on the conditions of the braking regions before fast flows. The observations of solar wind before the three fast flows suggest that it is difficult for the fast flows to trigger a substorm when the interplanetary magnetic field B_z of solar wind is weakly southward.

Ma *et al.*[7] study the occurrence rate, probability function of velocity and duration of earthward Bursty Bulk Flows (BBFs) in the Inner Plasma Sheet (IPS, β >0.5) using the data of Cluster in 2001 and 2002. The occurrence rate of earthward BBFs increases with distance from the Earth up to –19 R_e, which is in agreement with the previous observations of radial evolution of BBFs. About 54% of earthward BBFs in expansion phase have a velocity larger than 600 km·s^{-1}, whereas only 38% of earthward BBFs in growth and recovery phases have a velocity larger than 600 km·s^{-1}. The average velocity of earthward BBFs in expansion phase is 732 km/s, larger than those in growth phase (631 km/s) and recovery phase (617 km·s^{-1}). The durations of earthward BBFs basically decrease with the decrease of downtail distance from Earth due to the braking of earthward BBFs. The duration of earthward BBFs in expansion phase is larger than those in growth and recovery phases. The average durations in growth, expansion and recovery phases are respectively 49.3, 71.5 and 47.6 s. Therefore the ratios of transports of energy of earthward BBFs in growth, expansion and recovery phases can be estimated to be 0.51:1:0.47. Thus the earthward BBFs in the expansion phase have the largest capability of the transport of energy and can produce largest braking effects, such as inertial currents and auroral activities.

Using the data of three Cluster satellites, Cao *et al.*[8] compare the observations of BBF by single satellite with those by multi satellites. The results indicate that there exists remarkable difference between observations of BBF by single satellite and multi satellites. The observations of BBF by a single satellite depend on its position relative to the flow channel. The difference is caused by the localization characteristics of fast flows in the plasma sheet, and can lead to diverging views about substorm and causal relations among substorm phenomena.

A comprehensive examination of particle and wave data from multiple Thermal Emission Imaging System (THEMIS) satellites has been made of an electron injection structure in the magnetotail as it propagated earthward from −20 R_e to −11 R_e on 27 February 2009 by Deng *et al.*[9] The electron injection, which was closely associated with a dipolarization front and bursty bulk flows, occurred within a thin plasma boundary layer and had both perpendicular and parallel energization, with very little energy dispersion. The thin plasma boundary layer had a thickness comparable to the ion inertial length and displayed different plasma characteristics at different locations. Strong electromagnetic waves between the lower hybrid frequency and the electron gyrofrequency, as well as electrostatic waves up to the electron plasma frequency, were observed within the thin plasma boundary layers. The two outermost spacecraft at X = −20.1 R_e and X = −16.7 R_e detected intense whistler waves, most likely driven by an observed electron temperature anisotropy with $T_\perp/T_\parallel > 1$. Closer to Earth at X = −11.1 R_e, whistlers were not seen, consistent with the observed electron distribution having $T_\perp/T_\parallel < 1$. Near the electron injection region, nonlinear electrostatic structures such as electrostatic solitary waves and double layers were also observed. These nonlinear electrostatic structures can interact with the electron distribution and accelerate electrons; high energy distributions could be generated if the electrons encountered a large number of these structures. The observations show that non-ideal MHD, nonlinear and kinetic behavior is intrinsic to the electron injections with multi-scale coupling.

Zhou *et al.*[10] study a substorm ion injection event by using Magnetohydrodynamic (MHD) and Large-scale Kinetic (LSK) simulations. On 23 March 2007 the Time History of Events and Macroscale Interactions during Substorms (THEMIS) satellite constellation provided us with a unique opportunity to study a substorm injection in the region beyond geosynchronous orbit. On this date all five THEMIS spacecraft observed a substorm injection in the near-Earth magnetotail (X≈−7 R_e). They traced the trajectories of millions of protons coming from the solar wind in the time-dependent magnetic and electric fields obtained from a global MHD simulation of this substorm. The results reproduced the main features of the injection observed by THEMIS and Los Alamos National Laboratory (LANL) spacecraft, including the timing and dispersion properties of energetic flux increases. It was found that there were primarily two energization regions where particles gained energy during the substorm. One is around the near-Earth X line (X≈−20 R_e), where particles were mostly accelerated nonadiabatically by strong electric fields (both inductive and potential). The others were several stretched or localized regions between $X = -7\ R_e$ and $X = -18\ R_e$, where particles were accelerated in nonadiabatic motion under the potential electric field.

Chu *et al*.[11] study two substorms at 04:05 UT and 04:55 UT on February 26, 2008 with observations from THEMIS satellites and ground-based measurements of aurora and magnetic field. They show detailed features of the two substorms with extra attention to the first one, especially on the relationship between Magnetic Reconnection (MR) and substorm activities. In the earlier stage of each substorm, a first auroral intensification occurring 2–3 min after mid-tail MR is signified as an initial onset. The auroral expansion was short-lived, slow and very limited, which is similar to the characteristic of a pseudo breakup. A second auroral intensification and poleward expansion, which indicate the substorm major onset, occurred almost simultaneously with earthward flow and dipolarization in the near earth tail and other phenomenon related to substorm expansion phase. During the growth phase of two substorms, the polar cap open flux ψ kept increasing; while ψ reduced quickly during the substorm expansion and recovery phase. This variance of ψ indicates the evolution of two substorm expansion phases were related to the reconnections of tail lobe open field lines. Analysis of substorm activities revealed the two substorms were small ones; while MR rate indicated the MRs of the two substorms were weak. The observations suggest mid-tail MR initiates the pseudo breakup; earthward flow transports magnetic flux and energy to near earth and braking of the flow finally causes the formation of Substorm Current Wedge (SCW) and Current Disruption (CD) to generate dipolarization and auroral expansion, which they signify as substorm expansion onset. The results are consistent with the Near Earth Neutral Line (NENL) and Synthesis scenario of MR and CD (RCS) model, and supportive evidence of two step initiation scenario of substorms.

On 26 February 2008, the THEMIS satellites observed two substorms that occurred at about 04:05 UT and 04:55 UT. Pu *et al*.[12] 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 coincident 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.

Kan *et al*.[13] present a new M-I coupling model of substorm during southward IMF based on the THEMIS observations of two events on 1 March 2008. The first event (E-1) is classified as a pseudo-breakup: brightening of the onset arc preceded the first dipolarization onset by 71±3 s, but the breakup arcs faded within ~5 min without substantial poleward expansion and the dipolarization stopped and reversed to thinning. The second event (E-2) is identified as a substorm: brightening of the second onset arc preceded the second dipolarization onset by 80±3 s, leading to a full-scale expanding auroral bulge during the substorm expansion phase for ~20 min. The Alfvén travel time from the ionosphere to the dipolarization onset region is estimated at ~69.3 s in E-1; at ~80.3 s in E-2, which matched well with the observed time delay of the dipolarization onset after the brightening of the onset arc, respectively in E-1 and E-2. Brightening of the onset arc precedes the depolarization onset suggest that the onset arc brightening is caused by the intense upward field-aligned currents originating from the divergence of the Cowling electrojet in the ionosphere. The Cowling Electrojet Current Loop (CECL) is formed to close the field-aligned currents at all times. The closure current in the Alfvén wave front is anti-parallel to the cross-tail current. Dipolarization onset occurs when the Alfvén wave front incident on the near-Earth plasma sheet to disrupt the cross tail current in the dipolarization region. Slow MHD waves dominate the disruption of the cross-tail current in the depolarization region.

A research topic of great interest to the space physics community is the observation of plasmas flowing at hundreds of kilometers per second in the Earth's plasma sheet. Although considerable effort has been made to understand the source of fast-flowing plasmas, many questions remain unanswered about the mechanisms that produce high-speed flows and the effects they have on magnetospheric disturbances, especially their contributions to magnetospheric convection and substorms. Fu *et al*.[14] discuss briefly the history of high-speed flows and review the proposed mechanisms, signatures of high-speed flows in auroras and their interaction with the background plasma. They then summarize the relationships between high-speed flows and magnetic structures, discuss questions associated with substorms, and finally pose several important scientific questions that need to be addressed.

For the first time, a substorm event with double onsets is shown observationally by Liu *et al*.[15] under northward IMF condition in this study. Magnetic field data from ground stations and from geosynchronous satellite, and aurora data from IMAGE satellite are examined to study the substorm activity. The results show that the intensity and the spatial extent of the event are as large as those of typical substorms. Another interesting finding is that two expansion onsets seem to occur during the event. A possible mechanism for the two onsets was proposed. The energy source for the event was also discussed.

Liu *et al*.[16] study the difference, if any, between the response of the polar ionosphere to spontaneous substorms and that to trigger-associated substorms in terms of electrodynamic parameters including ionospheric current vectors, the electric potential, and the current function[17]. The results show that, in the first approximation, the ionospheric parameters for the two types of substorms are quite similar. It is therefore conceived that spontaneous substorms are not very different from trigger-associated substorms in the development of substorm processes in the magnetosphere-ionosphere system. They demonstrate, however, that spontaneous substorms seem to have a more clearly identifiable growth phase, whereas trigger-associated substorms have a more powerful unloading process. Changes in the current intensity and the electric potential drop across the polar cap at the recovery phase are also quite different from each other. Both the current intensity and the cross polar cap potential drop show a larger decrease at the recovery phase of trigger-associated substorms, but the potential drop decreases only slightly and the currents in the late morning sector are still strong for spontaneous substorms. They interpret these findings as an indication of the relative importance of the unloading process and the directly driven process in conjunction with the north-south polarity of the interplanetary magnetic field. There still exists a strong directly driven process at the recovery phase of spontaneous substorms. For trigger-associated substorms, however, both the directly driven process and the unloading process become weak after the peak time.

The magnetic field dipolarization in the vicinity of substorm onset and during substorm expansion phase in the period of 06:00–06:40 UT on 15 February 2008 is investigated by Duan *et al*.[17]with observations from multiple probes of THEMIS. It is found that the magnetic dipolarization at substorm onset (the onset time was about 06:14 UT.) was not accompanied by obvious magnetic disturbance and ion bulk speed variation. The magnetic dipolarizations taking place during the substorm expansion phase observed by P4 (−10.97, 2.04, −3.03) R_e and P3 (−11.32, 1.15, −3.10) R_e were mostly accompanied by high speed earthward ion bulk flow, but the magnetic dipolarizations occurring during the substorm expansion phase observed by P5 (−9.45, 1.07, −2.85) R_e were not accompanied by high speed earthward ion bulk flow. Before substorm onset THEMIS P3, P4, P5 all observed the B_x component fluctuation with a period of about 300 s. After substorm onset earthward high speed ion bulk flow and significant magnetic disturbances both occurred at P3 and P4 locations. These results indicate that there is no one-to-one relationship between the near-Earth magnetic dipolarization and the earthward ion bulk flow. In particular, the magnetic dipolarization occurring on the earthward side of the inner near-Earth plasma sheet is not accompanied by high speed earthward ion bulk flow. The dipolarization at substorm onset is a local and small scale phenomenon. There are multiple magnetic dipolarizations occurring during the substorm expansion phase. The dipolarization process is very complex and is not simply an MHD process. It is accompanied by some kinds of plasma instabilities, the plasma sheet azimuthal expansion not only by earthward ion bulk flow during substorm. A sharp increase of the *AE* index does not always give an accurate substorm onset time for substorm analysis.

On the basis of joint observations of TC-1 at about −12.5 R_e and Geotail at about −8 to −9 R_e in the near-Earth plasma sheet in the magnetotail, Duan *et al*. [18] study the plasma instabilities in the vicinity of substorm onset occurred at about 02:53:20 UT on September 28 2004 were investigated. The observation results indicate that (1) the location of substorm onset triggering region is small within the inner plasma sheet in the near-Earth magnetotail, (2) the lower-hybrid instability is incited in the substorm triggering region and the lower-hybrid waves with the quasi-perpendicular propagation occur during substorm onset, (3) the magnetic dipolarization and the magnetic disturbance in the outside of near-Earth plasma sheet are very weak during substorm onset. The multiple magnetic dipolarization with different feature took place during substorm onset and substorm expansion phase.

3 Magnetic Reconnection

With TC-1, Cluster, and Geotail observations, Zhang *et al*. statistically analyze earthward and tailward Convective Bursty Flows (CBFs) from 7 to 31 R_e to understand the distribution of X lines in the magnetotail[19]. They also analyze the effect of the solar wind condition on the X lines with ACE satellite observations. The statistical results show that the earthward CBFs can be distributed widely, from 7 to 31 R_e. TC-1 exploration shows that tailward CBFs with negative B_z in the central plasma sheet can seldom be observed inside 13 R_e. Tailward CBFs with negative B_z are mainly distributed outside 17 R_e, thus indicating that near-Earth X lines are most likely to occur outside 17

R_e. According to Cluster observations, the occurrence of tailward CBFs has a sudden increase from 17 to 19 R_e. Geotail observations show a slow increase of tailward CBFs outside 20 R_e. Both Cluster and Geotail observations indicate that the near-Earth X lines could occur inside 20 R_e. The solar wind condition has a significant effect on the occurrence of the X line in the magnetotail. The occurrence of the X line can increase under strong solar wind and decrease under weak solar wind.

Lu *et al*.[20] study the development of the structure of symmetric reconnection layer in the presence of a shear flow parallel to the anti-parallel magnetic field component by using a set of one-dimensional (1-D) Magnetohydrodynamic (MHD) equations. The Riemann problem is simulated through a second-order conservative TVD scheme, in conjunction with Roe's averages for the Riemann problem. The simulation results indicate that besides the MHD shocks and expansion waves, there exist some new small-scale structures in the reconnection layer. For the case of zero initial guide magnetic field (*i.e.*, B_{y0}=0), a pair of Intermediate Shock (IS) and Slow Shock (SS) is formed in the presence of the parallel shear flow. The critical velocity of initial shear flow V_{zc} is just the Alfven velocity in the inflow region. As $V_{z\infty}$ increases to the value larger than V_{zc}, a new Slow Expansion wave (SE) appears in the position of SS in the case $V_{z\infty} < V_{zc}$, and the one of the current density drops to zero. As plasma β increases, the out-flow region is widened. For $B_{y0}\neq 0$, a pair of SSs and an additional pair of Time-Dependent Intermediate Shocks (TDISs) are found to be present. Similar to the case of B_{y0}=0, there exists a critical velocity of initial shear flow V_{zc}. The value of V_{zc} is, however, smaller than the Alfven velocity of the inflow region. As plasma β increases, the velocities of SS and TDIS increase, and the out-flow region is widened. However, the velocity of downstream SS increases even faster, making the distance between SS and TDIS smaller. Consequently, the interaction between SS and TDIS in the case of high plasma β influences the property of direction rotation of magnetic field across TDIS. Thereby, a wedge in the hodogram of tangential magnetic field comes into being. When $\beta\to\infty$, TDISs disappear and the guide magnetic field becomes constant.

The tearing mode instability plays a key role in the triggering process of reconnection. The triggering collisionless tearing mode instability has been theoretically and numerically analyzed by many papers. However due to the difficulty to get observationally the wave number, it is still unknown if the tearing mode instability can be excited in an actual plasma sheet prior to reconnection onset. Using the data from four Cluster satellites prior to a magnetospheric reconnection event on 13 September 2002, Wei *et al*.[21] utilize the wave telescope technique to obtain the wave number which corresponding to peak of power spectral density. The wave length is about 18 R_e and consistent with previous theoretic and numerical results. After substituting the wave vector and other necessary parameters of observed current sheet into the triggering condition of tearing mode instability, they found that the near-Earth current sheet prior to reconnection is unstable to tearing mode.

A three-dimensional (3-D) global hybrid simulation is carried out by Pang *et al*.[22] for the generation and structure of magnetic reconnection in the magnetosheath because of the interaction of an interplanetary Tangential Discontinuity (TD) with the bow shock and magnetosphere. Runs are performed for solar wind TDs possessing different polarization senses of magnetic field (north-to-south or south-to-north from the leading to trailing side of the incident TD) and initial half-widths. Two-step compression processes are shown in the transmitted TD, including a "shock compression," as the TD passes through the shock followed by a subsequent "convective compression" while the TD is moving in the magnetosheath toward the magnetopause. In cases with a relatively thin solar wind TD, 3-D patchy reconnection is initiated in the transmitted TD, forming magnetosheath flux ropes. Differences between these flux ropes and those due to magnetopause reconnection are discussed. Multiple components of ion particles are present in the velocity distribution in the magnetosheath merging, accompanied by ion heating. For cases with a relatively wide initial TD, a dominant single X line appears in the subsolar magnetosheath after the transmitted TD is narrowed through the two-step compression process. Specifically, in the cases with a south-to-north field rotation across an incident thin TD, the magnetosheath flux ropes could re-reconnect with the closed geomagnetic field lines to generate a closed field line region with mixed magnetosheath and magnetospheric plasmas, which may contribute to the transport of solar wind plasma into the magnetospheric boundary layer.

Electrostatic Solitary Waves (ESWs) are observed in the vicinity of the magnetic null of the widely studied magnetic reconnection taking place at the near-Earth tail when current sheet becomes dramatic thinning during substorm time on 1 October 2001. Li *et al*.[23] use the Imada method for the 2-D reconnection model and study the characteristics of ESWs near the X-line region and the magnetic null points. The result shows that the amplitude of the observed ESWs in the vicinity of X-line region ranges from 0.1 $mV\cdot m^{-1}$ to 5 $mV\cdot m^{-1}$, and the amplitude is larger near the magnetic null points. The generation mechanism and the role of ESWs associated with magnetic reconnection are also discussed.

Magnetic reconnection is a crucial physical process in laboratory and astrophysical plasmas. Plasma waves are believed to provide the dissipation mechanism in magnetic reconnection. Huang *et al*.[24] analyze the properties of low-frequency waves in a magnetotail reconnection diffusion region with a small guide field and high β. Using the k-filtering method on the magnetic field data measured by Cluster spacecraft, they found that low-frequency waves in the diffusion region were highly oblique propagating mode. They compared the measured dispersion relation with theoretical ones calculated using the linear (hot) two-fluid and Vlasov-Maxwell theory. It is found that the observed waves in the diffusion region (with high plasma β) follow the dispersion relation of the Alfvén-Whistler wave mode. Comparisons with previous simulations and observational results are also discussed.

Previous theoretical and simulation studies have suggested that the anti-parallel and component re-connection can occur simultaneously on the dayside magnetopause. Certain observations have also been reported to support global conjunct pattern of magnetic reconnection. Wang *et al*. [25] show direct evidence for the conjunction of anti-parallel and component MR using coordinated observations of Double Star TC-1 and Cluster under the same IMF condition on 6 April, 2004. The global MR X-line configuration constructed is in good agreement with the “S-shape” model

Understanding the structure of the diffusion region of magnetic reconnection is crucial to pinpoint the mechanism of energy conversion from magnetic field to plasma. Characteristics of a diffusion region with guide field (*i.e.*, component reconnection) may be significantly different from those of a diffusion region without guide field (*i.e.*, antiparallel reconnection). Zhou *et al*.[26] attempt to understand the structure of a diffusion region with guide field by studying the density cavity along separatrix. They present an event in which a density cavity was detected by the Cluster spacecraft in a diffusion region in the presence of guide field. The cavity was located around the separatrix region on the southern hemisphere of the neutral sheet and earthward of the X-line and was coincident with strong magnetic field compression. The width of the cavity was on the ion inertial scale. This cavity contained a relatively strong antiparallel current, which was mainly contributed by parallel streaming electrons with energy of 1–10 keV. Enhancements of lower hybrid wave and electromagnetic whistler wave were observed inside the cavity. These waves are probably excited by parallel streaming electrons along separatrix via electron beam instability. Two-dimensional electromagnetic particle-in-cell simulation was employed to study the structure of the density cavity. The location and scale of the cavity and the signature of electric current and electron velocity are consistent with our observations. It is found that there was displacement between the position of electron density minimum and out-of-plane magnetic field maximum in reconnection with guide field. However, this displacement is much less than that in reconnection without guide field. There was no significant acceleration for electrons to reach energy larger than 30 keV at the cavity.

A sharp Dipolarization Front (DF) has recently been detected in the Earth’s magnetotail and is associated with complex kinetic effects. Zhou *et al*. [27] present one event where a tailward propagating negative DF (with B_z decreasing sharply to negative value) was observed near a reconnection region. The thickness of the negative DF is comparable with the local ion gyro-radius/inertial length. There is a strong field-aligned current at the front. Electromagnetic whistler wave enhancements are observed around the front, associated with counter-streaming electron beams. They further compare the features of the observed negative DF with the recent kinetic simulation results, as well as the Earthward propagating DFs observed by the THEMIS spacecraft.

On 21 Feb. 2009, THEMIS-C satellite observed the classical signal of magnetic flux rope at magnetotail of $X=-15.7R_e$. Zhang *et al*.[28] take the method of Grad-Shafranov reconstruction to investigate the characteristics and structure of magnetotail flux rope. The results give the characteristic physics parameters such as the invariant axis direction, the cross scale length, the magnetic flux in flux rope, etc. With no constraint from model on shape of the flux rope, they reconstruct the distribution of magnetic field and electric current density on the cross section of magnetic flux rope at magnetotail. Our results show that the magnetic field at the central region of magnetic flux rope can be described by force-free, while with the increase of radial distance, the fields display no force-free at the region where the magnetic fields deviate from the axial symmetric distribution.

The magnetic field in many regions of magnetosphere has a complex topological structure. As a parameter to measure the topological complexity, the concept of magnetic helicity is a useful tool in magnetospheric physics. Zhang *et al*.[29] present a case study of magnetic helicity in the Flux Rope (FR) in the near-Earth Plasma Sheet (PS) based on the in-situ observation from THEMIS for the first time. With the help of the Grad-Shafranov reconstruction technique, they determine the spatial distribution of magnetic field and evaluate the magnetic helicity in the flux rope. The conservation of magnetic helicity during multiple X-line reconnections and the transport of magnetic helicity between different magnetic field configurations are also discussed. The further application of helicity in magnetosphere would provide us more knowledge about the topologic property of the magnetic fields there and more attention should be paid to that.

While the Cluster spacecraft were located near the high-latitude magnetopause, between 10:10 and 10:40

UT on 16 January 2004, three typical Flux Transfer Event (FTE) signatures were observed [30]. During this interval, simultaneous and conjugated all-sky camera measurements, recorded at Yellow River Station, Svalbard, are available at 630.0 and 557.7 nm that show Poleward-Moving Auroral Forms (PMAFs), consistent with magnetic reconnection at the dayside magnetopause. Simultaneous FTEs seen at the magnetopause mainly move northward, but having duskward (eastward) and tailward velocity components, roughly consistent with the observed direction of motion of the PMAFs in all-sky images. Between the PMAFs, meridional keograms extracted from the all-sky images, show intervals of lower intensity aurora which migrate equatorward just before the PMAFs intensify. This is strong evidence for an equatorward eroding and poleward moving Open-Closed Boundary (OCB) associated with a variable magnetopause reconnection rate under variable IMF conditions. From the durations of the PMAFs they infer that the evolution time of FTEs is 5–11 minutes from its origin on the magnetopause to its addition to the polar cap.

A number of Flux Transfer Events (FTEs) were observed between 09:00 and 12:00 UT on 11 February 2004, during southward and dawnward IMF, while the Cluster spacecraft array moved outbound through the northern, high-altitude cusp and dayside high-latitude boundary layer, and the Double Star TC-1 spacecraft was crossing the dayside low-latitude magnetopause into the magnetosheath south of the ecliptic plane[31]. The Cluster array grazed the equatorial cusp boundary, observing reconnection-like mixing of magnetosheath and magnetospheric plasma populations. In an adjacent interval, TC-1 sampled a series of sometimes none standard FTEs, but also with mixed magnetosheath and magnetospheric plasma populations, near the magnetopause crossing and later showed additional (possibly turbulent) activity not characteristic of FTEs when it was situated deeper in the magnetosheath. The motion of these FTEs are analyzed in some detail to compare to simultaneous, poleward-moving plasma concentration enhancements recorded by EISCAT Svalbard Radar (ESR) and "Poleward-Moving Radar Auroral Forms" (PMRAFs) on the CUTLASS Finland and Kerguelen Super Dual Auroral Radar Network (SuperDARN) radar measurements. Conjugate SuperDARN observations show a predominantly two-cell convection pattern in the Northern and Southern Hemispheres. The results are consistent with the expected motion of reconnected magnetic flux tubes, arising from a predominantly sub-solar reconnection site. They are able to track north and south in closely adjacent intervals as well as to map to the corresponding ionospheric footprints of the implied flux tubes and demonstrate these are temporally correlated with clear ionospheric velocity enhancements, having northward (southward) and eastward (westward) convecting flow components in the Northern (Southern) Hemisphere. The durations of these enhancements might imply that the evolution time of the FTEs is about 18–22 minutes from their origin on magnetopause (at reconnection site) to their addition to the magnetotail lobe. However, the ionospheric response time in the Northern Hemisphere is about 2-4 minutes longer than the response time in the Southern Hemisphere.

4 Solar Wind-Magnetosphere-Ionosphere Couping

On 3 September 2009, the Time History of Events and Macroscale Interactions during substorms (THEMIs) satellites observed a significant intensification of chorus in response to the interplanetary shock in the Earth's dayside plasma trough. Fu *et al.* [32] analyze the wave-particle interaction and reveal that the chorus intensification can be caused by the gyroresonance between the chorus and the energetic electrons. When the electrons are scattered from resonance points to low-density region along the diffusion curves, a part of their energy can be lost and then transferred to amplify the chorus. During the compression of magnetosphere, the temperature anisotropy of electrons is enhanced. This makes the electron diffusion and chorus intensification very effective. The maximum growth rate after the shock is about 50% greater than that before the shock. The lower energy (15–25 keV) electrons contribute more to the growth of chorus due to the larger density gradient along the diffusion curve. The < 10 keV electrons are almost isotropic so they contribute little to the amplification of chorus. They investigate the free energy for the chorus intensification and find that it can be generated through the local betatron acceleration and radial diffusion processes. The local betatron acceleration results from the shock-induced compression of magnetosphere. The linear and nonlinear growth rates are also compared. They find the linear diffusion process works well for the present case.

During the interval from 06:15 to 07:30 UT on 24 August 2005, the Chinese TC-1 satellite observed the multiple responses of the near-Earth magnetotail to the combined changes in solar wind dynamic pressure and Interplanetary Magnetic Field (IMF)[33]. The magnetotail was highly compressed by a strong interplanetary shock because of the dynamic pressure enhancement (15 nPa), and the large shrinkage of magnetotail made a northern lobe and plasma mantle move inward to the position of the inbound TC-1 that was initially in the plasma sheet. Meanwhile, the dynamic pressure fluctuations (0.5–3 nPa) behind the shock drove the quasiperiodic oscillations of the magnetopause, lobe-mantle boundary, and geomagnetic field at the same frequencies: one dominant frequency was around 3 mHz and the other was around 5 mHz. The quasi-periodic oscillations of the lobe-mantle boundary caused the alternate entries of TC-1 into the northern lobe and the plasma mantle. In contrast to a single squeezed or deformed magnetotail by a solar wind discontinuity moving tailward, the compressed and oscillating magnetotail can better indicate the dynamic evolution of magnetotail when solar wind dynamic pressure increases and fluctuates remarkably, and the near-Earth magnetotail is quite sensitive even to some small changes in the solar wind dynamic pressure when it is highly compressed. Furthermore, it is found that a considerable amount of oxygen ions (O^+) appeared in the lobe after the southward turning of IMF.

How the solar wind affects the location of the magnetopause has been widely studied and excellent models of the magnetopause based on in situ observations in the solar wind and at the magnetopause have been established, while the careful insight into the responses of the magnetopause to the variations in the solar wind can still provide us some new information about the processes in space plasmas. The short distance from Cluster to TC-1 on 9 March 2004, between 06:10 and 08:10 UT, gives us a good opportunity to precisely monitor the responses of the magnetopause to the variations in the solar wind. On the basis of the combined observations between Cluster, TC-1, and Super DARN, Zhang *et al*.[34] analyze the magnetopause crossings associated with magnetopause motion or magnetic reconnection when the solar wind conditions have a series of variations. New results about the time delays for the propagation from the solar wind monitor to the magnetopause of the Interplanetary Magnetic Fields (IMF) and of the solar wind dynamic pressure, respectively, and the intrinsic time for reconnection onset at the magnetopause are obtained. The most important feature of the event is that the dynamic pressure and the IMF in the solar wind do not arrive at the magnetopause at the same time, which will direct us to find out how the variation in the solar wind dynamic pressure is transported from the bow shock to the magnetopause. Another significant feature is that this event presents a shorter intrinsic time, 2 min, for reconnection onset at the dayside magnetopause than that given by the previous work of Le *et al*. (1993) and Russell *et al*. (1997).

Geomagnetic perturbation is an important aspect to determine the capability of a 3-D MHD model in predicting space weather. Taking the substorm event of 8 March 2008 as an example, Wang *et al*.[35] compare the Equivalent Current Systems (ECS) in the ionosphere derived from the global PPMLR-MHD simulation model and the ground-based magnetic field observations using the KRM inversion algorithm. The evolution of ECS is utilized to give a global view of the temporal and spatial development of the magnetic fields on the ground. The PPMLR-MHD model has generally reproduced the main characters of the large-scale magnetic field variation on the ground. The magnetic latitude and local time distribution of the ECS is in reasonably agreement with the inversion results during the disturbed period. They hopefully consider the ECS to be a promising numerical forecast product of the global geomagnetic variation from a global 3-D MHD model in the future.

The magnetosphere is outermost layer of the geospace. Interaction of the solar wind with the magnetosphere is one of the key links among the space weather chain process from the Sun to Earth, thus becomes one of the key issues in space weather study. The characteristics of the geospace, including time-dependent, multiple components, and non-linearity, make the traditional analytic study very difficult. Numerical simulations, as new means to investigate the coupling system, have played an important role in recent decades. The global MHD simulation about the magnetosphere started in 1970s, and limited to 2-D initially. Since the intrinsic 3-D characters of the magnetosphere, 3-D MHD simulations thrived in 1980s. Wang *et al*.[36] briefly illustrates the characteristics of the 3-D global magnetosphere MHD simulations, and their current status. The framework of the 3-D global MHD magnetosphere simulation and its application to the interaction of interplanetary shocks with the magnetosphere, large-scale current systems, reconnection voltage and cross polar potential drop, K-H instability in the magnetopause *etc*. are presented.

Tang *et al*.[37] examine the effects of the ionospheric conductance on the intensification of the westward electrojet current in the ionosphere based on the Piecewise Parabolic Method with a Lagrangian Remap (PPMLR) global MHD simulation model. The ionospheric conductance is empirically linked to the plasma pressure in the plasma sheet. The simulation results are consistent with observations: When the Pedersen and Hall conductances are small, the ionospheric current shows a two-cell pattern; when the conductances increase and the ratio SH/SP$\geqslant$2, an intense westward electrojet appears in the midnight sector. This intense westward electrojet is the Cowling current driven by the induced southward electric field due to the blockage of the northward Hall current from closure in the equatorial plasma sheet. The simulation shows the development of the Cowling electrojet is essential to the intensification of the westward electrojet in the ionosphere.

Inspired by the fact that spacecraft at geosynchronous orbit may observe an increase or decrease in the magnetic field in the midnight sector caused by interplanetary Fast Forward Shocks (FFS), Sun *et al*.[38] perform global MHD simulations of the nightside magnetospheric magnetic field response to Interplanetary (IP) shocks. The model reveals that when a FFS sweeps over the magnetosphere, there exist mainly two regions: a positive response region caused by the compressive effect of the shock and a negative response region which is probably associated with the temporary enhancement of earthward convection in the nightside magnetosphere. IP shocks with larger upstream dynamic pressures have a higher probability of producing a decrease in B_z that can be observed in the midnight sector at geosynchronous orbit, and other solar wind parameters such as the Interplanetary Magnetic Field (IMF) B_z and IP shock speed do not seem to increase this probability. Nevertheless, the southward IMF B_z leads to a stronger and larger negative response region, and a higher IP shock speed results in stronger negative and positive response regions. Finally, a statistical survey of nightside geosynchronous B_z response to IP shocks between 1998 and 2005 is conducted to examine these model predictions.

Solar wind dynamic pressure (P_{dyn}) enhancements have been observed to cause large-scale auroral brightening. The mechanism for this kind of auroral brightening is still a topic of current space research. Using the global Piecewise Parabolic Method Lagrangian Remap (PPMLR)-MHD simulation model, Peng *et al*.[39] investigate three auroral brightening events caused by dynamic pressure enhancement under different Interplanetary Magnetic Field (IMF) conditions: (1) $B_z < 0$ and $B_y > 0$ on 11 August 2000, (2) $B_z < 0$ and $B_y < 0$ on 8 May 2001, and (3) $B_z \geq 0$ on 21 January 2005. They show that the auroral location depends on the IMF conditions. Under southward IMF conditions, when B_y is negative, the duskside aurora is located more equatorward at around 70° Magnetic Latitude (MLAT) for all magnetic local times; when B_y is positive, the duskside aurora can even reach beyond 80° MLAT. A smaller and more localized response is seen when the IMF B_z is nearly zero or northward, as shown in previous studies. Our simulation results are consistent with these observations, indicating that the observed aurora activities could be caused by solar wind dynamic pressure enhancements. The simulation results suggest that the enhancement of P_{dyn} can increase the ionospheric transpolar potential and the corresponding field-aligned currents, leading to the observed auroral brightening.

Standing Shock Waves (SSWs) are reported by Guo *et al*. to exist in the middle- and high-latitude magnetosheath through the global magnetohydrodynamic simulations[40]. There are two or one SSWs for constant northward (or southward) Interplanetary Magnetic Field (IMF); they extend into the magnetosheath region and further interact with the bow shock. Because of the extension of SSWs into the interplanetary space, especially when IMF turns southward, an indented bow shock emerges in front of the magnetosphere. The SSWs are excited by the indentations of the magnetopause in the super magnetosonic solar wind flows in the magnetosheath; for northward IMF, one of the indentations is located in the cusp region and the other corresponds to the neutral point in the tailward of the cusp; for southward IMF, the indentation simply locates in the cusp region. They examine the Rankine-Hugoniot relations across the shock fronts and find the numerical model results are consistent with theoretical predictions.

Observations show that the geosynchronous magnetic field in midnight sector sometimes decreases when an Interplanetary (IP) Fast Forward Shock (FFS) passes Earth, even though the magnetosphere is always compressed. Wang *et al*.[41] perform case studies of the response observed by the GOES spacecraft at geosynchronous orbit near midnight to two IP shocks passing Earth. One shock produces a decrease in B_z (a negative response) and the other an increase in B_z (a positive response). A global 3-D MHD code is run to reproduce the responses at geosynchronous orbit, and to further provide information on the initiation and development of B_z variations in the entire magnetosphere. The model reveals that when a FFS sweeps over the magnetosphere, there exist mainly two regions, a positive response region caused by the compressive effect of the shock and a negative response region which is probably associated with the temporary enhancement of earthward convection in the nightside magnetosphere. The spacecraft may observe an increase or decrease of the magnetic field depending on which region it is in. The numerical results reproduce the main characters of the geosynchronous magnetic field response to IP shocks for these two typical cases.

Interplanetary (IP) shocks disturb the magnetosphere-ionosphere system resulting in geosynchronous magnetic field changes and sudden impulses observed by ground-based magnetometers. Wang *et al*.[42] extend the implications of a previous statistical study and show that Sudden Impulses (SIs) can be used to estimate some parameters at the L_1 point and geosynchronous orbit, including the change of the square root of solar wind dynamic pressure across the shock and the associated geosynchronous magnetic field changes near the subsolar region. It should be pointed out that the relationship between magnetospheric field change and SIs amplitude and the solar wind dynamic pressure is not a single valued one, but a statistical relationship is useful in cases when interplanetary data are not available. Empirical formulae deduced from observations can be used to estimate certain IP shock characteristics and geosynchronous magnetic field changes from sudden impulse data observed on the ground, with the prediction efficiency as high as 90% and 86%, respectively. These estimates are useful for studying historic, pre-space era data or if the L_1 and geosynchronous data are not available at some future time.

Liu *et al*.[43] present A quantitative model about the location and Shape of Magnetopause (MP) in the noon-midnight meridian plane is given by analyzing the computing date from three-dimensional global MHD simulation of the magnetosphere. Data processing results show the function which was presented by Ref.[3] based on the satellite observational data can also be used to describe MP in noon-midnight meridian plane. The location and shape of the MP in the noon-midnight meridian plane are more complicated than those in the equatorial plane. Although the MP in cusp region is ignored, the location and shape of MP need still be fitted by two different curves. The dynamic pressure of the solar wind (D_P) and the north-south component of the interplanetary magnetic field (IMF B_z) are two main factors determining the size and shape of MP. While for northward IMF B_z, r_0 increases with increasing northward B_z; for southward IMF B_z, the standoff distance r_0 decreases with increasing southward IMF B_z. On the whole, r_0 is mainly affected by the dynamic pressure D_P, r_0 decreases with D_P increasing. The other variable α, the level of tail flaring, increases with southward IMF increasing, which means the magnetopause flares more strongly and more magnetic flux transfers from the dayside to the nightside. The value of arises slightly with D_P increasing, which implies that D_P also helps to some extent flux transfer from the dayside to the nightside.

As far as the role of the Interplanetary Magnetic Field (IMF) in the Solar wind-Magnetosphere-Ionosphere (SMI) coupling is concerned, the role of the IMF B_x has more or less been ignored. Recent studies have shown that the IMF B_x plays an important role in the geometry of the bow shock under low Alfvén Mach numbers. Using global MHD simulations, Peng *et al*.[44] presents a further examination of the effects of the IMF B_x on the geometry of the magnetopause, the ionospheric transpolar potential, and the magnetopause reconnection rate, which quantify the SMI coupling process, under low Alfvén Mach numbers. The role of the IMF B_x manifests itself in three aspects: (1) the magnetopause shifts toward either north or south, depending on whether the $B_x \cdot B_z$ is negative or positive, whereas the bow shock expands in the opposite direction; (2) during southward IMF, the magnetic merging line shifts northward (southward) on the day side and southward (northward) on the night side for $B_x > 0$ ($B_x < 0$); (3) both the ionospheric transpolar potential and the magnetopause reconnection rate decrease with increasing B_x, and the relative reduction may reach as high as 20% under extreme cases. The physical mechanism for this reduction is attributed to the change in the width of the magnetosheath, which is sensitive to the variation of B_x under low Alfvén Mach numbers.

Kan *et al*.[45] propose a quasi-steady nonlinear circuit model for the Solar Wind-Magnetosphere-Ionosphere (SW-M-I) coupling to study the observed saturation of polar cap potential. The oval conductance is shown to be a nonlinear circuit element since it increases with increasing dayside reconnection E field driving the proposed circuit. Oval conductance is produced by precipitating particles energized by enhanced sunward convection in the plasma sheet driven by reconnection at the dayside magnetopause and in the plasma sheet. The asymptotic saturation potential is shown to increase with (1) decreasing internal resistance of the dynamo region, (2) increasing length of dayside reconnection line, (3) increasing ratio of nightside to dayside reconnection potentials, and (4) increasing ratio of nightside to dayside internal resistances.

A constant dawn-dusk B_y component is set as an Interplanetary Magnetic Field (IMF) condition in our global MHD simulations to investigate the effects of IMF B_y on the closure of the Field-Aligned Current (FAC) in the magnetosphere. On the basis of the steady state magnetosphere results, Guo *et al*. [46] trace streamlines of FAC from the ionosphere to draw the global geometry of current streamlines in the magnetosphere. Unlike those cases in which the IMF is purely northward or southward, the introduction of the dominant IMF B_y significantly changes the topologies of the current streamlines. Cusp and mantle currents arise, and the symmetry of the FAC across the noon-night meridional plane breaks in the ionosphere. In addition to the self-closed currents in the Northern or Southern hemispheres, three more types of current streamlines connecting the two ionospheres are shown from the simulation results. The first current, including the cusp current, originates from the southern ionosphere and flows into the northern ionosphere. The second current, mainly the mantle current, and the tail current are connected to form a single current system, threading most of the magnetosphere along a spiral-like path and closing through the two lobes in the far magnetotail. The third current flowing out of the southern and into the northern ionosphere connects the two ionospheres by finally closing through the bow shock instead of the magnetopause. Quantitative results are presented and discussed for the four types of current streamlines and indicate that for the dominant IMF B_y conditions the bow shock current should be included among the magnetosphere-ionosphere current system.

The Kelvin-Helmholtz (K-H) instability is found to occur at the low-latitude magnetopause through global magnetohydrodynamic simulations during a period of northward interplanetary magnetic field[47]. The simulation results present the global picture of the nonlinear evolution of the K-H instability at the magnetopause. At the low-latitude boundary layer (within the latitude of about 30°), vortices are generated by the K-H instability at the dayside magnetopause and transported to the far distant magnetotail region along the flank of the magnetosphere; two modes of surface waves propagate along the inner and outer edge of the magnetopause boundary layer, respectively, from the initial point to the tail region; the wavelengths of the inner and outer modes are estimated to vary from 1 to 8 R_e as the longitude increases. The vortices are initiated at a longitude of about 28° relative to the Sun-Earth line in the equatorial plane, and their evolution along the magnetopause boundary is studied in detail. They present the characteristics of the inner and outer mode surface waves near the magnetopause boundary layer and find different behaviors of the fast-mode surface waves on the two sides of the magnetopause boundary: the variations of the density and the magnetic field strength of the quasi-fast mode waves are in phase on the magnetosphere side (inner mode), while they are out of phase on the magnetosheath-side (outer mode). The obtained period of the surface waves coincides with the generation period of the vortex at the dayside magnetopause, which is considered to be the intrinsic period of the magnetopause for the corresponding interplanetary condition.

Hu *et al.*[48] presents a brief summary of our recent work based on global MHD simulations of the Solar wind-Magnetosphere-Ionosphere (SMI) system with emphasis on the electrodynamic coupling in the system. The main conclusions obtained are summarized as follows. (1) As a main dynamo of the SMI system, the bow shock contributes to both region 1 Field-Aligned Current (FAC) and cross-tail current. Under strong interplanetary driving conditions and moderate Alfvén Mach numbers, the bow shock's contribution may exceed more than fifty percent of the total of either region 1 or cross-tail currents. (2) In terms of more than 100 simulation runs with due southward Interplanetary Magnetic Field (IMF), they have found a combined parameter *f*. Both the ionospheric transpolar potential and the magnetopause reconnection voltage vary linearly with *f* for small *f*, but saturate for large *f*. (3) The reconnection voltage is approximately fitted by sin 3/2 ($\theta_{\rm IMF}$ /2), where $\theta_{\rm IMF}$ is the IMF clock angle. The ionospheric transpolar potential, the voltage along the polar cap boundary, and the electric fields along the merging line however defined they may be respond differently to $\theta_{\rm IMF}$, so it is not justified to take them as substitutes for the reconnection voltage.

Geomagnetic Sudden Impulses (SI) observed at the dayside dip equator normally show a decrease and then an increase in the *H* magnetic field component, *i.e.*, a Preliminary Reverse Impulse (PRI) followed by a main impulse. Using global geomagnetic field measurements, Hen *et al.*[49] examine an unusual SI event observed at the dayside dip equator, which shows a clear precursor ~1 min before the PRI onset. The precursor was observed simultaneously at both the dayside dip equator and in the southern polar region but was not observed at all in the northern polar region. The global ground variations after the PRI onset were, however, consistent with a conventional SI model of the magnetospheric response to a sudden enhancement of the solar wind dynamic pressure. Considering that the interplanetary magnetic field B_x, B_y, and B_z components were positive with the B_y component dominant for this event, the authors suggest that the SI precursor was caused by high-latitude magnetic reconnection that occurred only (or first) in the dawn quadrant of the southern hemisphere, the effect of which has for the first time been clearly identified at the dayside dip equator. This implies that electric field effects occurring in the polar ionosphere due to magnetopause reconnection may be rapidly monitored at the dayside dip equator. In addition, the authors argue that the quasi-simultaneous (time difference is less than 10 s) appearance of the disturbance fields both in the polar region and at the dip equator confirmed in this study is extremely important for theoretically explaining the transmission of the polar electric field to the dayside dip equator, because different theories give different travel times for a disturbance field propagating from polar region to the dip equator. Our observations lend strong evidence for validity of the waveguide model.

A number of poleward-moving events were observed between 11:30–13:00 UT on 11 Feb. 2004, during periods of southward Interplanetary Magnetic Field (IMF), while the steerable antenna of the EISCAT Svalbard Radar (ESR) and the Tromsø VHF Radar pointed nearly northward at low elevation[50]. In this interval, simultaneous SuperDARN CUTLASS Finland radar measurements showed Poleward-Moving Radar Aurora Forms (PMRAFs) which appeared very similar to the density enhancements observed by the ESR northward-pointing antenna. These events appeared quasi-periodically with a period of about 10 minutes. Comparing the observations from the above three radars, it is inferred that there is an almost one-to-one correspondence between the Poleward-Moving Plasma Concentration Enhancements (PMPCEs) observed by the ESR and the VHF radar, and the PMRAFs measured by the CUTLASS Finland radar. These observations are consistent with the interpretation that the polar cap patch material was generated by photo-ionisation at sub-auroral latitudes, and that the plasma was structured by bursts of magnetopause reconnection giving access to the polar cap. There is clear evidence that plasma structuring into patches was dependent on the variability in IMF $|\boldsymbol{B}_y|$. The duration of these events implies that the average evolution time of the newly opened flux tubes from the sub-auroral region to the polar cap was about 33 minutes.

The propagation of the ULF waves in the Pc1 range (0.1–10 Hz) from magnetosphere to ground is examined by Shi *et al*.[51] in the presence of oblique background magnetic fields. The analytic solution is derived to analyze the influences of the Ionospheric Alfven Resonator (IAR), conductivities and the frequency of the ULF waves on the geomagnetic signal. The results of the numerical calculation show: the shear mode exhibits resonant structure vertically; the geomagnetic signal reaches its peak at the IAR resonant frequencies which is increasing with dip angle; the variation of Hall conductivity leads to the modulation of IAR resonant frequencies and the transmission of the ULF waves which effectively influence the spectrum of geomagnetic signal at ground.

5 Radiation Belt, Ring Current and Plasmasphere

Extending previous studies, a full-circle investigation of the ring current has been made using Cluster 4-spacecraft observations near perigee, at times when the Cluster array had relatively small separations and nearly regular tetrahedral configurations, and when the *Dst* index was greater than −30 nT (non-storm conditions)[52]. These observations result in direct estimations of the near equatorial current density at all Magnetic Local Times (MLT) for the first time and with sufficient accuracy, for the following observations. The results confirm that the ring current flows westward and show that the in situ average measured current density (sampled in the radial range accessed by Cluster 4–4.5 R_e) is asymmetric in MLT, ranging from 9 to 27 nA·m^{-2}. The direction of current is shown to be very well ordered for the whole range of MLT. Both of these results are in line with previous studies on partial ring extent. The magnitude of the current density, however, reveals a distinct asymmetry: growing from 10 to 27 nA·m^{-2} as azimuth reduces from about 12:00 MLT to 03:00 and falling from 20 to 10 nA·m^{-2} less steadily as azimuth reduces from 24:00 to 12:00 MLT. This result has not been reported before and they suggest it could reflect a number of effects. Firstly, they argue it is consistent with the operation of region-2 Field Aligned-Currents (FACs), which are expected to flow upward into the ring current around 09:00 MLT and downward out of the ring current around 14:00 MLT. Secondly, they note that it is also consistent with a possible asymmetry in the radial distribution profile of current density (resulting in higher peak at 4−4.5 R_e). note that part of the enhanced current could reflect an increase in the mean *AE* activity (during the periods in which Cluster samples those MLT).

Huang *et al*. study the rotation of the plasmasphere using a large plasmaspheric notch observed by the Extreme Ultraviolet (EUV) instrument onboard the IMAGE spacecraft on 2001/173[53]. The time scale is more than 20 h. On the magnetic equatorial plane the notch extends over more than 1.5 R_e in radial distance. By analyzing the brightness for four annuluses at different average values of *L* from 2.0 to 3.25 over time, they determine the rotation rate of the plasmasphere at different radial distances. The analysis reveals that, with the increase of *L*, the rotation rate of the plasmasphere tends to strongly decrease on the dusk side and slightly increase on the dawn side.

He *et al*. [54] study the relationship between the average structure of the inner magnetospheric large-scale electric field and geomagnetic activity levels with Double Star TC-1 data for radial distances between 4.5 R_e and 12.5 R_e and Magnetic Local Time (MLT) between 18:00 and 06:00 and *Z* (GSM) between −1.5 R_e and 1.5 R_e from July to October in 2004 and 2005. The sunward component of the electric field decreases monotonically as increases and approaches zero as the distance off the Earth is greater than 10 R_e. The dawn-dusk component is always duskward, scaling in the magnitude from 0 mV·m^{-1} to 0.7 mV·m^{-1} as Kp increasing from 0 to 5^{-}. It decreases at about 6 R_e where the ring current is typically observed to be the strongest and shows strong asymmetry with respect to the magnetic local time. Surprisingly, the average electric field obtained from TC-1 for low activity is almost comparable to that observed during moderate activity, which is always duskward at the magnetotail (8–12 R_e).

During the period 19–22 November 2007, the near-equatorial satellites THEMIS D (T_hD) and E (T_hE) traversed the Earth's morningside magnetosphere once per day and for nearly 2 h the orbits tracked close to each other, providing an excellent opportunity to investigate the evolution of Energetic Electrons Fluxes (EEFs) on two time scales. By analyzing the electrons in the energy range 100–300 keV, Fu *et al*.[55] find that the EEFs undergo different evolutions in the different subregions of Earth's morningside magnetosphere during a moderate storm. The evolutions at three specific locations, showing, respectively, the features of electron loss, acceleration, and conservation, have been analyzed in detail. Our observations reveal that, during storm time, the evolution of EEFs involves five processes: (1) the resonant interaction between chorus and energetic electrons, which can contribute to both loss and acceleration of electrons depending on the distribution of phase space density; (2) the radial diffusion, which is indicated by the good coherence between ULF waves and EEFs and dominates in the region where the chorus is relatively weak; (3) the adiabatic transport, which affects the EEFs at $L > 6$ during the recovery phase and prefers to work on large time scale (>1d); (4) the magnetopause shadowing, which can evacuate electrons at $L > 7$ during the storm main phase but play minor roles during the recovery phase, when the magnetopause was moving outward; (5) the magnetospheric convection, which can significantly affect the dynamics of the <100 keV but not the >100 keV electrons. All these five processes couple to each other and determine the EEFs together.

It took about 12 h for the Imager for Magnetopause to Aurora Global Exploration (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 [56]. 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.

Fu *et al.* [57] report coordinated observations of a density trough within the plasmasphere using the measurements from the Radio Plasma Imager (RPI) and Extreme Ultraviolet imager (EUV) on the IMAGE satellite and the measurements from DMSP-F15. The density trough inside the plasmasphere with a width of about 0.7 R_e in terms of L shell (from L≈2.3 to L≈3.0) was observed in situ by RPI when IMAGE traversed the plasmasphere in 2130 Magnetic Local Time (MLT) sector. The plasmasphere images taken by the IMAGE EUV instrument confirm that the density trough is inside the plasmasphere. A 2-D electron density image constructed from the RPI active sounding measurements reveals that the density trough extends along the magnetic field from the IMAGE orbit to at least 41° magnetic latitude. Meanwhile, the DMSP-F15 satellite, circling the Earth at about 850 km altitude, detected a light ion density trough at the same time on the same L shells and similar MLT sector. The coordinated observations with the IMAGE and DMSP-F15 satellite demonstrate, for the first time, that the density trough is a low-density plasmaspheric structure extending from the plasmasphere to the topside ionosphere along the geomagnetic field lines.

Yuan *et al.*[58] report observations from a Cluster satellite showing that ULF wave occurred in the outer boundary of a plasmaspheric plume on September 4, 2005. The band of observed ULF waves is between the He^+ ion gyrofrequency and O^+ ion gyrofrequency at the equatorial plane, implying that those ULF waves can be identified as EMIC waves generated by ring current ions in the equatorial plane and strongly affected by rich cold He^+ ions in plasmaspheric plumes. During the interval of observed EMIC waves, the footprint of Cluster SC3 lies in a subauroral proton arc observed by the IMAGE FUV instrument, demonstrating that the subauroral proton arc was caused by energetic ring current protons scattered into the loss cone under the Ring Current (RC)-EMIC interaction in the plasmaspheric plume. Therefore, the paper provides a direct proof that EMIC waves can be generated in the plasmaspheric plume and scatter RC ions to cause subauroral proton arcs.

6 Outer Magnetosphere

The current sheet in Earth's magnetotail often flaps, and the flapping waves could be induced propagating towards the dawn and dusk flanks, which could make the current sheet dynamic. To explore the dynamic characteristics of current sheet associated with the flapping motion holistically and provide reasonable physical interpretations, detailed direct calculation and analysis have been applied to one approximate analytic model of magnetic field in the flapping current sheet[59]. The main results from the model demonstrate: (1) the magnetic fluctuation amplitude is attenuated from the center of current sheet to the lobe regions; The larger wave amplitude would induce the larger magnetic amplitude; (2) the curvature of Magnetic Field Lines (MFLs), with maximum at the center of current sheet, is only dependent on the displacement Z along the south-north direction from the center of current sheet, regardless of the tilt of current sheet; (3) the half-thickness of neutral sheet, h, the minimum curvature radius of MFLs, R_{cmin}, and the tilt angle theta of current sheet, d, satisfies $h = R_{cmin}$ cosdeta ; (4) the gradient of magnetic strength forms a double-peak profile, and the peak value would be more intense if the local current sheet is more tilted; (5) current density j and its j_y, j_z components reach the extremum at the center of CS. j and j_z would be more intense if the local current sheet is more tilted, but it is not the case for j_y; and (6) the field-aligned component of current density mainly appears in the neutral sheet, and the sign of it would change alternatively as the flapping waves passing by. To check the validity of the model, one simulation on the virtual measurements has been made, and the results are in well consistence with actual observations of Cluster.

The penetration of plasma sheet ions into the inner magnetosphere is very important to the inner magnetospheric dynamics since plasma sheet ions are one of the major particle sources of ring current during storm times. However, the direct observations of the inner boundary of the plasma sheet are fairly rare due to the limited number of satellites in near equatorial orbits outside 6.6 R_e. Cao *et al*.[60] use the ion data recorded by TC-1 from 2004 to 2006 to study the distribution of Inner Boundary of Ion Plasma Sheet (IBIPS) and for the first time show the observational distribution of IBIPS in the equatorial plane. The IBIPS has a dawn-dusk asymmetry, being farthest to the Earth in the 06:00–08:00 LT bin and closest to the Earth in the 18:00–20:00 LT bin. Besides, the IBIPS has also a day-night asymmetry, which may be due to the fact that the ions on the dayside are exposed more time to loss mechanisms on their drift paths. The radial distance of IBIPS decrease generally with the increase of *Kp* index. The mean radial distance of IBIPS is basically larger than 6.6 R_e during quiet times and smaller than 6.6 R_e. during active times. When the strength of convection electric field increases, the inward shift of IBIPS is most significant on the night side (22:00–02:00 LT). For $Kp \le 0^+$, only 16% of IBIPSs penetrate inside the geosynchronous orbit. For $2 \leqslant Kp < 3^+$, however, 70% of IBIPSs penetrate inside the geosynchronous orbit. The IBIPS has weak correlations with the *AE* and *Dst* indexes. The average correlation coefficient between R_i and *Kp* is –0.58 while the correlation coefficient between R_i and *AE*/*Dst* is only –0.29/0.17. The correlation coefficients are local time dependent. Particularly, R_i and *Kp* are highly correlated (r =–0.72) in the night sector, meaning that the radial distance of IBIPS R_i in the night sector has the good response to the *Kp* index These observations indicate that *Kp* plays a key role in determining the position of IBIPS.

The injection of plasma sheet ion to inner magnetosphere plays an important role during the time of magnetic sub-storm and storm periods. In the past, researches of such injection were all processed by the method of drift path theory of certain magnetic moment particles. Ding *et al*.[61] extend the past certain magnetic moment magnetosphere particle drift path theory in (U,B) coordinate to certain energy magnetosphere particle drift path theory. Because particle's drift orbit is associated with its charge, they take proton as an example. Then they discuss the characters of different energy particles' boundary between their open and close drift path and its variation with *Kp* index during their transportation to the Earth. In high energy situation, the radial distance to the Earth of plasma sheet ions' boundary increases with their energy, and the distance in dawn side is much larger than that in dusk side. But in low energy situation, such thing will completely change. The radial distance decrease with ion energy and the radial distance in dusk side will be larger than that in dawn side. Their simulation results also show that with the increase of *Kp* index, all boundaries of various energy particles in the plasma sheet will move towards the Earth. But performances of ion boundaries in high and low situations are different. To low energy situation, the inner boundary shape of ion almost keeps constant with the increase of *Kp* index. To high energy situation, its shape will change remarkably with *Kp* index. In two extreme cases, that is, E=20keV, Kp=6 and E=10keV, Kp=3, the ion boundaries even show two different regions, one is the closed circling Earth region and the other is the isolated tapered region in dawn side. The boundary of plasma sheet certain-energy-E particles is just the connection of energy-E point in various magnetic moments Alfven layer.

The origin of the flapping motion of the earth's magnetotail current sheet is one of the most important problems in the magnetotail dynamics. Using Cluster data, Sun *et al*.[62] make a statistical research on the motion properties of the magnetotail current sheet of 2001 and 2003. They calculate the velocities of the magnetotail current sheet using new methods and obtain the distribution of the magnetotail current sheet velocities in the X-Y plane in GSE coordinate system. Their results show that although most of the current sheets were propagating toward the tail flanks and those of the exceptions lay in dusk side, which is consistent with previous studies, the proportions of the current sheet which were propagating toward midnight (where $|Y_{GSE}|=0$) were higher than those in previous studies. Motions of the current sheet in the middle area ($|Y_{GSE}|<8\ R_e$) of the magnetotail are investigated. Relatively high value of the Z component of the velocity further confirms that the middle area of the magnetotail might be a source region for the motion of the current sheets which were propagating towards the tail flanks. According to our case studies, the way the current sheets propagated toward midnight area differs significantly from that toward dusk and dawn side, from which they infer that there might be two different kinds of current sheet motions originated from different sources. The statistical results of this work may give some clues for further studies on the origin of the flapping motion of the magnetotail current sheet.

Interplanetary Linear Magnetic Holes (LMHs) are structures in which the magnetic field magnitude decreases with little change in the field direction. They are a 10%–30% subset of all interplanetary Magnetic Holes (MHs). Using magnetic field and plasma measurements obtained by Cluster-C1, Sun *et al*. [63] survey the LMHs in the solar wind at 1 AU. In total 567 interplanetary LMHs are identified from the magnetic field data when Cluster-C1 was in the solar wind from 2001 to 2004. They study the relationship between the durations and the magnetic field orientations, as well as that of the scales and the field orientations of LMHs in the solar wind. It is found that the geometrical structure of the LMHs in the solar wind at 1 AU is consistent with rotational ellipsoid and the ratio of scales along and across the magnetic field is about 1.93:1. In other words, the structure is elongated along the magnetic field at 1 AU. The occurrence rate of LMHs in the solar wind at 1 AU is about 3.7 per day. It is shown that not only the occurrence rate but also the geometrical shape of interplanetary LMHs has no significant change from 0.72 AU to 1 AU in comparison with previous studies. It is thus inferred that most of interplanetary LMHs observed at 1 AU are formed and fully developed before 0.72 AU. The present results help us to study the formation mechanism of the LMHs in the solar wind.

Shen *et al*. [64] investigate the structure of the magnetic field near the Magnetopause (MP) by analyzing the multiple-point magnetic measurements from the Cluster mission. The spatial distribution of the curvature radius of the MP surface at the noon-midnight meridian and for situations with moderate dynamical pressure of solar wind is inferred from direct measurements of magnetic field curvature for the first time. The investigation focuses on conditions of strong magnetic shear and in which a clear boundary layer is present at the MP. It has been confirmed that the magnetic field lines surrounding the cusp bend sunward at the pre cusp region and tailward at the post cusp region, implying the existence of a cusp field indentation. The minimum curvature radius of the near-MP field at both pre cusp and post cusp regions is about 2 R_e. As the latitude decreases, the curvature radius at the MP increases gradually, so that, as the subsolar point is approached, the curvature radius of the MP is nearly equal to the geocentric distance. These results compare well with existing MP models but reveal the limitations inherent in such statistical estimates of local MP curvature, particularly surrounding the cusp regions. The analysis of the magnetic measurements has also verified the existence of the magnetic bottles at both pre cusp and post cusp regions, which may play a role for the trapping of the charged particles of magnetosphere.

7 Geomagnetic Field and Auroras

In order to study the response of auroral electrojets for a sawtooth event observed by LANL satellites on 30 September 2000, Lin *et al*. obtain large scale 2-dimensional ionospheric equivalent current systems for the high-latitude ionosphere to study the variations of auroral electrojets during the sawtooth event using spherical elementary current system method with data of high-latitude magnetometers in the Northern Hemisphere [65]. By comparing characteristics of enhancements of nightside ionospheric westward electrojets with those of positive magnetic bays in middle/low-latitude ground magnetic field *H* components after each sawtooth injection, it is demonstrated that there are current wedges formed during this sawtooth event. The local time width of current wedges suggested by the two observations are both around 11 hours (MLT). In addition, time durations for middle/low-latitude magnetic bays to reach maximum variations were generally longer than those for high-latitude electrojets, implying that source currents for middle/low-latitude magnetic bays are multiple.

Using 2 years of coordinated CHAMP and DMSP observations, Wang *et al*. [66] investigate for the first time the relationship between Subauroral Polarization Streams (SAPS), ionospheric Hall current (electrojet), upper thermospheric zonal wind, and mass density at subauroral regions in the dusk and premidnight sectors, separately for both hemispheres. For comparison, they also analyze the same parameters as a function of magnetic latitude (30°–80° magnetic latitude) during non-SAPS periods. During periods of non-SAPS, the neutral wind exhibits similar features as during SAPS events in the dusk to premidnight sector, streaming westward in the same direction as the plasma drift. Both neutral and plasma velocities peak at the same latitude regardless of SAPS occurrence. For higher geomagnetic activity both velocities are faster and the peaks shift equatorward. During non-SAPS periods, the ratio between plasma and neutral wind velocity is on average 2.75 ± 0.4 in both hemispheres irrespective of geomagnetic activity. The neutral wind during SAPS events gets enhanced by a factor of 1.5/1.2 for $Kp < 4$ and 1.3/1.9 for $Kp \geq 4$ in the Northern/Southern Hemisphere, respectively, as compared to non-SAPS time. The velocity difference between SAPS and neutral wind is also larger during SAPS period than during non-SAPS period, and the difference tends to increase with increasing geomagnetic activity. The peak latitude of the eastward auroral electrojet appears 1.5° poleward of the plasma drift during SAPS events, confirming the formation of SAPS equatorward of the high-conductivity channel.

These SAPS-induced large winds can heat the upper thermosphere. As a result they observed a 10% enhanced mass density at 400 km altitude with respect to periods without SAPS. In addition a density anomaly peak occurs collocated with the SAPS, displaced from the electrojet peak. They regard this as an indication for efficient thermospheric heating by ion neutral friction.

Wang and Luhr investigate the seasonal and diurnal variation of SAPS (Subauroral Polarization Streams) occurrence based on 3663 SAPS events identified in DMSP ion drift observations in the Northern Hemisphere during July 2001 and June 2003[67]. Their relationships with high latitude convection electric field, substorm, and ionospheric conductivity are addressed. SAPS occurrences show a clear seasonal and diurnal variation with the occurrence rates varying by a factor of 5. It is found that the convection electric field might play a dominant role in association with SAPS occurrence. Peak convection electric fields mark the occurrence maximum of SAPS. Substorm might play a secondary role related to SAPS occurrence. It account for the secondary maximum in SAPS occurrence rate during December solstice. Our work demonstrates that the substorm induced electric field can develop SAPS during relatively low global convection. Somewhat low flux tube-integrated conductivity is favorable for SAPS to develop. Another topic is the temporal relationship between SAPS and substorm phases. SAPS can occur at substorm onset, substorm expansion and recovery phases. Most probably SAPS tend to occur 60 min / 45 min after substorm onset during quiet/ more disturbed geomagnetic activity, respectively. This indicates that enhanced global convection helps SAPS to develop quicker during substorms. The peak plasma velocity of SAPS is increased on average only by 5%–10% by the substorm process.

Wang *et al*. show that the ionospheric azimuthal plasma velocity jets near the open-closed field line boundary on the nightside can be associated with the peak in the ionospheric conductivity gradient. Both model and DMSP observations have been utilized to conduct this investigation. The model tests show that when the gradient of conductivity in the poleward boundary becomes sharper, convection peaks appear around the poleward edge of the aurora. The model results have been confirmed by DMSP observations. Hundreds of large ion flow events are identified from one year DMSP observations, with flow speed larger than 500 $m\cdot s^{-1}$ that occurred poleward of the aurora. Among them, 280 (74%) events are found to be associated with conductivity gradient peaks. Most of the convection jets occur in winter when conductivity gradients are expected to be large. The convection jets tend to occur at later local times (21:00–22:00 MLT) at 70°−72° MLat. These events are preceded by increasing of the merging electric field suggesting that they occur after the expansion of the polar cap. Both observation and model results show that the conductivity gradient at the polar cap boundary are one of the important elements in establishing the convection jets.

A survey of dayside aurora excitation at 557.7 nm, which was acquired from an all-sky imager at Yellow River Station in Ny-Ålesund, Svalbard, shows that there are 4 intense emission maxima in the dayside oval, centered near 0630/76, 0830/76, 1400/75, and 1600/75 (unit: MLT/ MLAT), respectively [69]. Tracing the magnetospheric sources of these cores along geomagnetic field lines, the 08:30− and 14:00 MLT cores are corresponding with the pre noon and post noon Magnetospheric Boundary Layers (MBLs), and the 06:30− and 16:00 MLT cores are located at the dusk and dawn MBLs, respectively. The potential solar wind-magnetosphere dynamic processes resulting in these auroral features are discussed.

A survey of dayside 557.7/630.0 nm auroral emission, acquired from the all-sky imagers at the Yellow River Station (YRS) in Ny-Ålesund, Svalbard, shows that the dayside auroral oval could be divided into 5 Auroral Active Regions (AARs), *i.e.*, the dawnside (Da/06:00−07:30 MLT) and duskside (Du/15:30−17:00 MLT) green aurora sectors, the prenoon (W/07:30−10:00 MLT) and postnoon (H/13:00−15:30 MLT) peaks for 557.7/630.0 nm auroral emissions, the midday gap (M/10:00V13:00 MLT) for green aurora[70]. The 630.0 nm intensities in W, M, and H nearly increase linearly with the Kan-Lee electric field. The 630.0 nm auroral emissions in W and H show a double-peak feature associated with the change of IMF clock angle, one peak at 90° and the other at 270°. The 630.0 nm emission in M, however, is dominantly excited during the clock angle of 90°−270°. It is considered that the 630.0 nm emissions in W/H and M are related to the prenoon/ postnoon anti-parallel reconnection at the high-latitude magnetopause and the subsolar component reconnection, respectively. Moreover, the 630.0 nm intensity in the dayside oval shows the monotonic increase with the absolute value of the north-south oriented electric field (E_z), but the increasing rate of the intensity in the postnoon (prenoon) oval is larger than that in the prenoon (postnoon) oval when IMF B_y is negative (positive). Only the 557.7 nm intensity in region M and H/Du increases gradually with the absolute value of negative E_z. These features should be associated with the change of inter-hemispheric currents produced by E_z.

Liu *et al*. [71] examine temporal variations of a dayside aurora and corresponding ionospheric plasma convection observed by All-Sky Camera (ASC) and Super Dual Auroral Radar Network (SuperDARN) over Zhongshan (ZHS), located at −74.5º in Magnetic Latitude (MLAT) in Antarctica, during a geomagnetic Sudden Commencement

(SC) event occurred on 27 May 2001. Simultaneous ASC observations at South Pole (SP, −74.3° MLAT) are also analyzed. During the SC time, ZHS and SP were located in the postnoon (16:10 MLT) and prenoon (11:00 MLT) sectors, respectively. Before the SC onset (14:58 UT), the ASC at ZHS observed an auroral arc with moderate intensity in the poleward direction of the Field of View (FOV), and the SuperDARN radar detected sunward ionospheric plasma flow over ZHS. Just after the SC onset, the auroral intensity over ZHS decreased rapidly and the direction of the plasma flow was reversed to anti-sunward. Decrease of auroral intensity and reversal of the associated plasma convection in response to a sudden increase of the solar wind dynamic pressure at the early stage of a SC event has never been noticed before. The authors suggest that these observational results were generated by a downward Field Aligned Current (FAC) and are consistent with a physical model of SC. The model predicts appearance of a pair of FACs flowing downward (upward) in the postnoon (prenoon) sector at the very beginning of SC. This suggestion is supported by additional observations. For example, the authors find that the auroral intensity observed at SP in the prenoon sector was weak before the SC onset but clearly increased after the onset. The authors also find that the decrease of the auroral intensity at ZHS lasted about 4 minutes, and which is nearly the same as the duration of the convection reversal observed by the radar and of the auroral enhancement over SP. Furthermore, about 4 minutes later of the SC onset, the aurora over ZHS was dramatically intensified and the plasma convection returned to the sunward direction with velocity much higher than that before the SC onset. Consistence of these observational results with the model is discussed and the authors argue that they present the first optical observational evidence supporting the validity of the model.

Eight years of magnetic field data, taken while the four Cluster spacecraft pass through, or adjacent to, the equatorial ring current, have been surveyed to investigate the effects on the Earth's magnetic field of the externally driven current systems connecting the ionosphere, cusp and ring current regions. Zhang *et al.* [72] extend previous work to cover a greater range of orbit location and external conditions. They compare the modeled magnetic field from different global field models with data from the four Cluster spacecraft. Comparing with the different models allow us not only to characterize each model's performance, but also provides insight into the physical sources of observed signals. The data generally deviate much less from the expected model field during the years close to the solar minimum, implying that the models perform better during weaker geomagnetic activity. There are particular deviations from the models associated with the ring current (well-defined smooth trends) and region 2 Field Aligned Currents (FACs) or low-altitude cusp FACs (sharp bipolar signatures). During the ring current crossings (through perigee, at 4–5 R_e), the T96 model always overestimates the ring current, while the T01 and T89 models sometimes underestimate it. The sharp bipolar signatures are not always sampled, implying a localized extent, but only the T96 and T01 models include forms for the region 2 FACs and T01 appears to model these better. Overall, all deviations from T01 are much smaller than for the other models, indicating that this model achieves the best fit to the data. The 4 Cluster spacecraft observe nearly the same signatures at small separations (during the early years of the mission) but do sample different signatures at large separations (during the later years). Using the four-spacecraft technique, they infer that the region 2 FACs, with a transverse thickness of 0.17–0.54 R_e, and cusp FACs, with a thickness of 0.06–0.12 R_e, are very stable in size and location.

8 Plasma Waves

Using the data of Cluster on 8 November 2004, Wang *et al.* [73] analyze the ULF wave associated with earthward periodical high speed flow in the plasma sheet. The results show that the ULF waves in the magnetic field and temperature appear, enhance and end at the same times with those of periodical high speed ion flow. Particularly, the oscillation frequencies in ion flow velocity, magnetic field and ion temperature are all between 60–70 mHz, *i.e.*, in the frequency range of Pi1. These observations show that there is a close correlation among the ULF wave in the magnetic field, temperature and periodical high speed flow. The oscillations of the high speed flow is approximately out of phase with the ULF wave in the magnetic field, and in phase with the ULF wave in the temperature. The results of Minimum Variance Analysis show that although the wave propagation direction includes earthward component, the main propagation direction is towards the centre of plasma sheet and perpendicular to both the high speed flow velocity and magnetic field. All these observations indicate that the periodical high speed flow can generate the ULF waves at the same frequency.

Charged particle dynamics in magnetosphere has temporal and spatial multi-scale; therefore, numerical accuracy over a long integration time is required. A Variational Symplectic Integrator (VSI) for the guiding-center motion of charged particles in general magnetic field is applied to study the dynamics of charged particles in magnetosphere[74]. Instead of discretizing the differential equations of the guiding-center motion, the action of the guiding-center motion is discretized and minimized to obtain the iteration rules for advancing the dynamics. The VSI conserves exactly a discrete Lagrangian symplectic structure and has better numerical properties over a long integration time, compared with standard integrators, such as the standard and adaptive fourth order Runge-Kutta (RK4) methods. Applying the VSI method to guiding-center dynamics in the inner magnetosphere, they can accurately calculate the particles' orbits for an arbitrary long simulating time with good conservation property. When a time-independent convection and corotation electric field is considered, the VSI method can give the accurate single particle orbit, while the RK4 method gives an incorrect orbit due to its intrinsic error accumulation over a long integrating time.

Both hybrid and full particle simulations and recent experimental results have clearly evidenced that the front of a supercritical quasi-perpendicular shock can be nonstationary. One proposed mechanism responsible for this nonstationarity is the self-reformation of the shock front being due to the accumulation of reflected ions. On the other hand, a large number of studies have been made on the acceleration and heating of Pickup Ions (PIs) but most have been restricted to a stationary shock profile only. Herein, one-dimensional test particle simulations based on shock profiles issued from one-dimensional particle-in-cell simulation are performed in order to investigate the impact of the shock front nonstationarity (self-reformation) on the acceleration processes and the resulting energy spectra of PIs (protons H^+) at a strictly perpendicular shock[75]. PIs are represented by different shell distributions (variation of the shell velocity radius). The contribution of Shock Drift Acceleration (SDA), Shock Surfing Acceleration (SSA), and Directly Transmitted (DT) PI's components to the total energy spectra is analyzed. Present results show that (1) both SDA and SSA mechanisms can apply as pre-acceleration mechanisms for PIs, but their relative energization efficiency strongly differs; (2) SDA and SSA always work together at nonstationary shocks (equivalent to time-varying shock profiles) but SDA, and not SSA, is shown to dominate the formation of high-energy PIs in most cases; (3) the front nonstationarity reinforces the formation of SDA and SSA PIs in the sense that it increases both their maximum energy and their relative density, independently on the radius of PI's shell velocity; and (4) for high shell velocity around the shock velocity, the middle energy range of the total energy spectrum follows a power law $E_k{-1.5}$. This power law is supported by both SDA and DT ions (within two separate contributing energy ranges) for a stationary shock and mainly by SDA ions for a nonstationary shock. In both cases, the contribution of SSA ions is comparatively weak.

Reflection and acceleration mechanisms of heavy ions (with different initial thermal velocities and different charge-mass ratios) interacting with a nonstationary shock front (self-reformation) are analyzed in detail[76]. Present preliminary results show that: (1) the heavy ions suffer both Shock Drift Acceleration (SDA) and Shock Surfing Acceleration (SSA) mechanisms; (2) the fraction of reflected heavy ions increases with initial thermal velocity, charge-mass ratio and decreasing shock front width at both stationary shocks (situation equivalent to fixed shock cases) and nonstationary shocks (situation equivalent to continuously time-evolving shock cases); (3) the shock front nonstationarity (time-evolving shock case) facilitates the reflection of heavy ions; (4) a striking feature is the formation of an injected monoenergetic heavy ions population which persists in the shock front spectrum for different initial thermal velocities and ions species. The impact of the shock front nonstationarity on the heavy ions spectra within the shock front region and the downstream region are detailed separately. Present results are compared with previous experimental analysis and theoretical models of Solar Energetic Particles (SEP) events. The variations of Fe/O spectra in high energy part have been retrieved, and the nonstationary effects of shock front strongly amplify these variations.

In terms of global Magnetohydrodynamic (MHD) simulations of the solar wind-magnetosphere ionosphere system, Hu *et al.* [77] investigate the rotational asymmetry of the Earth's bow shock with respect to the Sun-Earth line. This work is limited to simple cases in which the solar wind is along the Sun-Earth Line, and both the Earth's magnetic dipole moment and the Interplanetary Magnetic Field (IMF) are perpendicular to the Sun-Earth line. It is shown that even for the case of vanishing IMF strength the bow shock is not rotationally symmetric with respect to the Sun-Earth line: the east-west width of the cross section of the bow shock exceeds the north-south width by about 9%–11% on the terminator plane (dawn-dusk meridian plane) and its sunward side, and becomes smaller than the north-south width by about 8% on the tailward side of the terminator plane. In the presence of the IMF, the configuration of the bow shock is affected by both the shape of the magnetopause and the anisotropy of fast magnetosonic wave speed. The magnetopause expands outward, being stretched along the IMF, and the extent of its expansion and stretch increases when the IMF rotates from north to south. In the magnetosheath, the fast magnetosonic wave speed is higher in the direction perpendicular to the magnetic field than that in the parallel direction. Therefore, the stretch direction of the magnetopause is perpendicular to the maximum direction of the fast magnetosonic wave speed, and their effects on the bow shock position are exactly opposite. The eventual shape of the bow shock depends on which effect dominates. On the tailward side of the terminator plane, the anisotropy of fast magnetosonic wave speed dominates, so the cross section of the bow shock is wider in the direction perpendicular to the IMF. On the terminator plane and its sunward side, the shape of the bow shock cross section depends on the orientation of the IMF: the bow shock cross section is still wider in the direction perpendicular to the IMF under generic northward or dawn-dusk IMF cases, but it becomes narrower in the direction perpendicular to the IMF instead under generic southward IMF cases. In light of the intimate relationship between the shape of the bow shock and the orientation of the IMF, it is proposed to take the IMF as the datum direction so as to extract the parallel half width $R_{b\|}$ and the perpendicular half width $R_{b\perp}$ as the scale parameters. In comparison with the commonly used east-west half width y_b and the north-west half width z_b, these parameters provide a more reasonable description of the geometry of the bow shock. Simulation data show that under the assumption of isotropic orientation of the IMF, the statistical averages of y_b/z_b and $R_{b\|}/R_{b\perp}$ are both smaller than 1 on the terminator plane, which agrees with relevant observational conclusions.

Du *et al.* [78] present the direct spacecraft observations of wave mode conversion in the magnetotail for the first time. On February 28, 2008, the satellites P4 and P3 of THEMIS observe wave signals with a period of about 100 s in the magnetotail at about 11 R_e. At the same time, geomagnetic activity is very quiet and there are no wave signals observed by the ground-based stations. From P4 observations, Alfvén and slow mode waves are identified during two successive intervals, while the coexistence and slow wave regions are observed by P3. The mode conversion between the Alfvén and slow mode waves takes place while THEMIS are crossing the central current sheet. The sharp curvature of the background magnetic field should be the primary reason of this mode conversion.

Magnetotail reconnection event are observed associated by strong low frequency electromagnetic wave activities[79]. The strong wave activity frequencies ranges from below the ion gyrofrequency to above the electron plasma frequency. The observed wave activities during the reconnection event frequency between ion gyrofrequency and electron gyrofrequency are explored mainly. They focus on the observations in magnetotail, especially on those observed by Cluster spacecraft recently. Then compare the observations with theoretical analysis if possible. Whistler wave active is frequently observed during reconnection event by Cluster. The role of these waves in the reconnection onset and supporting the reconnection, in anomalous resistivity was discussed.

Lin *et al.*[80] study the structure and kinetic properties of slow-mode shocks near the Pasma Sheet Boundary Layer (PSBL) associated with magnetic reconnection by Cluster observation. The presence of slow-mode shocks is confirmed by traditional Rankine-Hugoniot (RH) analysis and Monte-Carlo shock fitting method. The Walén analysis, applied to the tailward flow associated with slow-mode shocks, also supports that plasma was accelerated across a Petschek-type slow-mode shock connected to the diffusion region. Back-streaming ions were observed on the shock layer, and cold ions were accelerated and heated by slow-mode shocks. In addition, whistler and electrostatic solitary waves were observed around the slow-mode shocks. These waves might be excited by the observed field-aligned electron beams near the shocks

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