2003-2006

China National Report on Geomagnetism and Aeronomy

For

The 24rd General Assembly of IUGG

Perugia, Italy, 2-13 July, 2007

By Chinese National Committee for

The International Union of Geodesy and Geophysics

Beijing, China

June, 2007

PREFACE

The present report summarizes contributions to geomagnetism and aeronomy study by Chinese researchers during the past quadrennial period 2003--2006. Seven papers are included in the report. One paper on geomagnetism study mainly reviews magnetic field measurement, spatial-temporal characteristics of varying magnetic field, physical processes and model. Five papers present progress in the research on solar-terrestrial physics, including middle-upper atmospheric physics, ionospheric physics, magnetospheric physics, solar upper atmosphere and interplanetary physics. The other reviews development of space exploration in china.

The Geospace Double Star Program (DSP) contains two satellites named TC-1 and TC-2 those were launched respectively in December 2003 and July 2004. The two satellites of DSP and four satellites of Cluster make coordinated observations and form six point measurements in Geospace. They have continuously provided spatial and temporal multi-scale science data. DSP has brought out new focus on the solar-wind, magnetospheric and ionospheric research, and many important new science results. Therefore, in this report, we add the paper on some DSP exploration and data analysis results.

I would like to thank Xu Wenyao, Xiao Zuo, Wang Jingxiu, Yi Fan, Cao Jinbin, Feng Xueshang and Shi Jiankui, as well as other co-authors for their contribution to the papers in this report.

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PRIMARY EXPLORATION AND INVESTIGATION RESULTS OF DOUBLE STAR PROGRAM

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1. Introduction

1.1 Brief Introduction of Double Star Program

The Double Star Program (DSP) was first proposed by China in January 1997. It is the first project of international collaboration between China and ESA.

Double Star Program contains two satellites(TC-1: 577-78691Km, i =28.25º, and TC-2: 558-38362Km, i =89.88º) which operate in the near-earth equatorial and polar regions not covered by the exiting ISTP missions in the geospace.The main science objectives is to investigate the global processes of magnetospheric space storms and their responses to interplanetary disturbances.

Double Star coordinate with Cluster, to form a “Six Point Exploration” in the Geospace for the first time.

1.2 The operation status of Double Star

- The equatorial Satellite (TC-1) was launched in December 2003, the polar satellite (TC-2) was launched in July 2004.
- Till now, the TC-1 and TC-2 satellites operate normally. All the payloads on the TC-1 and TC-2 satellites work normally, they have provided and continuously giving data of very good quality. Till Dec. 2006, the TC-1 satellite have provided data about 204Gb, and TC-2 satellite have provided data about 160Gb. The Double Star already has very good conjunction with Cluster, to form coordinated and simultaneous explaration in the important magnetospheric active regions.

1.3 DSP-Cluster constellation has yielded the hot points of the magnetosphere study.

- January to April of each year, DSP and Cluster are traveling in solar wind, bow shock, magnetosheath, and magnetopause, obtain a great deal of multi-scale data. The associated exploration will benefit the studies of substorm driven processes
- May to June of each year, DSP and Cluster are traveling in cusp and the high-latitude boundary layer near the Earth, the associative exploration data may benefit the studies of the coupling of the magnetosphere and ionosphere
- July to October of each year, DSP and Cluster are traveling in magnetic lobe, plasma sheet boundary layer, and plasma sheet, the associative exploration data may benefit the studies of the globe and multi-scale processes which trigger the magnetosphere space storms

2. A Part Preliminary Exploration and Investigation Results of Double Star Program

2.1 The solar wind density hole observed for the first time by Double Star and Cluster

The combined observations of the Cluster and the Double Star TC-1 satellites have discovered the presence of ion density holes in the solar wind, upstream of the Earth's bow shock, of thousands kilometers in size. More than 140 of such density holes were found, always observed with upstream particles (propagating against the solar wind flow), suggesting that backstreaming energetic particles interacting with the solar wind are important.

2.2 Magnetic Reconnection at the Magnetopause

From January to April the apogee of TC-1 is in the dayside solar wind or magnetosheath. With an inclination of 28.25^o and an orbital period of 27.4 h, TC-1 has numerous opportunities to measure the low-latitude reconnection signatures when it traverses across the dayside magnetopause. Several interesting studies have been done based on these measurements.

Pu et al. (2005a) made a systematical study of TC-1 observations in spring 2004 and describe three representative events in which reconnection was operating nearby the spacecraft: (1) Event on 21 March 2004 for southward IMF. The spacecraft was passing nearby the X-line, the reconnection site can be remotely monitored. The averaged shear angle across the magnetopause near the X-line was found to be ~116^o. (b) Event on 12 March 2004 for southward IMF. TC-1 observed the magnetospheric part of the quadrupolar field together with a consistent flow reversal, indicating that the spacecraft was passing through the diffusion region. A non-zero guide-field of ~28 nT was found close to the X-line. Event on 26 March 2004 for northward IMF. The shear angle across the local magnetopause can be estimated to be ~57^o due to the presence of a strong guide field of ~40 nT. A v_y reversal from being dawnward in the magnetosheath to duskward in the magnetospheric low-latitude boundary layer was also observed. Since the most straightforward way to distinguish component reconnection from anti-parallel reconnection is to determine if there is a guide field at/near the reconnection site, or whether the shear angle across its local magnetopause noticeably deviates from 180^o (Pu et al., 2005a). These observations are clearly consistent with near equatorial component merging, suggesting that component reconnection really occur at the dayside low-latitude magnetopause. Furthermore, when a pronounced magnetic shear across the magnetopause exists in the B_y component, reconnection may operate at the dayside low-latitude magnetopause for northward IMF B_z.

From 23:10 to 23:50 UT on 18 March 2004, the TC-1 detected eight Flux Transfer Events (FTEs)/open flux ropes at the outbound crossing of the southern dawnside magnetopause. Its GSM position was (7.5, -5.5, -5.4) R_E. Xiao et al. (2005) made a detailed study of this multiple flux rope event. It is shown that the event occurred under the condition of southward IMF B_z and noticeably negative IMF B_y. The flux ropes appeared quasi-periodically with a repeated period of approximately 2 minutes. Notable guide field existed inside all ropes. This event is quite similar to the multiple flux rope event observed by Cluster on 26 January 2001 at the northern duskside high-latitude magnetopause in which quasi-periodical period of flux ropes was ~78 s (Pu et al., 2005b). A detailed comparison of these two events is made in the paper. The IMF and solar wind conditions in the 18 March 2004 and the 26 January 2004 cases are quite close. Therefore, these two events should have a similar reconnection scenario and global signatures. Flux ropes in these events are both moving poleward; the projections of their convection velocity on the GSM (y,z) plane are more or less opposite to each other. Since TC-1 and Cluster in these two events were located, respectively, in the southern/dawn and northern/dusk magnetopause, these simply imply that the X-lines, where the flux ropes were produced, were located in between the TC-1 and Cluster positions at the low-latitudes, with almost the same tilted angles with respect to the equatorial plane and that the FTEs/open flux ropes were produced in pair via component reconnection near the equatorial region and them move opposite away from the source area .

Wang et al. (2007) reported an observation of FTE signatures at the dayside magnetopause, which were consecutively observed on 4 January 2005 by both the TC1 spacecraft and the Cluster quartet, while the spacecraft were traversing through the northern-dusk magnetopause. The event occurred as a magnetosheath FTE first at the Cluster spacecraft at about 07:13 UT on 4 January 2005 and crossed each of the others within 2 minutes. The spatial separations between the Cluster spacecraft were of the order of 200 km. The TC1 signature occurred about 108s after Cluster. All findings including magnetic fluxes, orientations and hot ion velocity distributions strongly suggest that Cluster and TC1 encountered the magnetosheath branch of the same flux tube at two different positions along its length and this is borne out by computation of the expected time delay. Four-spacecraft timing is used to obtain the velocity of FTE. The following features of the flux rope are obtained (in GSM coordinates). Scale size: 1-2 R_E; Orientation at (4.29, 12.54, 1.72) R_E : (-0.545, 0.184, 0.818); convection velocity: (-44, 340, 178) km/s; Magnetic flux($10^5 Wb$) contained in the flux rope: ~15×10^5Wb. This study suggests that the FTE flux ropes move dominantly in the azimuthal direction, not in the Z-direction as the present models of FTEs assumed.

2.3 A Part results observed by TC-2/NUADU

NUADU was one of the most advanced imaging payload aboard TC-2 spacecraft which still operating around the near Earth polar orbit after losing of HENA/IMAGE. This instrument enable telemeter ENA spatial distribution and its temporal evolution in the ring current region, which was important in investigation of the processes of storm and substorm.

(1) First recorded 3-D ENA source distribution in one orbit

Due to preponderance of the TC-2 orbit, NUADU with its high temporal and spatial resolution monitored an ENA source successfully in the same orbit at different positions at 7 Nov. 2004 from 18:32:51 to 23:49:19 UT during a major storm which drew a first clear 3-D view of the ENA source.

(2) ENA aurora

During TC-2 passed through the south pole cap, from 12:09 to 12:20 14 Sep. 2004, when Dst=-50 nT, NUADU observed the evolution process of a ENA aurora.

(3) Pitch Angle Distribution (PAD) and evolution observed by TC-2/NUADU

During commission at 4 Sep. 2004, NUADU (81-158 keV), without ion-sweeping HV, observed an evolution process of PAD, while FGM aboard TC-2 recorded ambient magnetic field . During decreasing of magnetic field, the PAD diffused from high to low.

(4) Ring like pitch angle distribution

During a storm at 17 Jan. 2005 (from 13:09:41 to 13:30:23 UT), NUADU recorded 77 frames of pitch angle distribution of ions with energy higher than 180 keV. It was first to exhibit the dumbbell PAD in 4π solid angle view which distributed as two closed rings around the magnetic field line symmetrically.

During this obervation, it is the first recorded a double-ring structures, where there are hollow rings point by blue dash arrows with lower ion fluxes at pitch angle 60° and 120 ° respectively. It accompanied by an ambient magnetic field disturbance and its actual formation mechanism still in the investigation.

2.4 A Part results of Particle an Wave Observed by TC-1 and TC-2

(1) The long duration energetic electron loss event associated with low frequency electromagnetic waves observed for the first time by Double Star.

The loss mechanism of relativistic electrons in the magnetosphere has been one of unsolved key problems of magnetospheric physics. On November 9, 2004, the LFEW and HEED on board TC1 made a joint observation of relativistic electron event during a strong geomagnetic storm, and for the first time observed a long duration relativistic electron loss event which was caused by the burst of low frequency electromagnetic waves.

(2) Statistical analysis of magnetic field and particle distributions in the ecliptic plan (from 13 RE to –13 RE) measured by TC-1 satellite.

2.5 Magnetospheric Substorm Triggering Processes.

(1) Global “Front” Triggering Model of Magnetospheric substorm derived from Double Star and Cluster observed results

By analysis of data of DSP/TC-1 and Cluster recorded in the near-earth plasma sheet, Z.X.Liu et al. observed, for the first time, the triggering processes of substorm in the front region (FR), which formed by the interaction between the near-earth tailward flow (NETF) and the earthward flow. Main observational results include: (1) the NETF acted on the structure of magnetic field, which may stretch the field line from a dipole-like to a tail-like configuration, and transport magnetic flux into the near-earth plasma sheet; (2) the correlation of the NETF and the earthward convection with the substorm onset were higher than 80% in statistics; (3) when the NETF was suddenly slowdown, the processes of the magnetic field dipolarization, the aurora brightening and the substorm onset were observed almost at the same time; (4) during the magnetic field dipolarization, a series of phenomenon relate to the substorm onset were observed simultaneously, such as, the By enhancement which arouse a sudden field aligned current increasing, the ion temperature rising, which indicate the magnetic energy transform to the thermal energy, the anisotropy of temperature incurase suddenly, a strong magnetic field disturbance, and low-frequency wave generation. Base on above observational facts, we propose a new magnetospheric substorm triggering model, called substorm front triggering model, which interpreted the time sequence processes of the substorm driving and triggering.

（2） Flux Pileup in the Near Earth Tail

Zhang et al. (2007) made such a study based on the TC-1 measurements in 2004. They found that among 94 substorm events measured in 2004, there are 53 events in which TC-1 clearly observed flux pileup in the near Erath tail. They first conduct a case study of an event on 17 September

2004, then carried out a statistical investigation of the 53 cases. Their main findings are: (a) Magnetic flux pileup characterized by continuous enhancement of B_z is closely related to the reduction of the plasma thermal pressure, as well as inward propagation of Pi2 oscillations in B_z component. (b) Flux pileup starts almost simultaneously with aurora breakup within ~1–3 minutes, indicating that substorm onset is in intimate association with flux pileup. (c) Sudden plasma sheet expansion with sharp increases in ion temperature and density is seen in all events, which occurs typically ~11 minutes after the beginning of pileup. The plasma sheet expansion is shown to be in close relation with the primary substorm dipolarization.

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PROGRESS OF SOLAR PHYSICS IN 2006

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Abstract

Recently, Chinese solar physicists obtain impressive progress in many aspects of frontier areas of solar research. Here, for an exemplification, we report the key advances in 2006, which are concluded into eight perspectives, i.e., Long-term variation of solar activity, Solar magnetic fields, Solar flares at multiple-wavelength, Coronal Mass Ejections, Solar energetic particles , Radio Solar physics , Theoretical studies and MHD simulations , and Instruments developments. All the works exemplified in this report are published in the international leading journals. Totally, there are approximate 100 papers published, among which we will only mention some of them in this report.

1. Long-term variation of solar activity

1.1 Long-term variation

The Relationship between Solar Maximum Amplitude and Max-Max Cycle Length was studied by Du (2006a). The maximum amplitude of a solar activity cycle is found to be inversely correlated (r=-0.769) with the newly defined max-max cycle length two cycles earlier in a 13 month mean of monthly sunspot numbers. Meanwhile, a 14 cycle periodicity is found in the fitted residuals. The max-max cycle length can be used as one of the indicators to predict amplitudes. As a result, the amplitudes of cycles 24 and 25 are estimated to be 150.3±22.4 and 102.6±22.4, respectively. Du (2006b) also found a weak 5-cycle periodicity (r = -0.64) in the maximum amplitudes of the modern era sunspot cycles (11–23), slightly stronger than the 8-cycle (Gleissberg) periodicity (r = 0.60). A new parameter called `effective duration', defined as the total sunspot numbers in a cycle divided by the maximum amplitude, is proposed. This parameter carries some information of the amplitude five cycles later, and may become one of the parameters to study solar activity and the theory of solar dynamo. With the relationship above, the amplitude of cycle 24 is estimated to be 115.7 ± 19.7, where the error is the standard error. A weighted average method to determine the epochs of solar cycle extrema and hence the solar cycle lengths is suggested by Du et al. (2006a, 2006b, 2006c, 2006d). Comparing to the previous methods, this method has the advantage that the extremum epochs are easily and uniquely determined. The amplitude of a solar-activity cycle is found to be well correlated (r = -0.811) with the descending time three cycles earlier, in smoothed monthly-mean sunspot numbers for Cycles 8 – 23. The descending time therefore can be used as one of the indicators to predict the amplitudes. As a result, the amplitudes of Cycles 24 – 25 are estimated to be 114.8 ± 17.4, 111.6 ± 17.4, respectively, where the error bar equals ± standard error. The maximum amplitudes of solar activity cycles are found to be well anti-correlated (r = -0.72) with the newly defined solar cycle lengths three cycles before (at lag -3) in 13-month running mean sunspot numbers during the past 190 years. This result could be used for predicting the maximum sunspot numbers. The amplitudes of Cycles 24 and 25 are estimated to be 149.5±27.6 and 144.3±27.6, respectively.

Using 342 NSO/Kitt Peak solar synoptic charts, Song, W. *et al* (2006) study the large-scale solar cycle features of photospheric magnetic flux to set further constraints. (1) They find the mean latitudes (φ) of the boundaries of the polar regions to be near 55.35d during solar minimums and 67.61d during solar maximums. There is a good correlation between the variability of its area and the sunspot number with a time lag of 5 years. (2) A unipolar poleward flow is found in the high-latitude region (|φ|∈[40deg,60deg]) during solar maximums because of the different gradients between the positive flux and the negative flux in the active belts from |φ|=20deg to |φ|=40deg. (3) The flux peak time keeps steady from |φ|=40deg to |φ|=20deg and then shifts forward with a speed of 32.2 day deg^{-1} toward the equator. At the same time, the total magnetic flux increases with an average gradient of -2.48 × 1020 Mx deg^{-1} and then decreases with an average gradient of 3.63×1020 Mx deg^{-1}. These typical characteristics may provide us with hints for constructing a more reliable solar dynamo.

1.2 Solar cycle behavior

Using data from the Carte Synoptique solar filaments archive, Li K. *et al.* (2006a, 2006b) investigate whether there is a time lag between high-latitude solar activity and low-latitude solar activity. The cross-correlation analysis of the number of high-latitude filaments per Carrington rotation (NHF) and that of low-latitude filaments per Carrington rotation (NLF) shows, although inconclusively, that NLF possibly lags behind NHF. The periodic characteristics of both NHF and NLF clearly indicate that the activity of high-latitude filaments is evidently leading the activity of low-latitude filaments. Thus, the present study suggests that high-latitude solar activity leads low-latitude solar activity in time phase. The Morlet wavelet is utilized to analyze the periodicity of the number of solar filaments at latitudes over 50° during Carrington solar rotations 876 – 1823. For solar filaments at latitudes over 50°, the most eminent periods are about 10.23 and 10.90 years, which correspond to the Schwabe period of high-latitude solar activity, and the these periods make-up a highly significant proportion of the time span considered. The periods of 1.3 and 1.7 years and the quasi-biennial 2 – 3-year oscillation often mentioned in the literature are not found to be a feature of every solar cycle but seem to appear only from time to time.

1.3 Solar cycle prediction

Du (2006c) presented a method to estimate the onset of a new solar cycle by re-investigating the relationship between descending and ascending phase durations in terms of weighted extremum times. The lagged cross-correlation method is used to analyze their relationship. The descending phase durations are found to be anti-correlated (correlation coefficient, -0.77) with the ascending phase durations three cycles earlier, in the 13-month running mean sunspot numbers since cycle 8. From linear regression analysis, the descending phase duration of cycle 23 is estimated to be 78±7 months; thus, cycle 24 should start near March 2007, where the error bar equals ± standard error.

Using the data from observations of polar faculae by the National Astronomical Observatory of Japan from July 1951 to December 1998, Li, K. *et al*. (2006c) investigate whether there is a time lag between high-latitude solar activity and low-latitude solar activity. The cross-correlation analysis of the smoothed monthly numbers of the polar faculae with the smoothed monthly sunspot numbers shows that, high-latitude solar activity should lead low-latitude solar activity in time phase. The periodic characteristics of both of them also indicate that high-latitude activity evidently leads low-latitude activity.

2. Solar magnetic fields

2.1. Active Regions

Based on a large number of SOHO/MDI longitudinal magnetograms, Cui *et al.* (2006) demonstrated that solar flare productivity increases with nonpotentiality and complexity. The relationship between the flare productivity and these measures can be well fitted with a sigmoid function. These results can be beneficial to future operational flare forecast models. Using the data from BBSO, YNAO and SOHO/MDI, the formation and evolution of a ring-filament is studied, which is located in NOAA AR 09470 from May 21 to 24, 2001 (Ma S. L. *et al.* 2006). It is found that: (1) the ring-filament's formation was well associated with newly-emerging flux. (2) all the eruptions of the filament happened during the decay of the emerging bi-poles.

As compared with the Mount Wilson Magnetic Classification (MWMC), effective distance (dE) is a useful parameter because it gives a quantitative measure of magnetic configuration in active regions. Guo *et al.* (2006) have analyzed magnetograms of 24 active regions of different types with MWMC. They have studied the evolution of magnetic fields of five active regions using d E, total flux (F t) and tilt angle (Tilt) quantitatively. Furthermore, 43 flare-associated and 25 CME-associated active regions have been studied to investigate and quantify the statistical correlation between flares/CMEs and the three parameters. The main results are as follows: (1) There is a basic agreement between d E and MWMC. (2) The evolution of magnetic fields can be described in three aspects quantitatively and accurately by the three parameters, in particular by d E on the analysis of δ-type active regions. (3) The high correlation between d E and flares/CMEs means that d E could be a promising measure to predict the flare-CME activity of active regions.

In a solicited talk, Wang (2006e) briefly summarize the latest observations and current understanding on the evolution of solar magnetic fields. Emphasis will be put on the following three perspectives: (1) elementary evolution processes, (2) structural organization and large-scale patterns, (3) cyclic evolution of the Sun's magnetic fields. They clarify the key unresolved problems and suggest future working directions in this key research area of solar astrophysics, and try to connect the relevant solar studies with the more general studies of stellar magnetic fields. Wang (2006f) also studied the nonpotentiality evolution and energy transport in NOAA AR 10720, a flare-productive and CME-correlative region on Jan 2005.

2.2. Helicity

Zhang M. (2006) reported in a letter her analysis of a large sample of photospheric vector magnetic field measurements. The sample consists of 17200 vector magnetograms obtained from January 1997 to August 2004 by Huairou Solar Observing Station of the Chinese National Astronomical Observatory. Two physical quantities, and current helicity, are calculated and their signs and amplitudes are studied in a search for solar cycle variations. Different from other studies of the same type, they calculate these quantities for weak ($100G<|B_z|<500G$) and strong

(|B_z|>1000G) fields separately. For weak fields, they find that the signs of both and current helicity are consistent with the established hemispheric rule during most years of the solar cycle and their magnitudes show a rough tendency of decreasing with the development of solar cycle. Analysis of strong fields gives an interesting result: Both and current helicity present a sign opposite to that of weak fields. Implications of these observations on dynamo theory and helicity production are also briefly discussed.

2.3. Fine-scale magnetic fields in coronal hole

The magnetic flux distribution between a coronal hole and a quiet region is compared by Zhang J. *et al.* (2006), based on the data from Big Bear Solar Observatory (BBSO) deep magnetograms and Hα images in a quiet region and a coronal hole on September 14-16, 2004. They have explored the magnetic flux emergence, disappearance, and distribution in the two regions. Some results are obtained. (1) The evolution of magnetic flux in the quiet region is much faster than that in the coronal hole, as the flux appearing in the form of ephemeral regions in the quiet region is 4.3 times as large as that in the coronal hole, and the flux disappearing in the form of flux cancellation is 2.9 times as fast as in the coronal hole. (2) More magnetic elements with opposite polarities in the quiet region are connected by arch filaments, estimating from magnetograms and Hα images. (3) They measured the magnetic flux of about 1000 magnetic elements in each observing region. The flux distribution of network and intranetwork elements is similar in both polarities in the quiet region. For network fields in the coronal hole, there are many more negative elements than positive elements. However, for the IN fields, there are many more positive elements than negative elements. (4) In the coronal hole, the fraction of negative flux obviously changes with a different threshold flux density; 73% of the magnetic fluxes with a flux density larger than 2 G have negative polarity, and 95% of the magnetic fluxes are negative, if they only consider the fields with a flux density larger than 20 G. These results demonstrate that in a coronal hole, stronger fields are occupied by one predominant polarity, but the majority of weaker fields are occupied by the opposite polarity.

2.4. Coronal magnetic field diagnosis

Based on the approximations of the non-thermal gyro-synchrotron radiation, Huang (2006a) calculates the propagation angle and coronal magnetic field self-consistently with brightness temperature, spectral index, frequency, turnover frequency, and polarization degree in solar microwave bursts. Hence, the coronal magnetic fields parallel and perpendicular to the line-of-sight in the sources of microwave bursts are calculated theoretically, and discussed in an event observed by the Nobeyama Radio Polarimeters (NoRP). Two impulsive microwave bursts observed by Owens-Valley Solar Arrays (OVSA) is studied (Huang, 2006b). The fast time variation of the turnover frequency in these bursts is quite different from the constant value in the earlier conclusion. The observational turnover frequencies are consistent with the calculations using the non-thermal gyro-synchrotron radiation model. It is found that the turnover frequency may play an important role for calculating the coronal magnetic field on the basis of Dulk and Marsh's approximations.

Ji, *et al.* (2006) presented the results from a high-cadence (~40 ms) Hα blue-wing observation of an M1.1-class solar flare, which occurred in NOAA AR 10687 on 2004 November 1. In collaboration with RHESSI, the observation was made with the Hα Fine Structure Telescope at the GanYu Solar Station of the Purple Mountain Observatory. For this flare, a pair of conjugate Hα kernels shows a kind of converging motion during the impulsive phase. After the impulsive phase, there appears a normal separation motion. The motion of one Hα kernel is perpendicular to the magnetic neutral line, while another kernel's converging shows both perpendicular and parallel components. Nevertheless, the shear angle decreases during the converging motion, clearly showing the relaxation of a sheared magnetic field. All of the above features are confirmed with hard X-ray (HXR) footpoints observed by RHESSI. They also obtained the time profiles of the rate of change of the shear angle and the relative velocity of the two kernels with Hα observations. Both of these time profiles show a good correlation with RHESSI HXR light curves in the higher energy range (>~50 keV). This indicates that, during the peak times of the flare, the relaxation process may have occurred rapidly. This event was also observed by the Nobeyama Radio Heliograph (NoRH), showing a single microwave source. Using NoRH maps at 17 GHz with 1 s cadence, they obtained the time profile of the radio source's velocity using the same method that they used with Hα images. The velocity-time curve of the microwave source shows a good correlation with that obtained from the two Hα kernels.

Li, H. *et al*, (2006a) studied the magnetic field evolution and topology of the active region NOAA

10486 before the 3B/X1.2 flare of October 26, 2003, using observational data from the French–Italian THEMIS telescope, the Michelson Doppler Imager (MDI) onboard Solar and Heliospheric Observatory (SOHO), the Solar Magnetic Field Telescope (SMFT) at Huairou Solar Observation Station (HSOS), and the Transition Region and Coronal Explorer (TRACE). Three dimensional (3D) extrapolation of photospheric magnetic field, assuming a potential field configuration, reveals the existence of two magnetic null points in the corona above the active region. They look at their role in the triggering of the main flare, by using the bright patches observed in TRACE 1600 Å images as tracers at the solar surface of energy release associated with magnetic reconnection at the null points. All the bright patches observed before the flare correspond to the low-altitude null point. They have no direct relationship with the X1.2 flare because the related separatrix is located far from the eruptive site. No bright patch corresponds to the high-altitude null point before the flare. It is concluded that eruptions can be triggered without pre-eruptive coronal null point reconnection, and the presence of null points is not a sufficient condition for the occurrence of flares. They propose that this eruptive flare results from the loss of equilibrium due to persistent flux emergence, continuous photospheric motion and strong shear along the magnetic neutral line. The opening of the coronal field lines above the active region should be a byproduct of the large 3B/X1.2 flare rather than its trigger.

A loss of magnetic field confinement is believed to be the cause of coronal mass ejections (CMEs), a major form of solar activity in the corona. The mechanisms for magnetic energy storage are crucial in understanding how a field may possess enough free energy to overcome the Aly limit and open up. Zhang M. *et al.* (2006) investigate another hydromagnetic consequence of magnetic-helicity accumulation. They proposed a conjecture that there is an upper bound on the total magnetic helicity that a force-free field can contain. This is directly related to the hydromagnetic property that force-free fields in unbounded space have to be self-confining. Although a mathematical proof of this conjecture for any field configuration is formidable, its plausibility can be demonstrated with the properties of several families of power-law, axisymmetric force-free fields. They put forth mathematical evidence, as well as numerical, indicating that an upper bound on the magnetic helicity may exist for such fields. Thus, the accumulation of magnetic helicity in excess of this upper bound would initiate a non-equilibrium situation, resulting in a CME expulsion as a natural product of coronal evolution.

Gu *et al.* (2006) presented that a 2D velocity field of the eruptive prominence (EP) of March 5, 1991 from its spectral data observed at the Yunnan Observatory and the velocity distributions along the entrance slit are derived for different observing frames. Under the assumption that matter in the EP undergoes axial, radial and possible rotational motions, They construct a theoretical velocity distribution of the EP along the entrance slit, to derive, by fitting, the angular velocity of rotation and the other three parameters (axial velocity v_0, radial velocity v_r and the angle between the EP plane and the line of sight). They found that an averaged angular velocity of 3.0 x 10^{-3} arc s^{-1} and the variation of with the height above the solar limb. As the EP rises, the matter within it in fact moves along a spiral path around its axis. The spiral motion may be explained by the theory of plasma `double pole diffusion' (DPD) caused by a sharp density gradient between the eruptive prominence and the surrounding corona. A theoretical angular velocity ' is estimated based on the DPD and basically coincides with obtained from the optimal velocity fitting.

3. Solar flares at multiple-wavelength

3.1. Optical spectroscopic diagnosis

Some results of the first spectropolarimetric observations of the $3p\ ^1P_1$–$4d\ ^1D_2$ Mg I line at 5528.4 Å made during a solar flare is presented (Xu, 2006). The line is found to be polarized with a polarization degree at the line center that reaches up to 3% and a direction of polarization nearly parallel to the local transverse magnetic field. After eliminating scattering, the Zeeman effect, and the intensity gradient as possible origins of the observed polarization, this polarization is interpreted as due either to a low-energy proton beam or to the return current associated with electron beams.

Li, H. *et al.* (2006b) show the results of high temporal resolution spectroscopic observation and study in Hα, Ca II 8542 Å, and He I 10830 Å lines for the 2B/M1.9 confined disk flare on September 9, 2001, combining with GOES soft X-ray (SXR) and Yohkoh hard X-ray (HXR) observations. Apparent redshifted and red-asymmetric profiles were observed in the initial phase.

The redshift lasted until the late phase. The derived velocity depends on both the spectral line and the used method. The redshift velocities computed from the line centers of the observed emission profiles (0) are of the order of 10 km/s both inside and outside the streak area. However, the velocities determined from the excess profiles by the bisector method ( ) are larger in the streak (18–50 km/s). Both   and the red full widths (RFWs) derived from the excess profiles show temporal variations similar to the HXR light-curve in the streak area. Moreover, the Hα line wings of nonthermal characteristics, the redshift velocities, and the lifetime of impulsive broadening suggest that the streak is related to non-thermal electron bombardment. Spectral simulations reveal that they cannot reproduce the observed profiles in the three lines simultaneously with a set of parameters, indicating that the flare atmosphere was not homogeneous along the line-of-sight. Most of the observed H profiles showed a 'flat-top' structure, implying the flare plasma was optically thick for this line. The electron temperatures (Te) deduced from the line-center intensity of the three lines are similar and estimated to be higher than 7200 K. The obvious central reversal of the Hα profiles due to absorption of materials in the impulsive phase lasted more than 2 min. However, the far blue wings of the Ca II 8542 Å profiles in the impulsive phase showed low-intensity emission, which is suggestive of the existence of large turbulence or macroscopic motion (>50 km/s), which is inconsistent with the current flare model.

Based on four different atmospheric models, including the effects of nonthermal electron beams with various energy fluxes, the Hα and Ca II 8542 Å line profiles have been calculated (Cheng, *et al.* 2006). These two lines have different responses to thermal and nonthermal effects, and can be used to diagnose the thermal and nonthermal heating processes. Applying the method, the heating effect has been identified quantitatively during an X-class flare eruption on October 19, 2001. It is found that the nonthermal effects at the outer edge of the flare ribbon are more notable than that at the inner edge, while the temperature at the inner edge seems higher. On the other hand, the results show that nonthermal effects increase rapidly in the rise phase and decrease quickly in the decay phase, but the atmospheric temperature can still keep relatively high for some time after getting to its maximum. For the two kernels that they analyze, the maximum energy fluxes of the electron beams are $\sim10^{10}$ and 10^{11} ergs cm^{-2} s^{-1}, respectively. However, the atmospheric temperatures are not so high, i.e., lower than or slightly higher than that of the weak flare model F1 at the two kernels.

3.2. High energy emissions

Li and Gan (2006a) selected a sample of 859 flares observed in hard X-rays (HXRs) by BATSE and in soft X-rays (SXRs) by GOES to study the timing of the SXR and HXR emission. Each sample event presents a simple light curve; i.e., the HXR has only one short time peak and the SXR seems to be a response to the pulse HXR emission. The statistical study shows that the peak time differences between the SXR and HXR emissions conform to a decay exponential function. This distribution, being similar to that for the flaring loop size discovered previously, suggests that the flaring loop size is the reason for the peak time difference between the SXR and HXR emissions. The longer the flaring loop is, the longer the time for chromospheric evaporation reaching the loop top is, i.e., the later the SXR peaks. Our result here provides a support for the traditional chromospheric evaporation model. The fact that the SXR can increase for some time after the end of HXR emission does not seem to be in contradiction with the Neupert effect, if one considers that the electron-driven evaporation needs some time to reach the loop top. Further hydrodynamic modeling is obviously necessary to explain the observations. An occulted flare occurred at about 06:07 UT on November 2, 2002 (Li and Gan, 2006b). The RHESSI X-ray images show two separate parts. The lower part consists of a complete loop and the upper part a coronal source which well extends above the solar limb. The loop source shrank for about 4 minutes with a speed of ˜24 km/s during the early impulsive phase and then expanded at ~7 km/s, while the coronal source presented an upward motion at about 6 km/s. The temperature of the loop-top is always higher than that near the footpoints. The temperature of the loop increased with altitude, while that of the coronal source just showed opposite variation. These results indicate that the reconnection X-point of this flare is located in between the loop-top source and the coronal source.

A statistical analysis of RHESSI X-ray flares in the 12–25 keV band during the period from February 2002 to June 2005d is performed by Su, *et al.* (2006). They found that a power-law with an index of 1.80± 0.02 can fit well the frequency distribution of the peak count rates. This power-law does not change significantly with time. However, the frequency distribution of the flare durations cannot be fitted well by a single power-law. There is a weak correlation between the peak count rates and the characteristic times like rise times, decay times, or durations. But the correlation between the rise times and decay times seems to be strong. The frequency distribution of rise times for the sub-group events with a similar magnitude of peak count rates is also shown. In particular, a new parameter R_a , the growth factor of the count rate, is proposed as the peak count rate divided by the rise time, to reflect the characteristics of the rising phases of flares.

It was suggested by Parker that the solar corona is heated by many small energy release events generally called microflares or nanoflares. More and more observations showed flows and intensity variations in nonflaring loops. Both theories and observations have indicated that the heating of coronal loops should actually be unsteady. Using SOLFTM (Solar Flux Tube Model), Feng and Gan (2006) investigate the hydrodynamics of coronal loops undergoing different manners of impulsive heating with the same total energy deposition. The half length of the loops is 110 Mm, a typical length of active region loops. The loops are divided into two categories: loops that experience catastrophic cooling and loops that do not. It is found that when the nanoflare heating sources are in the coronal part, the loops are in non-catastrophic-cooling state and their evolutions are similar. When the heating is localized below the transition region, the loops evolve in quite different ways. It is shown that with increasing number of heating pulses and inter-pulse time, the catastrophic cooling is weakened, delayed, or even disappears altogether.

Chen and Ding (2006) presented observations of the 2002 September 30 white-light flare, in which the optical continuum emission near the Hα line is enhanced by ~10%. The continuum emission exhibits a close temporal and spatial coincidence with the hard X-ray (HXR) footpoint observed by RHESSI. They find a systematic motion of the flare footpoint seen in the continuum emission; the motion history follows roughly that of the HXR source. This gives strong evidence that this white-light flare is powered by heating of nonthermal electrons. They note that the HXR spectrum in 10-50 keV is quite soft with γ~7 and there is no HXR emission above 50 keV. The magnetic configuration of the flaring region implies magnetic reconnection taking place at a relatively low altitude during the flare. Despite a very soft spectrum of the electron beam, its energy content is still sufficient to produce the heating in the lower atmosphere, where the continuum emission originates. This white-light flare highlights the importance of radiative back-warming to transport the energy below when direct heating by beam electrons is obviously impossible.

3.3. Magnetism and mechanism

Huang and Ji (2006) presented a multi-wavelength analysis on a flare on September 9, 2002 with data of Owens Valley Solar Arrays (OVSA), Big Bear Solar Observatory (BBSO), Ramaty High Energy Solar Spectroscopic Imager (RHESSI), and Extreme UV Imager Telescope (EIT), and The Michelson Doppler Imager (MDI) on board of the Solar and Heliospheric Observatory (SOHO). The radio sources at 4.8 and 6.2 GHz located in the intersection of two flaring loops at 195 of SOHO/EIT respectively with two dipole magnetic fields of SOHO/MDI, in which one EIT loop was coincident with an X-ray loop of RHESSI at 12 25 keV, and two Hα bright kernels a1 and a2 of BBSO, respectively at the two footpoints of this loop; the second EIT loop connected another two Hα kernels b1 and b2 and radio sources at 7.8 and 8.2 GHz of OVSA. The maximum phase of microwave bursts was evidently later than that of hard X-ray bursts and Hα kernels a1 and a2, but consistent with that of Hα kernels b1 and b2. Moreover, the flare may be triggered by the interaction of the two flaring loops, which is suggested by the cross-correlation of radio, optical, and X-ray light curves of a common quasi-periodic oscillation in the rising phase, as well as two peaks at about 7 and 9 GHz of the microwave spectra at the peak times of the oscillation, while the bi-directional time delays at two reversal frequencies respectively at 7.8 and 9.4 GHz (similar to the peak frequencies of the microwave spectra) may indicate two reconnection sites at different coronal levels. The microwave and hard X-ray footpoint sources located in different EUV and optical loops may be explained by different magnetic field strength and the pitch angle distribution of nonthermal electrons in these two loops.

Using one-minute cadence vector magnetograms from Big Bear Solar Observatory (BBSO), Tan et al. (2006a) analyze the temporal behavior of derived longitudinal electric currents associated with two flares on July 26, 2002. One of the events is an M1.0 flare which occurred in active region NOAA 10044, while the other is an M8.7 flare in the adjacent region 10039. Rapid changes of magnetic fields in the form of flux emergence are found to be associated with both of these events. However, the temporal behavior of electric currents is very different. For the M1.0 flare, the longitudinal electric current density drops rapidly near the flaring neutral line; while for the

M8.7 flare, the current density rapidly increases, confirming the picture of the current-carrying flux emergence. They offer a possible explanation for such a difference: magnetic reconnection at different heights for the two events, near the photosphere for the M1.0 flare, and higher up for the M8.7 flare. From the similarities in magnetic configurations and plasma behaviors between tokamaks and solar current-carrying plasma loops, Tan and Huang (2006) apply the theory of neoclassical bootstrap current in tokamaks to the solar plasma loops. They present a simplified expression of the bootstrap current in the solar plasma loops and find that there may be a considerable component of the neoclassical bootstrap current in some compact current-carrying solar flare loops; e.g. the fraction of the bootstrap current is up to 44.6% of a flare loop of the event that occurred on Aug. 25, 1999. They suggest that the neoclassical effect changes the current distribution and affects the instability of solar plasma loops. Based on the data analysis of SXT/Yohkoh, HXT/Yohkoh, GOES, and NoRP, it is found that the timescale of the neoclassical tearing modes is consistent with the rising time of the impulsive phase during the event, while the timescale of the classical tearing modes is much longer than that of the event, which may provide important evidence of the bootstrap current and help us understand the mechanisms of the eruptive events, such as solar flares, prominence, and CMEs.

Li and Gan (2006c) presented an altitude decrease of the flare loop-top X-ray sources during the early impulsive phase with the RHESSI observations. The relevant evidence for the loop shrinkage has also recently been provided based on the Nobeyama radio images at 34 GHz. In this Letter, through analyzing the images observed with TRACE and RHESSI for the M2.5 flare on 2002 April 16, they present a new argument for the loop shrinkage: TRACE 195 Å loop shrinkage. The results show that in the early impulsive phase of about 5 minutes, the 195 Å loop in the running difference images shrank by about 30%, suggesting a mean apparent downward speed of approximately 15.3 km s-1. This speed is nearly the same as that deduced from the RHESSI 12-25 keV energy band but is greater than 7.7 km s-1 deduced from the RHESSI 6-12 keV energy band. The temporal behavior of 195 Å loop shrinkage is consistent with that revealed from the RHESSI X-ray sources. Further study shows that the TRACE 195 Å loop shrinkage is in the form of an oscillation, with a period of about 150 s and an amplitude of about 300 km. They discuss this oscillatory shrinkage with respect to a theoretical reconnection model. After summarizing the geometric relationship of the RHESSI flare X-ray sources with the TRACE flare loops, and the motion modes of RHESSI flare X-ray sources, Gan and Li (2006) concentrate on the newly discovered downward motion of flare looptop X-ray source. In particular, they present a new argument for the flare loop shrinkage during the impulsive phase: TRACE 195 Å loop shrinkage. The temporal behavior of 195 Å loop shrinkage and its magnitude are consistent with that revealed from the RHESSI X-ray sources. Further study shows that the TRACE 195 Å loop shrinkage is in the form of oscillation, with a period of about 150 s and an amplitude of about 300 km. They discuss this oscillatory shrinkage with respect to a numerical simulation of reconnection model.

4. Coronal mass ejections

4.1. Statistics

Coronal mass ejections (CMEs) are often categorized into flare-associated and filament-associated types, which logically is incomplete since there are many CMEs of the intermediate type. With this new classification, Chen, A. Q. *et al.* (2006) reexamine whether flare-associated CMEs and filament eruption-associated CMEs have distinct velocity distributions and to investigate which factors may affect the CME velocities. The CME events observed from 2001-2003 are divided into three types, i.e., the flare-associated type, the filament eruption-associated type, and the intermediate type. The magnetic environments of the source regions, e.g., the polarity orientation, the chirality of the filaments, etc., are examined. Our results indicate that the P-value of the likelihood between the flare-associated and the filament eruption-associated CMEs is as high as 0.79, which strongly suggests that they are a continuum of events rather than two distinct types. For the filament eruption-associated CMEs, the speeds are found to be strongly correlated with the average magnetic field in the filament channel. It is also found that there is a slight tendency for the filaments with the minority chirality to have weaker magnetic fields, and hence the corresponding CMEs have smaller eruption speeds. A slight tendency is also found for the CMEs associated with non-active region filaments to have higher eruption speeds than those with active region filaments. However, the polarity orientation of the filament channel has little effect on the eruption speed.

4.2. Large-scale source regions

Based on SOHO/MDI, EIT, Yohkoh/SXT, Hα, and other relevant observations, Zhou *et al.* (2006b) analyzed all the earth-directed halo coronal mass ejections (CMEs) in the interval from Mar. 1997 to Dec. 2003. A total of 288 earth-directed CMEs were studied and their associated surface activity events identified. Unlike the previous studies that often attributed a surface activity event or a given active region to a CME source region, this statistical analysis puts emphasis on the large-scale magnetic structures of CMEs, in which the CME-associated surface activity takes place. All the CMEs are found to be associated with large-scale source structures. The identified large-scale structures can be grouped into four different categories: extended bipolar regions (EBRs), transequatorial magnetic loops, transequatorial filaments and their associated magnetic structures, and long filaments along the boundaries of EBRs. The relative percentages of their associated CMEs are 36%, 40%, 13%, and 11%, respectively. The analysis indicates that CMEs are intrinsically associated with source magnetic structures on a large spatial scale. In the sample of 301 well identified earth-directed halo coronal mass ejections (CMEs) from March 1997 to December 2003, Zhou *et al.* (2006c) analyze all 21 CMEs associated with polar crown filament (PCF) eruptions. Here, the PCFs are viewed as the filaments that partially or totally lie along the boundaries of polar coronal holes, with average length over 1000″, and are intrinsically associated with extended bipole regions (EBRs). The current approach focuses on the CME properties and the flux change in the filament channels. According to the magnetic configurations where the PCFs lie, three classes of PCFs are identified. CMEs present distinguishable velocity distributions associated with each type of PCFs. About 28% of these CMEs present geoeffective. Approximately, 10^{15} Mx S-1 magnetic flux inflow into the filament channel and several times of 10^{20} Mx flux changed during the course of PCF eruption, which are speculated to trigger the PCF eruptions.

Wang J. X. *et al.* (2006) revisit the Bastille Day flare/CME Event of 2000 July 14. They demonstrate that this flare/CME event is not related to only one single active region (AR). Activation and eruption of a huge transequatorial filament are seen to precede the simultaneous filament eruption and flare in the source active region, NOAA AR 9077, and the full halo-CME in the high corona. Evidence of reconfiguration of large-scale magnetic structures related to the event is illustrated by SOHO EIT and Yohkoh SXT observations, as well as, the reconstructed 3D magnetic lines of force based on the force-free assumption. They suggest that the AR filament in AR 9077 was connected to the transequatorial filament. The large-scale magnetic composition related to the transequatorial filament and its sheared magnetic arcade appears to be an essential part of the CME parent magnetic structure. Estimations show that the filament-arcade system has enough magnetic helicity to account for the helicity carried by the related CMEs. In addition, rather global magnetic connectivity, covering almost all the visible range in longitude and a huge span in latitude on the Sun, is implied by the Nançay Radioheliograph (NRH) observations. The analysis of the Bastille Day event suggests that although the triggering of a global CME might take place in an AR, a much larger scale magnetic composition seems to be the source of the ejected magnetic flux, helicity and plasma. The Bastille Day event is the first described example in the literature, in which a transequatorial filament activity appears to play a key role in a global CME. Many tens of halo-CME are found to be associated with transequatorial filaments and their magnetic environment.

Based on five flare/CME events, the Large-Scale Magnetic Connectivity in CMEs is investigated (Zhang, Y. Z. *et al.* 2006). One is on May 12, 1997, for which there is only two active regions on the visible solar disc, and the magnetic configuration is rather simple. For other cases, many active regions were visible. They are the flare/CME events that occurred on Bastille Day of 2000, Oct. 28, 2003, Nov. 7, 2004 and Jan. 20, 2005. By tracing the spread of EUV dimming, which was obtained by SOHO/EIT 195 Å fixed-difference images, they studied the CME initiation and development on the solar disc. At the same time they reconstructed the 3D magnetic structure of coronal magnetic fields, extrapolated from the observed photospheric magnetograms by SOHO/MDI. In scrutinizing the EUV brightening and dimming propagation from CME initiation sites to large areas with different magnetic connectivities, they determine the overall coupling and interacting of multiple flux systems in the CME processes. Several typical patterns of magnetic connectivity are described and discussed in the view of CME initiation mechanism or mechanisms.

4.3. CME initiation

Yan *et al.* (2006) present a detailed analysis, based on multiwavelength observations and magnetic field extrapolation, of a radio and X-ray event observed on March 17, 2002. This event was accompanied by a Coronal Mass Ejection (CME) observed by the Large-Angle Spectrometric Coronagraph (LASCO) aboard SOHO. During the main event, the Reuven Ramaty High-Energy

Solar Spectroscopic Imager (RHESSI) mission observed a hard X-ray emission correlated in time with the development of a type III burst group. The CME development, the hard X-ray emission, and the type III burst group appear to be closely associated. The multifrequency Nançay Radioheliograph (NRH) shows that the type III bursts are produced at a distance from the active region that progressively increases with time. Their emitting sources are distributed along the western edge of the CME. They conclude the type III electron beams propagate in the interface region between the ascending CME and the neighboring open field lines. Due to the development of the CME, this region becomes progressively highly compressed. By measuring, at each frequency, the shift versus time of the type III positions, they estimate that the electron density in this compression region increased roughly by a factor of 10 over a few minutes. Another signature of this compression region is a narrow white light feature interpreted as a coronal shock driven by the CME lateral expansion.

Cheng *et al* (2006b) present Two candidate homologous CMEs occurring on 2002 May 22, originating from the same active region, AR 9948. Multi-wavelength data are collected in order to clarify the relationship between the CMEs, the associated flares and filament eruptions, and some other magnetic activities, which is of great importance to understand the mechanism of each phenomenon. It is tentatively suggested that the two CMEs are probably homologous. Bao *et al* (2006) report the investigation of a typical coronal mass ejection (CME) observed on 2003 February 18, by various space and on ground instruments, in white light, H-alpha, EUV and X-ray. The H-alpha and EUV images indicate that the CME started with the eruption of a long filament located near the solar northwest limb. The white light coronal images show that the CME initiated with the rarefaction of a region above the solar limb and followed by the formation of a bright arcade at the boundary of the rarefying region at height 0.46 solar radii from the solar surface. The rarefying process synchronized the slow rising phase of the eruptive filament, and the CME leading edge was observed to form as the latter started to accelerate apparently. The lower part of the filament was brightened in H-alpha images as the filament rose to a certain height and parts of the filament was visible in the GOES X-ray images during the rise. These brightenings imply that the filament may be heated by magnetic reconnection below the filament in the early stage of the eruption. They suggest that the possible mechanism which lead to the formation of the CME leading edge and cavity is the magnetic reconnection which takes place below the filament after the filament has reached a certain height.

It has been commonly accepted that coronal mass ejections result from the restructuring or reconfiguring of large-scale coronal magnetic fields. Wen et al (2006) analyzed four CME events using Nancay Radioheliograph (NRH) images and the experiments onboard the Solar and Heliospheric Observatory (SOHO) spacecraft to understand the coronal restructuring leading to CME initiation. They investigated the onset, duration, and position of the radio emissions in relation to EUV dimming and the inferred CME onset. Wen *et al.* (2006) also report that the early CME development on the solar disk is characterized by a series of distinct radio bursts. These non-thermal radio sources appeared in phase with coronal dimming shown by SOHO-EIT images, and located within the EUV dimming or on-going dimming regions. Three time scales are identified: the duration, the separation of individual radio bursts, and the overall time scale of all the non-thermal sources. They fall in the ranges of approximate tens of seconds to three minutes, one to three minutes, and 15-20 minutes, respectively. The individual radio emission seems to shift and expand at the speed of the fast magneto-acoustic waves in the corona; while the non-thermal radio emissions as a whole appear episodically to correspond to the successive coronal restructuring. If they define the triggering speed by dividing the overall spatial scale by the temporal scale of all the radio bursts, then the triggering speed falls in the range of 300-400 km/s. This implies that the general process of coronal restructuring and reconfiguring takes place at a speed slower than either the Alfvenic or acoustic speed in the corona. This is a type of speed of ``topology waves", i.e. the speed of successive topology changes from closed to open field configuration.

Coronal mass ejections CMEs are primary driver of disastrous space weather As large scale ejections of solar magnetic flux and magnetized plasma CMEs present a major challenge in solar physics and space science CME initiation is one of the most important issues which have not been resolved so far. To understand the initiation of CMEs, the detailed knowledge of CME source regions and triggering magnetism and activity is needed. Wang, J. (2006b) briefly review the current understanding and future trend in the relevant studies and discuss the urgently needed observations for future progress. It is particularly argued that the Chinese Kuafu Mission characterized by simultaneous monitoring the on-disk and outer coronal activities and their consequence in geo-space will be an ideal tool to grasp the details of CME initiation and to evaluate the geoeffectiveness of the on-going CMEs.

In 1985, a phenomenon in the solar photosphere, called magnetic flux cancellation, was first described in detail by Livi et al. (1985) [The cancellation of magnetic flux. I – On the quiet sun, *Aust. J. Phys.* 38, 855–873, 1985] and Martin et al. (1985) [The cancellation of magnetic flux. II – In a decaying active region, *Aust. J. Phys*. 38, 929–959, 1985]. Since then, it has been revealed that flux cancellation is intrinsically correlated to most, if not all, types of solar activity, such as flare, filament formation and eruption, and ubiquitous small-scale activity, e.g., X-ray bright point, explosive event, mini-filament eruption and so on. Only recently, it was discovered that flux cancellation appeared to be a key part of magnetic evolution leading to the initiation of coronal mass ejections (CMEs) [Zhang et al., Magnetic flux cancellation associated withthe major solar event on 2000 July 14. *ApJ.* 548, L99–102, 2001; Zhang et al., 2001b. Filament-associated halo coronal mass ejection, Chin. J. Astron. Astrophys., 1, 85–98, 2001; Zhang and Wang, Filament eruptions and halo coronal mass ejections, Astrophys. J. 554, 474–487, 2001]. On the other hand, the nature of flux cancellation has been a topic of persistent interest and debate. Wang, J. (2006c) review the observational properties of magnetic flux cancellation and the relevant theoretical studies, describe the vector magnetic field changes in flux cancellation in CME-associated active regions (ARs), and demonstrate that the well-observed flux cancellations fit nicely the scenario of magnetic reconnection in the lower solar atmosphere. It is suggested that magnetic reconnection in the lower solar atmosphere is a ubiquitous process on the Sun. It is a key element in the magnetic evolution of CMEs.

Zhou *et al.* (2006a) describe a clear case of the initiation of a propagating bright arc and a CME on 2002 December 28, which were associated with an eruptive prominence. In EIT 304 and 195 Å images, a very long filament showed evidence of severe twisting in one of its fragments, which appeared as a prominence on December 26; then, the prominence showed the conversion of its twist into writhe. Two days later, the prominence displayed a slow rising motion for hours.

Internal twisting and mass motion took place before the rapid acceleration and final eruption. The propagating bright arc and the following CME corresponded to the early rising and the subsequently eruptive phases of the prominence, respectively. Signatures of magnetic reconnection, i.e., a cusp structure and postflare loops in EUV wave bands and hard X-ray sources in the corona, were observed after the prominence eruption. It appears that the kink instability and the mass drainage in the prominence played key roles in triggering the initiation of the CME. However, the rather impulsive acceleration of the CME resulted from magnetic reconnection beneath the filament.

4.4. Waves and dimmings

Using H_α, EUV, photospheric magnetic field and white-light coronagraph data, Jiang, Y. C. *et al.* (2006a) study the eruption of an active-region H_α filament and associated partial-halo type coronal mass ejection (CME) occurring in NOAA AR 9616 on September 17, 2001. Accompanied by an M1.5 flare, the small active-region filament quickly erupted, a quiet-sun region outside the active region intensively darkened so a remote coronal dimming region was formed, and then a long H_α surge developed from the eruption site. During the eruption, remote EUV brightening appeared along the dimming boundary, leaving behind huge EUV loops connecting the eruption source region and the remote EUV brightening. Finally, as a definite indication of the start of CME, a large-scale dark rim appeared to span the eruption region. These observations indicate that a much larger-scale rearrangement of the coronal magnetic fields, eventually represented by the occurrence of the CME, was involved in the eruption of the filament with small spatial scale. The relationship between the filament eruption, flare and coronal dimming is also discussed.

Jiang, Y. C. *et al.* (2006b) report the eruption of a small filament on September 28, 2001. Followed by a two-ribbon flare, the eruption was associated with a partial halo coronal mass ejection. During the eruption, coronal bipolar double dimmings were formed on the regions of opposite magnetic polarities. The optical counterparts of the coronal dimmings, i.e., the Hα dimmings, were clear and showed similar appearance and consistent development. A remarkable fact is that the two dimmings were preceded by impulsive EUV and Hα brightenings at the flare's rise phase, suggesting that the eruption can be explained by the tether-cutting model. A filament eruption near the center of the solar disk on 1999 March 21 is also reported by (Jiang, Y. C. *et al.*, 2006c), based on multi-wavelength observations by the *Yohkoh* Soft X-Ray Telescope (SXT), the Extreme-ultraviolet Images Telescope (EIT) and the Michelson Doppler Imager (MDI) on the *Solar and Heliospheric Observatory* (SOHO). The eruption involved in the disappearance of an Hα filament can be clearly identified in EIT 195Å difference images. Two flare-like EUV ribbons and two obvious coronal dimming regions were formed. The two dimming regions had a similar appearance in lines formed in temperature range 6 x 10^4K to several 10^6K. They were located in regions of opposite magnetic polarities near the two ends of the eruptive filament. No significant X-ray or Hα flare was recorded associated with the eruption and no obvious photospheric magnetic activity was detected around the eruptive region, and particularly below the coronal dimming regions. The above surface activities were closely associated with a partial halo-type coronal mass ejection (CME) observed by the Large Angle and Spectrometric Coronagraphs (LASCO) on the SOHO. In terms of the magnetic flux rope model of CMEs, it is explained these multiple observations as an integral process of large-scale rearrangement of coronal magnetic field initiated by the filament eruption, in which the dimming regions marked the evacuated feet of the flux rope.

In order to determine whether EIT waves are generated by CMEs or pressure pulses in solar flares, Chen (2006) studied 14 non-CME-associated energetic flares, which should possess strong pressure pulses in their loops. These flares are selected near solar minimum, as this favors the detection of EIT waves. It is found that none of these flares are associated with EIT waves. Particular attention is paid to AR 0720, which hosted both CME-associated and non-CME types of flares. The SOHO/EIT images convincingly indicate that EIT waves and expanding dimmings appear only when CMEs are present. Therefore, it is unlikely that pressure pulses from flares generate EIT waves. EIT waves are often observed to be propagating EUV enhancements followed by an expanding dimming region after the launch of CMEs. It was widely assumed that they are the coronal counterparts of the chromospheric Moreton waves, though the former are three or more times slower. The existence of a stationary "EIT wave" front in some events, however, posed a big challenge to the wave explanation. Chen *et al.* (2006a) perform simulations to reproduce the stationary "EIT wave" front, which is exactly located near the footpoint of the magnetic separatrix, consistent with observations. The formation of the stationary front is explained in the framework of our model where “EIT waves” are supposed to be generated by successive opening of the field lines covering the erupting flux rope in CMEs.

4.5. CME interplanetary counterparts

To study interplanetary magnetic clouds (IMCs), it is important to find their configurations and boundaries from the observed magnetic field data. Feng *et al.* (2006) presents a novel method of identifying the configuration and boundaries of IMCs, where in the interplanetary magnetic field data, which are measured in the Geocentric Solar Ecliptic (GSE) coordinate system, are converted into an IMC natural coordinate system that can more clearly display the configuration and boundaries of the IMC as a flux tube. The establishment of the natural coordinate system is based on the idea that the IMC is a flux rope with approximately constant a force-free field configuration. They also apply this method to analyze four IMCs observed by the Wind spacecraft. Two of them are identified as having the flux rope configuration lying in the eclipticplane, and the other two are flux ropes vertical to the eclipticplane. The results demonstrate that our method can work well for real IMCs.

On the basis of previous works, Lin, J. *et al.* (2006) investigated CME propagations and the consequent type II radio bursts invoked by the CME-driven shocks. The results indicate that the onset of type II bursts depends on the local Alfvén speed (or the magneto-acoustic wave speed in the non–force-free environment), which is governed by both the magnetic field and the plasma density. This determines that the type II burst cannot appear at any altitude. Instead, its onset positions can never be lower than a critical height for the given coronal environment, which consequently determines the start frequencies of the emission: for an eruption taking place in the magnetic configuration with a background field of 100 G, the onset of type II bursts should occur at around 0.5 $R_\odot$ from the solar surface, and the corresponding start frequency of the fundamental component is about 150 MHz. This result is consistent with similar estimates based on observations that bring the corresponding frequency to a few hundred MHz. Our results further indicate that the onset of type II bursts depends on the rate of magnetic reconnection as well. When magnetic reconnection during the eruption is not fast enough, a type II burst may not occur at all even if the associated CME is fast (say, faster than 800 km s^{-1}). This may account for the fast and radio-quiet CMEs. Related to these results, properties of the associated solar flares and type III radio bursts, especially those used as the precursors of the type II radio bursts, are also discussed.

5. Solar energetic particles

5.1 Anisotropic and mass-dependent energization of heavy ions Ion acceleration

Some recent observations of the solar corona suggest that the heavy ions undergo an anisotropic (mainly across the magnetic field) and mass-dependent energization. Wu and Yang (2006) investigate the nonlinear interaction of heavy ions with kinetic Alfvén waves, in particular, their energization in the nonlinear kinetic Alfvén waves. Methods. Based on a three-component plasma model including electrons, protons, and heavy ions, a localized nonlinear structure of kinetic Alfvén wave is presented. In the nonlinear wave, the heavy ions are energized in the cross-field and field-aligned by the perpendicular polarization and the parallel acceleration of the wave electric field. Results. It is found that the ion cross-field energization depends on its mass and abundance in the same way that the velocity is proportional to the mass-charge ratio and decreases with the abundance ratio. On the other hand, the ion field-aligned energy is proportional to the charge, but is free of the mass and abundance. In the low abundance case (<10%), in particular, the minor heavy ions have strongly anisotropic temperature as well as are hotter and flow faster than protons. The resulting ion-proton temperature ratio is proportional to the mass number and the square of the mass-charge ratio, and the ion perpendicular-parallel temperature ratio is proportional to the cube of the mass-charge ratio. This anisotropic and mass-dependent energization mechanism by kinetic Alfvén waves for ions can be potentially important for understanding the microphysics of the energization of minor heavy ions observed in the solar corona. Kaladze and Wu (2006) reported that the nonlinear theory of vertical Rossby wave motion is applied to explain the detection of solitary structures in the solar photosphere. It is shown that the shallow-water approximation of the Rossby theory is perfectly consistent with the experimental data from the photosphere.

5.2. Electronics accelerations

Huang et al. (2006b) studied the 1998 November 28 X-class flare, which showed long-duration, two-ribbon α emission. (1) A soft X-ray loop system developed along the major magnetic neutral line in the impulsive phase. Hard X-ray and microwave emissions due to nonthermal electrons were located in some limited regions. While the compact hard X-ray loop was associated with weak, diffuse soft X-ray emission, two large microwave loops did not have soft X-ray counterparts.

(2) Time profiles of two large microwave loops were similar to that of hard X-ray total emission, which emanated mostly from the compact source, even in the fine time structure in the rising phase. (3) A super-hot thermal hard X-ray source appeared around the impulsive peak and was located along the major magnetic neutral line in the declining phase, coinciding with the bright soft X-ray emission. The thermal component can be explained within the standard reconnection model to the extent that the super-hot thermal plasma was heated in the large soft X-ray loop. However, the nonthermal electrons were accelerated in a localized region where three loops interacted with each other.

To study MHD shocks in space, it is important to find the shock frame of reference from the observed plasma and magnetic field parameters. These shock parameters have to satisfy the Rankine-Hugoniot relations. Lin C.C. et al. (2006) present a novel procedure for shock fitting of the one-fluid anisotropic Rankine-Hugoniot relations and of the time difference between two spacecraft observations in the case of small He^{2+} slippage. Here, a Monte-Carlo calculation and a minimization technique are used. The observed variables including the upstream and downstream magnetic fields, plasma densities, plasma betas, plasma anisotropies, W (the difference between the downstream and upstream velocities, W=V2-V1), and δt (the time difference between two spacecraft observations) are used in our procedure where V is defined as the center of mass velocity of plasmas. A loss function based on a difference between the calculated and the observed values is defined, and the best fit solution is found by searching for the minimum loss function value. For shocks that cannot be fitted well, they introduce two new parameters in the modified R-H relations, one in the normal momentum flux and the other in the energy flux equations. These two parameters are interpreted as the equivalent “normal momentum” and “heat” fluxes needed in the R-H relations. They provide two degrees of freedom in the system, and their amounts can be estimated from our procedure. Several synthetic shocks are given to verify our procedure. They also apply this procedure to two interplanetary shocks observed by both the WIND and Geotail spacecraft. The results demonstrate that our method works for both the synthetic and the real shocks. The method can provide accurate shock normal estimations for perpendicular and parallel shocks as well. Given that the model is based on the RH relations that do not include the effect of alpha particle (He^{2+}) slippage, it can only be applied to the cases with an ignorable slippage pressure tensor. We have investigated the pressure tensor due to alpha particle slippage using the WIND spacecraft data. It is found that in general the slippage pressure is small in comparison with the thermal pressure of the system and can be ignored. Thus the model can be applied to most interplanetary shocks observed near the ecliptic plane. However, when the slippage pressure is large, the magnetic coplanarity theorem is not valid any more. A more general model that involves slippage pressure tensor is a major and important development that is beyond the scope of the present study.

Trotte et al. (2006) present a detailed analysis of spectral and imaging observations of the November 5, 1998 (Hα 1B, GOES M1.5) flare obtained over a large spectral range, i.e., from hard X-rays to radiometric wavelengths. These observations allowed us to probe electron acceleration and transport over a large range of altitudes that is to say within small-scale (a few 103 km) and large-scale (a few 10^5 km) magnetic structures. The observations combined with potential and linear force-free magnetic field extrapolations allow us to show that: (i) Flare energy release and electron acceleration are basically driven by loop–loop interactions at two independent, low lying, null points of the active region magnetic field; (ii) <300 keV hard X-ray-producing electrons are accelerated by a different process (probably DC field acceleration) than relativistic electrons that radiate the microwave emission; and (iii) although there is evidence that hard X-ray and decimeter/metric radio-emitting electrons are produced by the same accelerator, the present observations and analysis did not allow us to find a clear and direct magnetic connection between the hard X-ray emitting region and the radio-emitting sources in the middle corona.

5.3. solitary kinetic Alfven waves

After the charge of heavy ions is considered, Yang and Wu (2006) obtained a Sagdeev equation for solitary kinetic Alfven waves (SKAWs) in a low-beta plasma with three components (electrons, protons, and ions). Numerical results show that the charge number of heavy ions q can cause the width of the solitary structure to decrease, but the density amplitude to increase.

5.4. solar energetic particles

Solar energetic particles (SEPs) from large solar flares give important information about the physical process in the solar corona and the heliosphere. Several observations have indicated that solar protons could sometimes be accelerated to at least tens of GeV, even hundreds of GeV, in intense solar energetic process. Wang R. and Wang J. (2006a) studied the solar proton differential energy spectra with energy range of 1 500 MeV at several time intervals during Bastille Day event. It was shown that the spectra could be fitted by a power law function before flare and after flare the power law spectra still existed above 30 MeV although spectra became softer with time. There was a spectral "knee" occurring at ˜30 MeV. They constructed a solar proton differential spectrum from 30 MeV to 3 GeV at peak flux time 10:30 UT and fitted it in the same manner. On the basis of a supposition of having the same power law spectrum in higher energy, they calculated the solar proton integrated fluxes in energy range of from 500 MeV to 20 GeV and compared them with other results obtained from experimental, modelling and theoretical calculations in other big historic SEP events. A Monte Carlo simulation was carried out for a primary proton beam at the top of the atmosphere producing secondary muons on the ground. Based on the simulation, possibility of registering the solar energetic proton beams with energies over 20 GeV was discussed.

Wang, R. (2006) present a statistical study of 163 solar proton events (SPEs) associated with X-ray flares, coronal mass ejections (CMEs) and radio type II bursts during January 1997–June 2005. These SPEs were categorized by the peak fluxes of >10 MeV solar protons into three groups. There are 37 large SPEs with fluxes of more than 100 protons cm-2 s-1 sr-1, 34 moderate SPEs with flux ranges of 10–100 protons cm-2 s-1 sr-1 and 92 minor SPEs with flux ranges of 1–10 protons cm-2 s-1 sr-1. To understand the determinant of solar proton events, they have examined the association of these SPEs with X-ray flares, CMEs and radio type II emissions from metric to decametric-hectometric (DH) wave ranges. The primary results from this study are: (1) most SPEs (112/163) corresponded to the solar flares favorably located at solar western hemisphere and the center of the activity source region tended to shifted to the west with increasing of the solar proton fluxes; (2) there seems a longitudinal cutoff for each group of SPEs, which also moves toward west with increasing of the solar proton flux; (3) each SPE observed at Earth was associated with a fast (average speed ~1228 km s^{-1}) and wide (average angle width of 266°) CME; (4) the percentage of these SPEs associated with metric (DH) type II burst increased from 54% (42%) to 81% (100%). Overall, The most intensive SPEs are more likely to be produced by major flares located near central meridian of the Sun and shock waves driven by very fast halo CMEs (v>=

1600 km s^{-1}). This suggested that CME-driven shock acceleration is a necessary condition for large SPEs production.

An investigation of the cosmic ray ground level enhancements during solar cycle 23 is also performed by Wang R. and Wang J. (2006b). Major solar energetic particle events associated with large solar flares can give rise to cosmic ray ground level enhancements (GLEs). Up to December 2003 during solar activity cycle 23, 13 GLEs (Number from 55 to 67) have been recorded by the worldwide network of neutron monitors. Nine of the 13 GLEs (69%) originated from the southern hemisphere and 11 of the 13 GLEs (85%) originated from the western hemisphere. All GLEs originated from the solar activity region within a latitude strip between S20° and N40° and a longitude west of E10°. Each GLE corresponds to a solar fast coronal mass ejection (CME) which had the potential of producing disturbances to the geospace. The average speed of CMEs is high up to 1762 km s-1. Among the 13 relevant CMEs 9 are responsible for nine major geomagnetic storms (defined by disturbance storm time index ~ -100 nT). The largest four geomagnetic storms (Dst ~ -277 nT) correspond to the four GLEs (Nos. 59, 62, 65 and 66) which have the highest proton flux with energy >10 MeV. It seems to imply that the solar proton events (SPEs) having great proton flux are more likely to be associated with major geomagnetic storms. Simultaneous existence of high flux SPEs, high optical flare classification, and fast halo CMEs near the central meridian of the Sun, as well as GLEs may be an effective indicator for predicting the occurrence of a strong geomagnetic storm.

6. Radio Solar physics

6.1. Fine structures in radio dynamic spectrum

Based on the data from the Nobeyama Radioheliograph (NoRH) and the Nobeyama Radio Polarimeters (NoRP) during the well-studied flare/CME event of 2002 April 21, Huang and Lin (2006) investigate high spatial resolution radio polarization of this event. A 17 GHz radio source at the loop top was seen by NoRH to move upward together with the expanding flare loops at a speed of around 10 km s-1. In the 5 minutes before the source began its upward motion, the Stokes V of the radio signals at 17 GHz showed quasi-periodic reversals between left-circular polarization (LCP) and right-circular polarization (RCP). Following this interval, the polarizations gradually turned to LCP. During this period, the polarization of the corresponding footpoint source maintained the RCP sense. The reversal of Stokes V between RCP and LCP was also detected at lower frequencies (1-2 GHz) by NoRP, without spatial resolution. The observed reversals between RCP and LCP of the radio signals from the top of the flare loop system can be taken as evidence that magnetic energy is released or energetic particles are produced at the magnetic reconnection site in a quasi-periodic fashion.

On April 21, 2002, a broadband solar radio burst was observed at about 01:00 - 03:00 UT with the digital spectrometers of National Astronomical Observatories of China (Wang and Zhong 2006). Also many fiber bursts superposed on the continuum bursts were detected in the frequency range of 2.6 – 3.8 GHz during the time interval. After data processing, some parameters of the fibers such as frequency drift rate, duration, bandwidth, and relative bandwidth were determined. The mean value of the frequency drift was in the range of 42.3 – 87.4 MHz s-1 (negative). A theoretical interpretation for the fibers was presented based upon a model of the velocity of Alfvén solitons. In this model, the source of the fiber emission was considered as the ducting of the solitons within the magnetic-mirror loop. Then the magnetic field strength of the fiber source was estimated to be about 130 ~ 270 G. Also a comparison of the magnetic field estimation was made with another model of whistler group velocity.

Ledenev et al. (2006) reported that "zebra-pattern" in solar continuum events (in type IV bursts) can be formed as a result of interference between direct and reflected rays coming from a source of small size in a stratified atmosphere. The emission is generated by plasma mechanism. Full emission flux is contributed from a great number of narrow-band short-lived sources of small sizes, which are formed by plasma waves captured in density minima of background plasma fluctuations. Chernov et al. (2006) present results of the first simultaneous observations of zebra patterns with super-fine spiky structure in the microwave range made at two observatories ˜1000 km apart (Beijing and Nanjing, China). The fine structure was recorded by a spectra polarimeter in the 5.2 – 7.6 and 2.8 – 3.6 GHz ranges at the Huairou station and by the spectrometer in the 4.5 – 7.5 GHz range at the Purple Mountain Observatory. Simultaneously, the locations of radio sources were observed by the Siberian Solar Radio Telescope (SSRT) at 5.7 GHz. For a general analysis of the April 10, 2001 event, the Solar and Heliospheric Observatory/Michelson Doppler Imager

(SOHO/MDI) data and Transition Region and Coronal Explorer (TRACE) images in EUV 171 Å line were used. The circular polarization degree was very weak for the burst background radio emission and moderate to strong for the fine structure. The polarization sign in all the cases probably corresponds to the extraordinary wave mode. Estimations of the magnetic field values in the whistler model for fine structure agree well with the extrapolated values from magnetic maps. Given the possibility of wave transformation in the perpendicular magnetic field and the spiky structure of the ZP, the whistler wave model appears to be the most appropriate explanation for the zebra stripe phenomenon.

The sources of six impulsive ^{3}He-rich solar energetic particle events were identified using imaging radio, optical, and energetic ion and electron data, together with calculated coronal fields obtained from extrapolating photospheric magnetograms using a potential field source surface (PFSS) model (Pick et al., 2006). These events were all studied in 2006 by Wang et al., who identified the particle sources as typically small, flaring active regions lying next to a coronal hole containing Earth-directed open field lines, located between W33° and W65°. By introducing radio imaging data it is conclusively identified that one of two simultaneous EUV jets was associated with the particle source. In addition, type III radio burst and energetic electron data introduced in this study constrain the injection times much more accurately than possible with low-energy ion data used in Wang et al. These new observations confirm the source identifications of Wang et al. and remove many of the remaining uncertainties. All of these events were associated with narrow, fast coronal mass ejections (CMEs), which are unusual for ^{3}He-rich solar energetic particle (SEP) events. Although the CMEs generally were ejected in directions well off the ecliptic plane, the PFSS calculations show the presence of magnetic field lines that made it possible for the energetic particle to quickly reach Earth. Some of these impulsive events were observed during periods in which ^{3}He was observed continuously over several days.

6.2 Statistics of type III burst

A detailed statistics and analysis of 264 type III bursts is performed based on the observations with the 625–1500 MHz spectrograph during the 23rd solar cycle (from July 2000 to April 2003, Ma Y. et al., 2006a). The main statistical results are similar to those of microwave type III bursts presented in the literature cited, such as the correlation between type III bursts and flares, polarization, duration, frequency drift rate (normal and reverse slopes), distribution of type III bursts and frequency bandwidth. At the same time, the statistical results also point out that the average values of the frequency drift rates and degrees of polarization increase with the increase in frequency and the average value of duration decreases with the increase in frequency. Other statistical results show that the starting frequencies of the type III bursts are mainly within the range from 650 to 800 MHz, and most type III bursts have an average bandwidth of 289 MHz. The distributions imply that the electron acceleration and the place of energy release are within a limited decimetric range. The characteristics of the narrow bandwidth possibly involve the magnetic configuration at decimetric wavelengths, the location of electron acceleration in the magnetic field near to the main flare, the relevant runaway or trapped electrons, or the coherent radio emission produced by some secondary shock waves. In addition, the number of type III bursts with positive frequency drift rates is almost equal to that with negative frequency drift rates. This is probably explained by the hypothesis that an equal number of electron beams are accelerated upwards and downwards within the range of 625 to 1500 MHz. The radiation mechanism of type III bursts at decimetric wavelengths probably includes these microwave and metric mechanisms and the most likely cause of the coherent plasma radiation are the emission processes of the electron cyclotron maser. Ma, Y. et al. (2006b) presented a statistics analyses of the microwave type III bursts, coronal mass ejections (CMEs), Hα flare and relevant events observed with 5200-7600 MHz spectrograph at the Chinese National Astronomical Observatory during the 23^{rd} solar cycle are carried out in this article. Some significant results are obtained from the relevant events. The radiation mechanism of that is also discussed from the observation characteristics.

7. Theoretical studies and MHD simulations

7.1 Dynamo theory

Using the Chebyshev-tau method, Jiang and Wang (2006) studied the generation of oscillatory non-axisymmetric stellar magnetic fields by the α^2-dynamo in spherical geometry. Following the boundary conditions given by Schubert & Zhang, the spherical α^2-dynamo consists of a fully convective spherical shell with inner radius r_i and outer radius r_o. A comparison of the critical dynamo numbers of axisymmetric and phi-dependent modes for different thicknesses of the convective shell and different α-profiles leads to the following qualitative results: (i) when the angular factor of α-profile is $\sin^n\theta\cos\theta$ (n = 1,2,4) the solutions of the α^2-dynamo are oscillatory and non-axisymmetric, (ii) the thinner the convective shell, the more easily is the non-axisymmetric mode excited and the higher is the latitudinal wave number, (iii) the thickness of the outer convective shell has an effect on the symmetries of the magnetic fields.

7.2. Extrapolation of magnetic fields in solar atmosphere

Song *et al.* (2006) reexamine the method of upward integration of a nonlinear force-free field (NFFF), which is, as is well known, an ill-posed problem. It can be modified to a well-posed one by the following means: instead of using finite difference to express partial derivatives, they use smooth continuous functions to approach magnetic field values, write down three field components consisting of amplitude functions multiplying morphology functions, and reduce four basic NFFF equations to ordinary differential ones. They are then solved in an asymptotic manner (zeroth-order, first-order, etc.). Considering the physical meaning of α, they found a self-consistent compatibility condition for the boundary values. Furthermore, a computation algorithm is proposed, similar to the usual time-dependent two-dimensional MHD simulation scheme. This algorithm is steady and robust against the noise in the magnetic field (in particular, the transverse field) measurement and is able to deal with concentrated photospheric currents. The algorithm runs very fast on an ordinary PC and lasts only 6 minutes for the 80×60 (x×y) mesh up to a height of 80 (= 216,000 km~0.3 R_{solar}). So it provides a powerful tool for solar scientists to analyze the magnetic field properties of solar active regions and to make predictions of solar activity.

A direct boundary integral formulation for a force-free magnetic field with finite energy content in the semispace above the Sun is given by Yan and Li (2006a). This is a new formulation for a three-dimensional nonlinear force-free field in which the boundary data can easily be incorporated. They have proposed an optimal method to numerically find the non-constant-α force-free field solution at any position in semispace. Therefore, the present computational procedure for the new representation is actually a pointwise method, so that no volume integration is needed. A test case study has been carried out to demonstrate the convergence, accuracy, and efficiency of the numerical procedures. The computational procedure is quite robust. The agreement between numerical and exact results validates the correctness and merits of the new formulation and computational procedure proposed. The application of the new direct boundary integral formulation to practical solar magnetic field problems is straightforward and prospective.

As a representation for the force-free magnetic field in the solar atmosphere, which is proposed by Yan & Sakurai, He and Wang (2006) suggest the boundary integral equation (BIE) . By using the force-free solutions given by Low & Lou, the validity of this method for magnetic extrapolation in open space above a spherical surface is checked. The magnetic fields selected for the examination have different ranges of α values that represent the extents to which the force-free fields deviate from the potential field. The field points selected for calculation cover the altitude ranging from $1.1R_0$ to $2.5R_0$, where R_0 denotes the radius of the spherical surface. The results of the examination support the application of the BIE method to large-scale and global extrapolation of the force-free magnetic field in open space above a spherical surface. The calculations also show that, for a complex force-free field with a large range of α values, the volume integral equation in the BIE method has a poor convergence property and more computing time is needed to obtain a meaningful result, whereas the altitude of the field point does not influence the convergence speed.

7.3. MHD simulation

For studying a flux rope eruption caused by magnetic reconnection with implication in coexistent flare-CME events, a time-dependent resistive magnetohydrodynamic simulation is carried out (Zhang, Y. Z. *et al.* 2006). An early result obtained in a recent analysis of double catastrophe of a flux rope system is used as the initial condition, in which an isolated flux rope coexists with two current sheets: a vertical one below and a transverse one above the flux rope. The flux rope erupts when reconnection takes place in the current sheets, and the flux rope dynamics depends on the reconnection sequence in the two current sheets. Three cases are discussed: reconnection occurs (1) simultaneously in the two current sheets, (2) first in the transverse one and then in the vertical one, and (3) in an order opposite that of case 2. Such a two-current-sheet reconnection exhibits characteristics of both magnetic breakout for CME initiation and the standard flare model.

7.4. magnetic reconnection

Magnetic reconnection is one of the most important processes in astrophysical, space and laboratory plasmas. Identifying the structure around the point at which the magnetic field lines break and subsequently reform, known as the magnetic null point, is crucial to improving our understanding of reconnection. But owing to the inherently three-dimensional nature of this process, magnetic nulls are only detectable through measurements obtained simultaneously from at least four points in space. Using data collected by the four spacecraft of the Cluster constellation as they traversed a diffusion region in the Earth's magnetotail on 15 September 2001, Xiao *et al.* (2006) report here the first in situ evidence for the structure of an isolated magnetic null. The results indicate that it has a positive-spiral structure whose spatial extent is of the same order as the local ion inertial length scale, suggesting that the Hall effect could play an important role in 3D reconnection dynamics.

Transition-region explosive events (TREEs) have long been proposed as a consequence of magnetic reconnection. However, several critical issues have not been well addressed, such as the location of the reconnection site, their unusually short lifetime (about one minute), and the recently discovered repetitive behavior with a period of three to five minutes. Chen and Priest (2006) perform MHD numerical simulations of magnetic reconnection, where the effect of five-minute solar p-mode oscillations is examined. UV emission lines are synthesized on the basis of numerical results in order to compare with observations directly. It is found that several typical and puzzling features of the TREEs with impulsive bursty behavior can only be explained if there exist p-mode oscillations and the reconnection site is located in the upper chromosphere at a height range of around 1900 km < h < 2150 km above the solar surface. Furthermore, the lack of proper motions of the high-velocity ejection may be due to a rapid change of temperature along the reconnection ejecta.

8. Instruments developments

Wang, J. (2006a) reported that a key basic research project Explosive Solar Activity and Disastrous Space Weather has been carried out for 5 years and its continuation aimed at learning the formation development and forecast of disastrous space weather in solar-terrestrial system is under active coordination In this review he summarize the efforts conducted by the cross-discipline research groups and the key advances made so far discuss the future scientific focus strategy and approach of the new project for the next 5 years Particular emphasis will be put on the considerations on the multi-discipline interaction and collaboration which are urgently needed to establish a solid scientific basis of space weather forecast.

Three solar equipments, 1-m near-infra solar telescope, solar radio heliograph, and solar space telescope, have been planed to build in later decades. They will be the most important observational equipments of Chinese solar physics in the later tens of years. The 1-m near-infra solar telescope will locate beside the Fuxian lake of Yunnan province in China. It is planed to observe the spectrum range from 0.3 m ~ 2.5 m. The solar radio heliograph collects the qualities with high spatial-resolution, high-frequency, high-temporal, and high-sensitivity. The solar space telescope is in the stage of readiness after the phase-B stage. It can provide the observations of the solar coronal active regions, coronal magnetic and velocity fields, as well as coronal and sun-earth interplanetary full-wavelength measurements. These observations will play great roles in understanding solar active regions and velocity fields, the storage and release of solar flare energy, CMEs, the formation of solar wind and the other sun-earth physical phenomena.

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STUDY OF HELIOSPHERIC PHYSICS IN CHINA

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Abstract Considerable progress for the study of heliospheric physics has been achieved by China's space physics community. Here is a brief summary of the latest advances in this area in China during the period of 2004–2006. It involves the theoretical study of coronal process of solar active phenomena and coronal mass ejections, the basic process in solar wind, the origin and acceleration of the solar wind, interplanetary coronal mass ejection and interplanetary shock, numerical study and evidences of magnetic reconnection, interaction of the solar wind with the magnetosphere, and space weather study.

Keywords Solar corona, Solar wind, Interplanetary coronal mass ejection, Space weather

1 Solar Corona

Using an axisymmetrical ideal magnetohydrodynamic (MHD) model in spherical coordinates, Hu[1] presents a numerical study of the energy buildup of coronal magnetic fields by photospheric shear motions. The unsheared potential field consists of a dipolar and an octopolar component with a neutral point somewhere at the equator. The separatrix crossing the neutral point divides the field into four topologically disconnected regions: a central arcade astride the equator, a bipolar field on each side of the central arcade, and an overlying arcade above the separatrix. A specific type of photospheric shearing is then introduced at the base of the central arcade, and the energy of the resultant sheared field is calculated. It is found for this special case that the magnetic energy of the sheared force-free field cannot exceed that of the corresponding partly open field in which the central and overlying arcades become fully open but the bipolar fields at the flank remain closed. So Hu[1] extends Aly's conjecture from fully open force-free fields to partly open ones in such a way that in the frame of ideal MHD, it is impossible to store more magnetic energy in the corona by photospheric shear motions at the base of any part of the closed flux of a force-free field than that of the field in which the sheared closed flux opens but the remainder remains closed.

The Aly conjecture on the maximum energy of force-free fields with a given normal component distribution at the lower boundary was recently extended from fully open force-free fields to partly open ones in such a way that in the frame of ideal MHD, it is impossible to store more magnetic energy in the corona by photospheric shear motions at the base of any part of the closed flux of a force-free field than that of the field in which the sheared flux opens, while the unsheared one remains closed. Hu and Wang[2] provide another example in support of such an extension, in which the unsheared field is a partly open bipolar field, and the photospheric shear is specified in terms of the footpoint displacements. A new numerical approach is proposed to implement a given footpoint displacement for two-dimensional force-free fields. It is found that the magnetic energy buildup of the system depends on the distribution of the displacement at the photosphere: the more the displacement concentrates to the center of the closed arcade, the larger the energy buildup will be acquired. During the shear, the unsheared field remains closed, whereas the sheared one tends to open in its outermost part. In any case, the maximum energy cannot exceed that of the corresponding partly open field, in which the sheared field is assumed to be open, but the unsheared one remains closed.

Starting from a dipole field and a given distribution of footpoint displacement of field lines on the photosphere, Hu and Li[3] find axisymmetric, force-free field solutions in spherical coordinates that have the same distribution of normal field on the photosphere and magnetic topology as the dipole field. A photospheric shear is introduced in the azimuthal direction in a region that strides across the equator and ends at latitude λs. The footpoint displacement has a sine distribution in latitude and a peak amplitude of φ_m. The magnetic energy E, azimuthal flux F_φ, and magnetic helicity H_T in the solar corona are then calculated for each force-free field solution. It is found that for a given shear region range λs, all of the three quantities increase monotonically with increasing φ_m. In particular, both F_φ and H_T have a linear dependence on φ_m. When φ_m reaches a certain critical value φ_{mc}, the force-free field loses equilibrium, leading to a partial opening of the field and the appearance of a current sheet in the equatorial plane. At this point, E, F_φ and H_T reach their maximum values, E_c, $F_{\varphi c}$ and H_{Tc}. E_c increases, and $F_{\varphi c}$ and H_{Tc} decrease with decreasing λs. It is found that E_c is always smaller than the open field energy, in agreement with the Aly conjecture. Of the three critical parameters, E_c has the weakest dependence on λs. Therefore, if one is interested in the transition of a magnetic configuration from a stable state to a dynamic one, the magnetic energy is probably the most appropriate marker of the transition.

Previous studies of the equilibrium property and catastrophic behavior of coronal magnetic flux ropes assumed that the background field is potential and the background plasma is in static equilibrium. Sun and Hu[4] abandon these assumptions and consider the effect of the background solar wind. For simplicity, Sun and Hu[4] take a polytropic process approximation in the energy equation and confine ourselves to axisymmetrical problems in spherical geometry. Steady solutions are obtained by time-dependent simulations for a system consisting of a magnetostatic helmet streamer astride the equator with a flux rope in it and a steady solar wind outside. The coronal flux rope is characterized by its azimuthal and annular magnetic fluxes and total mass. It is shown that the system possesses a catastrophic behavior. As the azimuthal or annular flux of the rope increases or the total mass in the rope decreases, the flux rope and the helmet streamer expand, the field lines in the outermost part of the streamer are gradually opened, and the originally static plasma there flows outward along the newly opened field lines and joins the solar wind. The magnetic energy of the system increases during this process. Sun and Hu found an energy threshold that is larger than the corresponding open field energy by about 8% if the field in the rope is close to force-free. The gravity raises the threshold by an amount that approximately equals the magnitude of the excess gravitational energy in the rope. The flux rope sticks to the solar surface in equilibrium if the magnetic energy of the system is below the threshold, whereas it erupts otherwise. In the latter case, the flux rope is gradually accelerated and reaches a velocity that is slightly larger than the background solar wind velocity. They argue that such a catastrophe may serve as a physical mechanism for slow coronal mass ejections. A brief comparison is also made between the present case and the magnetostatic case in the catastrophic behavior of the system.

Catastrophe of coronal magnetic rope embedded in a partly open mulltipolar background magnetic field is studied by Peng and Hu[5] by using a 2-dimensional, 3-component ideal MHD model in spherical coordinates. The background field is composed of three closed bipolar fields of a coronal streamer and an open field with an equatorial current sheet. The magnetic rope lies below the central bipolar field, and it is characterized by its annular and axial magnetic fluxes. For a given annual flux, there is a critical value of the axial flux, and for a given axial flux, there is a critical value of annual flux such that, below the critical value, the magnetic rope is attached to the solar surface and the system stays in equilibrium, but when the critical value is exceeded, the magnetic rope breaks free and erupts upward. This implies that catastrophe can occur in a coronal magnetic rope embedded in a partly open multipolar background magnetic field. Our computation gives a threshold value of magnetic energy that is about 15% greater than total energy of the partly open magnetic field (the central bipolar field open and the fields on either side closed). The excess energy may serve as source for solar explosions such as coronal mass ejections.

Using a relaxation method based on time-dependent ideal MHD simulations, Zhang, Hu and Wang[6] found 2.5-dimensional force-free field solutions in spherical geometry, which are associated with an isolated flux rope embedded in a quadrupolar background magnetic field. The background field is of Antiochos type, consisting of a dipolar and an octopolar component with a neutral point somewhere in the equatorial plane. The flux rope is characterized by its magnetic fluxes, including the annular flux Φ_p and the axial magnetic flux Φ_φ, and its geometric features described by the height of the rope axis and the length of the vertical current sheet below the rope. It is found that for a given Φ_p, the force-free field exhibits a complex catastrophic behavior with respect to increasing Φ_φ. There exist two catastrophic points, and the catastrophic amplitude, measured by the jump in the height of the rope axis, is finite for both catastrophes. As a result, the flux rope may levitate stably in the corona after catastrophe, with a transverse current sheet above and a vertical current sheet below. The magnetic energy thresholds for the two successive catastrophes are found to be larger than the corresponding partly open field energy. They argue that it is the transverse current sheet formed above the flux rope that provides a downward Lorentz force on the flux rope and thus keeps the rope levitating stably in the corona.

Time-dependent resistive MHD simulations are carried out by Zhang, Hu and Wang[7] to study a flux rope eruption caused by magnetic reconnection with implication in coexistent flare-CME (coronal mass ejection) events. An early result obtained in a recent analysis of double catastrophe of a flux rope system is used as the initial condition, in which an isolated flux rope coexists with two current sheets: a vertical one below and a transverse one above the flux rope. The flux rope erupts when reconnection takes place in the current sheets, and the flux rope dynamics depends on the reconnection sequence in the two current sheets. Three cases are discussed: reconnection occurs (1) simultaneously in the two current sheets, (2) first in the transverse one and then in the vertical one, and (3) in an order opposite that of case 2. Such a two–current-sheet reconnection exhibits characteristics of both magnetic breakout for CME initiation and the standard flare model. It is argued that both breakout-like and tether-cutting reconnections could be important for CME eruptions and associated surface activities.

Chen, Chen and Hu[8] investigate the catastrophic behavior of pre-existing coronal magnetic flux rope embedded in a dipolar or partially-open bipolar background field, which is either unsheared or sheared with given footpoint displacement of magnetic field lines. It is found that, in the unsheared background field, the catastrophic energy threshold decreases slightly with increasing extent of opening of the background field and increasing annular flux or decreasing axial flux of the flux rope, varying in the range between 1.08 to 1.1 times of the magnetic energy of the corresponding fully-open field. As the background field is sheared, on the other hand, catastrophe may be triggered by shear provided that the pre-sheared magnetic energy of the system is high enough. The catastrophic energy threshold is almost invariant but then increases monotonically with the increase of the presheared magnetic energy of the system, and it is bounded above by the energy of the corresponding flux rope system associated with an unsheared background field.

A major solar active event called Bastille Day Event occurred in AR 9077 on July 14, 2000. Simultaneous occurrence of a filament eruption, a flare and a coronal mass ejection was observed in this event. Previous analyses of this event show that before the event, there existed an activation and eruption of a huge trans-equatorial filament, which might play a crucial role in triggering the Bastille Day event. This implies that independent flux systems are closely related to and affect each other, which has encouraged Ding, Hu and Wang[9] to investigate the catastrophic behavior of a multiple coronal flux rope system with the use of a 2.5-D time-dependent MHD model. A force-free field that contains three separate coronal flux ropes is taken to be the initial state. Starting from this state, Ding, Hu and Wang[9] increase either the annular or the axial flux of a certain flux rope to examine the catastrophic behavior of the system in two regimes, the ideal MHD regime and the resistive MHD regime. It is found that a catastrophe occurs if the flux exceeds a certain critical value, or the magnetic energy of the system exceeds a certain threshold: the rope of interest breaks away from the base and escapes to infinity, leaving a current sheet below. Moreover, the destiny of the remainder flux ropes relies on whether reconnection takes place across the current sheet. In the ideal MHD regime, i.e., in the absence of reconnection, these ropes remain to be attached to the base in equilibrium, whereas in the resistive MHD regime they abruptly erupt upward during reconnection and escape to infinity. Reconnection causes the field lines to close back to the base and thus changes the background field outside the attached flux ropes in such a way that the constraint on these ropes is substantially relaxed and the corresponding catastrophic energy threshold is reduced accordingly, leading to a catastrophic eruption of these ropes. Since magnetic reconnection is generally inevitable when a current sheet forms and develops through an eruption of one flux rope, the eruption of this flux rope must lead to an eruption of the others. This provides an example to demonstrate the interaction between several independent magnetic flux systems in different regions, as implied by the Bastille Day event, and may serve as a possible mechanism for sympathetic events occurring on the Sun.

As demonstrated by many previous studies, a system consisting of an isolated coronal flux rope and a surrounding background magnetic field exhibits a catastrophic behavior. In particular, if the magnetic field of the system is force-free and axisymmetric in spherical geometry, the magnetic energy at the catastrophic point, referred to as the catastrophic energy threshold, is found to be larger than the corresponding partly or fully open field energy. Ding and Hu[10] take an octapole field as the background and introduces a flux rope within the central arcade of the octapole field. A relaxation method based on time-dependent ideal MHD simulations is used to find axisymmetric force-free field solutions in spherical geometry associated with the flux rope system. With respect to an increase of either the annular flux Φ_p or the axial flux Φ_φ of the rope, the system exhibits a catastrophic behavior as expected, and the catastrophic energy threshold is larger than that of the corresponding partly open field, in which the central arcade is opened up, but the remainder remains closed. For a given octapole field, the energy threshold depends on either Φ_p or Φ_φ at the catastrophic point, and it increases with increasing Φ_p or decreasing Φ_φ. On the other hand, the extent to which the central bipolar component of the octapole field is open also affects the energy threshold. These results differ from those for the bipolar background field case, in which the catastrophic energy threshold is almost independent of the magnetic properties of the flux rope at the catastrophic points and the extent to which the background field is open. The reason for such a difference is briefly discussed.

A method called complete orthogonal function series expression (OFSE) in Hilbert space is proposed by Ye et al[11] to solve the non-dissipative torsional Alfven wave in coronal loops. Every base function corresponds to an intrinsic angular frequency of each magnetic field line in the loop. Torsional Alfven wave resonance of the magnetic field lines arises when the driving angular frequency is equal to its intrinsic angular frequency. Using this method, they present a new form of the solution of torsional Alfven wave evolution under the boundary condition of being driven at the two foot-points. In the solution there exists a resonance term, from which it may be found that near the place of resonance with angular frequency ω a δ-type discontinuity appears at time t equal to odd multiples of $\pi/(2\omega)$. It is also found that the wave amplitude at the place of resonance linearly increases with time and the rate of increase is proportional to the Alfven wave speed, and inversely proportional to the length of the loop and is independent of the driving frequency.

Explosive events have been observed to occur consecutively in bursts at intermittent locations along the boundary near the opposite polarity. Fan, Feng and Xiang[12] explore a possible mechanism to interpret this burst-like characteristic of explosive events. The 2D MHD numerical simulations with resistivity have been carried out to reproduce the intermittent spatial-temporal magnetic reconnection events taking place along the long, compressible current sheet. The observed density enhancements in previously published results have been verified to be associated to magnetic reconnection sites. Late observational evidences, which support present attempts, have also been found, at least in morphological evolution of the consecutive explosive events.

Resonant absorption, first proposed by Ionson, was extensively studied as one of the major candidates for coronal heating, and it is believed that the Alfvenic fluctuation with large amplitudes and gradients established around the resonant layer is essential to this mechanism. On the basis of this point, Luo, Feng and Wei[13] investigate the effect of nonlinear coupling in the dissipative layer of a coronal loop driven by azimuthal footpoint motions with two frequencies. With a three-wave interaction model, we find that the pump mode (ω_2, k_2) could be intensively modulated by the large-amplitude resonant fluctuation v1 accumulated localizedly around the dissipative layer. The derived modified wavenumber (km > 10^2 k_2) implies strong phase mixing and the consequent phase modulation dissipation, and the resulting damping length Ld is smaller than the loop length L in the active regions, which may be instructive to explain the recent observation on the localized heating at the footpoints of coronal loops.

The characteristics of MHD fast wave propagation in the solar stratified atmosphere are studied by the ray tracing method by Zheng et al[14]. The propagation behavior of the wave fronts is described in detail. A magnetic field incorporating the characteristics field spreading expected in flux tubes is used, which represents the main feature of an active region. Partly ionization is considered beside the stratified solar atmosphere consisting chromosphere, transition region and corona. The study may explain the characteristics in observations of Moreton and extra-ultraviolet image telescope (EIT) waves. The wave front incurred by the disturbance initialized at the base of the transition region propagates fast initially due to strong magnetic field, and it slows down when arriving beyond the region of flux-tube. Meanwhile, the wave propagates in the corona with a more consistent speed, as seen in the observation of EIT waves. The speeds and propagated characteristics in chromosphere and corona of the wave fronts are in agreement with those observed in H_α Moreton and EIT waves, respectively.

The radiance and Doppler-velocity maps of the emission lines of Si II, C IV, and Ne VIII obtained in a quiet region of the Sun by SUMER (Solar Ultraviolet Measurements of Emitted Radiation) are correlated with the vertical component, B_z, of the magnetic field vector as extrapolated, by means of a force-free field model, from the photospheric magnetic field measured by MDI (Michelson Doppler Imager). Tu et al[15] found that, with increasing vertical height, each of the correlation coefficients initially increases to a maximum value before it decreases again. The height corresponding to this maximum is called the correlation height. For the data sets selected from a quiet-Sun region, the correlation heights of Si II and C IV are near 2 Mm, and for Ne VIII near 4 Mm. At their correlation heights, the averaged square root of the radiance of the emission lines of Si II and C IV, considered as a proxy of the plasma density, has a linear relationship with B_z. This result supports the empirical concept that the solar transition region is very thin and still affected by frozen-in convection. A way for improvement of such studies is also outlined.

By combining observations of the Sun made by SUMER and MDI aboard SOHO, the network structures in equatorial coronal holes have been studied by Xia, Marsch and Wilhelm[16], in particular the relationship between the ultraviolet emission-line parameters (line radiance, Doppler shift and line width) and the underlying magnetic field. The bases of coronal holes seen in chromospheric spectral lines with relatively low formation temperatures generally have similar properties as normal quiet-Sun regions, i.e., small bright patches with a size of about 2 arcsec to 10 arcsec are the dominant features in the network as well as in cell interiors. With the increase of the formation temperature, these features become more diffuse, and have an enlarged size. Loop-like structures are the most prominent features in the transition region. In coronal holes, we found that many of such structures seem to have one footpoint rooted in the intra-network and to extend into the cell interiors. Some of them appear as star-shape clusters. In Dopplergrams of the O VI line at 1032 Å, there are also fine structures with apparent blue shifts, although, on average, they are red shifted. Structures with blue shifts have usually also broader line widths. They seem to represent plasma above large concentrations of unipolar magnetic field, without obvious bipolar photospheric magnetic features nearby.

Xia et al[17]study the dynamic properties of EUV spicules seen at the solar limb. The selected data were obtained as time series in polar coronal holes by SUMER/SOHO. Their results reveal that spicules occur repeatedly at the same location with a birth rate of around 0.16/min as estimated at 10″ above the limb and a lifetime ranging from 15 down to ~3 minutes. It can be seen that some spicules showing a process of “falling after rising” indicated by the sudden change of the Doppler velocity sign. A periodicity of ~5 minutes is sometimes discernible in their occurrence. Most spicules have a height between 10″ and 20″ above the limb, and some can stretch up to 40″ . These “long macro-spicules” seem to be comprised of a group of high spicules. Some of them have an obvious periodicity in the radiance of ~5 minutes.

Analysis of observations from both space-borne (LASCO/SOHO, *Skylab* and Solar Maximum Mission) and ground-based (Mauna Loa Observatory) instruments show that there are two types of coronal mass ejections (CMEs), fast CMEs and slow CMEs. Fast CMEs start with a high initial speed, which remains more or less constant, while slow CMEs start with a low initial speed, but show a gradual acceleration. To explain the difference between the two types of CMEs, Low and Zhang **(**2002, Astrophys. J. **564**, L53) proposed that it resulted from a difference in the initial topology of the magnetic fields associated with the underlying quiescent prominences, i.e., a normal prominence configuration will lead to a fast CME, while an inverse quiescent prominence results in a slow CME. In this paper we explore a different scenario to explain the existence of fast and slow CMEs. Postulating only an inverse topology for the quiescent prominences, we show that fast and slow CMEs result from different physical processes responsible for the destabilization of the coronal magnetic field and for the initiation and launching of the CME. Wu et al[18] use a 2.5-D, time-dependent streamer and flux-rope MHD model (Wu and Guo, 1997, Solar Phys. 175, 719) and investigate three initiation processes, viz. (1) injecting of magnetic flux into the flux-rope, thereby causing an additional Lorentz force that will destabilize the streamer and launch a CME (Wu et al., Solar Phys. 175, 719,1997; J. Geophys. Res. 104, A7, 14,789, 1999); (2) draining of plasma from the flux-rope and triggering a magnetic buoyancy force that causes the flux-rope to lift and launch a CME; and (3) introducing additional heating into the flux-rope, thereby simulating an active-region flux-rope accompanied by a flare to launch a CME. We present 12 numerical tests using these three driving mechanisms either alone or in various combinations. The results show that both fast and slow CMEs can be obtained from an inverse prominence configuration subjected to one or more of these three different initiation processes.

On April 14, 1980, the spacecraft SMM observed the characteristic propagating of the CME eruption in the open magnetic field between two helmet streamers, and the distortion and deflection of the helmet streamer. By using the 2.5-dimension MHD equations, the complicated process of the interaction between the CME and helmet streamer is studied numerically by Huang[19]. The simulation result shows the characteristic propagating of this kind of CME, the distortion and deflection of the helmet streamer observed by spacecraft SMM, as well as the inverse effect of the axial component of the magnetic field inside the helmet streamer. This simulation result is also helpful for the study on the magnetic cloud and magnetic storm.

Xue, Wang and Dou[20] used an ice-cream cone model to analyze the geometrical and kinematical properties of the coronal mass ejections (CMEs). Assuming that in the early phase CMEs propagate with near-constant speed and angular width, some useful properties of CMEs, namely the radial speed (v), the angular width (a), and the location at the heliosphere, can be obtained considering the geometrical shapes of a CME as an ice-cream cone. This model is improved by (1) using an ice-cream cone to show the near real configuration of a CME, (2) determining the radial speed via fitting the projected speeds calculated from the height-time relation in different azimuthal angles, (3) not only applying to halo CMEs but also applying to nonhalo CMEs.

Wang et al[21] analyzed five major CMEs originating from NOAA active region (AR) 808 during the period of 2005 September 7–13, when the AR 808 rotated from the east limb to near solar meridian. Several factors that affect the probability of the CMEs' encounter with the Earth are demonstrated. The solar and interplanetary observations suggest that the second and third CMEs, originating from E67º and E47º, respectively, encountered the Earth, while the first CME originating from E77º missed the Earth, and the last two CMEs, although originating from E39º and E10º, respectively, probably only grazed the Earth. On the basis of icecream cone mode[20] and CME deflection model, we find that the CME span angle and deflection are important for the probability of encountering Earth. The large span angles allowed the middle two CMEs to hit the Earth, even though their source locations were not close to the solar central meridian. The significant deflection made the first CME totally miss the Earth even though it also had wide span angle. The deflection may also have made the last CME nearly miss the Earth even though it originated close to the disk center. They suggest that, in order to effectively predict whether a CME will encounter the Earth, the factors of the CME source location, the span angle, and the interplanetary deflection should all be taken into account.

Via an adequate superposition of a dipolar and a hexapolar field, the conjectured magnetic field is improved by Ye et al[22,23] so that it has opposite signs in the southern and northern poles. Then, by adopting the system of ideal MHD equations, a steady self-consistent solution for the interaction of the conjectured magnetic field and solar wind is obtained, giving a background structure with two coronal streamers qualitatively close to the observation. A model of the triggering of CME events with concentric magnetic configuration is adopted to study features of propagation of CMEs in the solar corona. The results show that the propagation of CME is confined between two coronal streamers. The closed magnetic configuration of CME is similar to that on the transverse section of magnetic cloud. This may be used to interpret some features of the observed magnetic clouds at 1 AU. In the vicinity of the CME, there are areas where pressure and Lorentz force play the chief role. This may be helpful for the analysis of observational data of CME events at 1 AU.

The evolution of coronal mass ejection/shock system is investigated[24] by numerically solving the usual set of two-dimensional single-fluid polytropic equations from 1 R_s to 1 AU in the meridian plane. The simulation result reveals that the coronal mass ejection/shock system formed near the sun evolves into the magnetic cloud/shock system near the earth's orbit through three phases: the initial formation, the dominant latitudinal expansion and the similar expansion.

Qualitative numerical result of a special type of coronal mass ejection (CME) is presented by Ye et al[25]. The magnetic field direction in front half part of central closed magnetic field of the CME is opposite to that of the solar global dipole. Numerical result shows that: between the two antidirectional magnetic field lines of the CME magnetic field and the solar global dipole, there exists a transitional magnetic field structure, the area scale of which becomes gradually large when CME propagates outward. The numerical results may explain why spacecrafts can observe a type of bipolar magnetic cloud, in front half part of which, the magnetic field direction is opposite to that of the solar global dipole. To obtain the numerical result, a background streamer with nested close magnetic field lines in it plays a central role for the CME initiation and propagation. The background steady state solution is approximated by a long time interaction between a potential magnetic field and Parker solar wind solution. The potential magnetic field is obtained by properly combining a dipole and a hexapole. Because for the dipole, interaction between the potential magnetic field and solar wind can not open the dipole up and a streamer containing nested close magnetic field structures for triggering the CME at a suitable position forms finally.

A statistical study is performed by Shen et al[26] to answer the question whether CHs have real effects on the intensities of SEP events produced by CMEs. A brightness gradient method is developed to determine CH boundaries. Using this method, CHs can be well identified, eliminating any personal bias. Then 56 front-side fast halo CMEs originating from the western hemisphere during 1997–2003 are investigated as well as their associated large CHs. It is found that neither CH proximity nor CH relative location manifests any evident effect on the proton peak fluxes of SEP events. These results are consistent with the previous conclusion suggested by Kahler that SEP events can be produced in fast solar wind regions and there is no requirement for those associated CMEs to be significantly faster.

2 Solar wind

The study of the basic process in solar wind plasma is crucial to our understanding of the interplanetary medium and transient phenomena in the solar wind. Measurements with Solar and Heliospheric Observatory (SOHO)/Charge, Element, and Isotope Analysis System (CELIAS) inspired a lot of studies concentrating on the effects of different species on the solar wind structures and their characteristics. Recently, Chen and Li[27] developed a three-fluid slow wind consisting of electrons, protons, and O^{5+} ions constructed to account for a recent UVCS/SOHO observation. In this model, ion-cyclotron waves, which are assumed to be generated by a Kolmogorov turbulent cascade, are assumed to play a key role in driving the slow solar wind. By reproducing recent measurements on the O^{5+} parameters along a streamer axis and the well-known average proton flux in the slow wind near Earth it is demonstrated that the ion-cyclotron resonance mechanism proposed to explain the observations in the coronal hole and fast wind may also be important to the ions in the slow solar wind.

Using recent coordinated UVCS and LASCO measurements by Strachan and coworkers to constrain the heating parameters of a one-dimensional single-fluid minor ion model, Chen et al[28] calculate the outflow velocity profile of O^{5+} ions in the flow tube overlying the helmet streamer, which has been supposed to be the source region of the slow solar wind at least during solar minimum. The background solar wind parameters and the flow tube geometry are taken from a recent two-dimensional solar wind model. They show that in this slow-wind source region the O^{5+} outflow speed varies nonmonotonically with increasing heliocentric distance. There is a local minimum of the outflow speed near the streamer cusp point (about $3R_s$), which is below the current observational sensitivity. This type of ion outflow in the slow solar wind is termed ``stagnated outflow" in this paper. They also show that the observed effective temperature in the perpendicular direction (to the magnetic field) and the outflow speed of the O^{5+} ions can be used to put limits on their parallel thermal temperature.

The origin of the solar wind in solar coronal holes has long been unclear. Tu et al[29] established that the solar wind starts flowing out of the corona at heights above the photosphere between 5 megameters and 20 megameters in magnetic funnels. This result is obtained by a correlation of the Doppler-velocity and radiance maps of spectral lines emitted by various ions with the force-free magnetic field as extrapolated from photospheric magnetograms to different altitudes. Specifically, we find that Ne^{7+} ions mostly radiate around 20 megameters, where they have outflow speeds of about 10 kilometers per second, whereas C^{3+} ions with no average flow speed mainly radiate around 5 megameters. Based on these results, a model for understanding the solar wind origin is suggested.

Tu, Marsch and Qin[30] revealed a correlation between the proton core plasma beta and the proton beam drift speed in units of the local Alfvén speed in high-speed solar wind with the Helios 2 spacecraft plasma data obtained in 1976. This relation reads $v_d/v_A = (2.16\pm0.03)\ \beta_{\parallel c}^{(0.281\pm0.008)}$ for the range $\beta_{\parallel c} = 0.1$ to 0.6, where $\beta_{\parallel c}$ is the proton core plasma beta determined from the proton core thermal velocity component parallel to the magnetic field, v_d is the proton beam drift speed relative to the core, and v_A is the local Alfvén speed. This relation places a tight constraint on theoretical models which describe the formation of the proton beam in the fast solar wind. It is also found that most of the observed proton beam distributions are stable with respect to the electromagnetic proton instability.

During Ulysses' first rapid pole-to-pole transit from September 1994 to June 1995, its observations showed that middle- or high-speed solar winds covered all latitudes except those between −20° and +20° near the ecliptic plane, where the velocity was 300–450 km/s. At poleward 40°, however, only fast solar winds at the speed of 700–870 km/s were observed. In addition, the transitions from low-speed wind to high-speed wind or vice versa were abrupt. The large-scale structure of solar wind observed by Ulysses near solar minimum is simulated by Feng and Xiang[31] by using the three-dimensional numerical MHD model. The model combines TVD Lax-Friedrich scheme and MacCormack II scheme and decomposes the calculation region into two regions: one from 1 to 22 R_s and the other from 18 R_s to 1 AU. Based on the observations of the solar photospheric magnetic field and an addition of the volumetric heating to MHD equations, the large-scale solar wind structure mentioned above is reproduced by using the three-dimensional MHD model and the numerical results are roughly consistent with Ulysses' observations. Their simulation shows that the initial magnetic field topology and the addition of volume heating may govern the bimodal structure of solar wind observed by Ulysses and also demonstrates that the three-dimensional MHD numerical model used here is efficient in modeling the large-scale solar wind structure.

Using the three-dimensional numerical MHD model introduced in Feng et al (Chinese Journal of Space Science, 2002, 4: 300), Xiang, Feng and Yao[32] conduct a three-dimensional

MHD simulation to study the steady solar wind in Carrington Rotation 1935. The numerical results demonstrate the neutral current has two peaks and two valleys, which is consistent with the result of PFSS model at WSO. The obtained proton number density at the 2.5 R_s is of the same order of magnitude as the result estimated from K coronal brightness during the Carrington rotations 1733-1742 in 1983 made by of Wei et al (J. Geophys. Res, 2003., 108(A6): 1238). The radial velocity profiles along heliocentric distance is consistent with the profile of low solar wind speed deduced by Sheeley and Wang et al (Astrophys J, 1997, 484: 472). However, it is not able to reproduce the fast-speed flow in coronal holes and slow solar wind in streamers because of oversimplified energy equation adopted in their model.

Finite-amplitude intrinsic Alfven waves exist pervasively in astrophysical and solar-terrestrial environment. It is generally believed that linear wave-particle resonant interaction between thermal protons and Alfven waves is ineffective when the proton beta is low. However, Wang, Wu and Yoon[33] demonstrates that the ions can be heated by Alfven waves via nonresonant nonlinear interaction. Contrary to the customary expectation, They found that the lower the plasma beta value, the more effective is the heating process. In addition, the ion temperature increase is more prominent along perpendicular direction.

Observations with Wind and other spacecraft of the solar wind have shown that the velocity distributions of energetic electrons associated with solar impulsive electron events are often nearly isotropic. It is believed that in each case the electrons are originally associated with a flare-associated beam. The issue of interest is: how can a beam of fast electrons evolve into such a final state? Lu, Wu and Wang[34] offers a theoretical explanation. They attribute the isotropization of the electron beam distribution to nonresonant pitch-angle scattering by enhanced Alfven waves in the corona and the solar wind. The proposed scenario is demonstrated with test particle calculations.

Lu and wang[35] carried out one-dimensional hybrid simulations of resonant scattering of protons and He^{2+} ions by ion cyclotron waves in an initially homogeneous, collisionless and magnetized plasma. The initial ion cyclotron waves have a power spectrum and propagate both outward and inward. Due to the resonant interaction with the protons and He^{2+} ions, the wave power will be depleted in the resonance region. Both the protons and He^{2+} ions can be resonantly heated in the direction perpendicular to the ambient magnetic field and leading to anisotropic velocity distributions, with the anisotropy higher for the He^{2+} ions than for the protons. At the same time, the anisotropies of the protons and He^{2+} ions are inversely correlated with the plasma $\beta_{/\!/p} = 8\pi n_p k_B T_{/\!/p} / B_0^2$, consistent with the prediction of the quasilinear theory (QLT).

Hybrid simulations are performed by Lu, Xia and Wang[36] to investigate the nonlinear evolution of parallel and oblique electromagnetic alpha/proton instabilities in the fast solar wind. The parallel proton plasma beta, defined as $\beta_{/\!/p} = 8\pi n_p k_B T_{/\!/p} / B_0^2$, is set equal to 0.15, and the initial average value of the alpha/proton relative flow speed is chosen as 1.76 V_A (V_A is the local Alfven speed). The influences of the temperature anisotropy of alpha particles ($T_{\perp\alpha}/T_{/\!/\alpha}$) and temperature anisotropy of protons ($T_{\perp p}/T_{/\!/ p}$) on the alpha/proton instabilities are also considered. The decrease of the temperature anisotropy of alpha particles ($T_{\perp \alpha}/T_{/\!/ \alpha}$) can significantly enhance the amplitude of both the magnetosonic and oblique Alfven modes and decelerate alpha particles more efficiently, while the temperature anisotropy of protons ($T_{\perp p}/T_{/\!/ p}$) tends to reduce the amplitudes of these two modes. Moreover, in the two-dimensional hybrid simulations the magnetosonic waves are first excited. Then the oblique Alfven waves are also excited and dominate the wave spectrum at the late stage of time evolution.

3 Interplanetary Coronal Mass Ejection and Interplanetary shock

Coronal Mass Ejections (CMEs) are spectacular solar events involving the expulsion of $10^{15\sim16}$ grams of solar material into the heliosphere. Generally speaking, “coronal mass ejection” refers to the phenomena seen with a white-light coronal imaging instrument. Solar wind structures which are the interplanetary counterparts of CMEs at the Sun now generally referred to as interplanetary coronal mass ejections (ICMEs), with a subset called magnetic clouds. These ICMEs often trigger geomagnetic storms, making them of great importance to space weather studies. Thus, much work has focused on ICME manifestations at 1 AU and their evolution in interplanetary space. The interplanetary responses to the great solar activities in late October 2003 are investigated by Wang et al[37]. The relationship between the interplanetary magnetic clouds and associated filaments is analyzed by Wang [38].

Based on a statistical result of the distribution of Earth-encountered halo CMEs in longitude, a deflection model of CME's propagation in the interplanetary medium is proposed by Wang et al[39]. This model suggests that fast CMEs will be deflected to the east while slow CMEs will be deflected to the west. The theoretical result is well consistent with the statistical result. Further an application of this model is made on the major CMEs during September 7-13 by Wang et al[40]. A highly consistency is obtained. These results suggest that the deflection effect of CMEs should be taken into account in space weather prediction.

Wang, Du and Richardson[41] identified and characterized interplanetary coronal mass ejections (ICMEs) observed by spacecraft in the solar wind, namely Helios 1 and 2, PVO, ACE and Ulysses, which together cover heliocentric distances from 0.3 to 5.4 AU. The primary identification signature used to look for ICMEs is abnormally low proton temperatures. About 600 probable ICMEs were identified from the solar wind plasma and magnetic field data from these spacecraft. They use these events to study the radial evolution of ICMEs between 0.3 and 5.4 AU, mainly in a statistical sense. The occurrence rate of ICME approximately follows the solar activity cycle. ICMEs expand as they move outward since the internal pressure is generally larger than the external pressure. The average radial width of ICMEs increases with distance. The radial expansion speed of ICMEs decreases with distance and is of the order of the Alfven speed. The density and magnetic field magnitude decrease faster in ICMEs than in the ambient solar wind but the temperature decreases more slowly than in the ambient solar wind. They also use a one-dimensional MHD model to investigate the radial expansion of the ICMEs and find that the radial expansion speed is of the order of the Alfven speed, consistent with the observations.

Wang and Richardson[42] investigated the ICMEs observed by Voyager 2 in the heliosphere between 1 and 30 AU. They also used abnormally low proton temperatures as the primary identification signature of ICMEs and use other plasma and magnetic field data to verify these identifications. The ICME rate is solar cycle dependent; during the solar minimum of 1986-1987 only a few ICMEs were identified each year, compared with tens per year during solar maxima. The average radial width of ICMEs increases with distance from 1 to about 10 AU; outside about 10 AU the average radial width is roughly constant. The radial expansion speed of ICMEs is of order of the Alfven speed. Comparison of the radial profiles of the ICME and background solar wind shows that the magnetic field decreases faster in ICMEs than in the solar wind, but that the density and temperature decrease more slowly than in the solar wind. Many ICMEs identified at Voyager 2 do not have obvious counterparts at Earth.

The magnetic cloud boundary layers (BL) that are located between the magnetic clouds and the ambient solar wind have many special magnetic and plasma structures. Wei et al[43] analyzed the observational data of 70 magnetic cloud BLs from the Three-Dimensional (3D) Plasma and Energetic Particle (3DP) and 50 BLs from the Solar Wind Experiment (SWE) instruments on Wind spacecraft from February 1995 to June 2003. From this analysis, they discover that the boundary layer of a magnetic cloud is a new non-pressure-balanced structure different from the jump layer (i.e. shocked front) of an interplanetary shock wave. The main results are that (1) the BL is often a non-pressure-balanced structure with the magnetic pressure decrease associated with the abrupt variation of field direction angle (q, f) for about 90% and more than 85% of the BLs investigated from 3DP and SWE data, respectively; (2) the events of heated and accelerated plasma in the BLs are about 90%, 85% and 85%, 82% of the BLs investigated, respectively, from 3DP and SWE data; (3) the reversal flows are observed and their occurrence ratio is as high as 80% and 90% of the BLs investigated from 3DP and SWE data, respectively; and (4) the plasma and field characteristics for the BLs are also obviously different from those in the Jump Layers (JLs) of shock waves. These results show that there exist important dynamic interactions inside the BLs. As a preliminary interpretation, this could be associated with the magnetic reconnection process possibly occurring inside the BLs. Thus the study of the BLs, as a new non-pressure balanced structure in interplanetary space, could open a “window” for revealing some important physical processes in interplanetary space.

Based on the WIND observational data for the plasma waves from Thermal Noise Receptor (TNR) working on the frequency 4~256 kHz and the solar wind and the magnetic fields, Wei Zhong and Feng[44] analyze the plasma wave activities in the 60 magnetic cloud's BLs and find that there are often various plasma wave activities in the BLs, which are different from those in the adjacent SW and the MC. The basic characteristics are that: (1) the enhancement of the Langmuir wave near the electronic plasma frequency (f_{pe}) is a dominant wave activity, which occupies 75% investigated samples; (2) the events enhanced both in the langmuir and ion acoustic ($f<f_{pe}$) waves are about 60% of investigated samples; (3) broadband, continuous enhancement events in the plasma wave activities were observed in the whole frequency band of TNR, and about 30% of the 60 samples, however, were not observed in the SW and the MC investigated events; (4) although the ratio of the temperatures between the electron and proton, $T_e/T_p \leq 1$, the ion acoustic wave enhancement activities are still often observed in the BLs, which makes it difficult to explain them by the traditional plasma theory. New results reported in this paper further show that the magnetic cloud's BL is an important dynamic structure, which could provide useful diagnosis for understanding the cloud's BL physics and could expand a space developing space plasma wave theory.

The observations of the slow shocks associated with the interplanetary coronal mass ejections near 1 AU have seldom been reported in the past several decades. Zuo, Wei and Feng[45] identified an interplanetary slow shock observed by Wind on September 18, 1997. This slow shock is found to be the front boundary of a magnetic cloud boundary layer. A self-consistent method based on the entire R-H relations is introduced to determine the shock normal. It is found that the observations of the jump conditions across the shock are in good agreement with the R-H solutions. In addition, the typical interior magnetic structure inside the shock layer is also analyzed using the 3s time resolution magnetic field data. As a potential explanation to the formation of this kind of slow shock associated with magnetic clouds, this slow shock could be a signature of reconnection that probably occurs inside the magnetic cloud boundary layer.

When the incident solar wind H^+ and other minor ions cross a shock, they are decelerated differentially by the electrostatic potential at the shock. Therefore ring beam distributions of the minor ions are formed downstream of a quasi-perpendicular shock in the downstream frame. Moreover, the H^+ distribution downstream of the quasi-perpendicular shock usually has large perpendicular temperature anisotropy. The He^{2+} ring beam distribution and H^+ temperature anisotropy can excite helium cyclotron waves and proton cyclotron waves, respectively. Lu and Wang[46] perform one-dimensional hybrid simulations to investigate the competition between the helium cyclotron waves and proton cyclotron waves, and their influences on the evolution of He^{2+}. When the wave spectrum is dominated by the helium cyclotron waves, He^{2+} and O^{6+} approximately move on the surface of a sphere, which results in shell-like distributions for He^{2+} and O^{6+}. With the increase of the H^+ temperature anisotropy $T_{\perp p}/T_{/\!/ p}$, the amplitude of the proton cyclotron waves also increases. When it is sufficiently large and comparable with that of the helium cyclotron waves, the motions of He^{2+} and O^{6+} are irregular, which results in bi-Maxwellian distributions of He^{2+} and O^{6+}. They also investigate the influence of the plasma $\beta_{/\!/ p}$ on the excited ion cyclotron waves and the evolution of the He^{2+} and O^{6+} distributions. The simultaneous observations for He^{2+} and O^{6+} in the downstream of shocks with Active Magnetospheric Particle Tracer Explorers (AMPTE)/CCE spacecraft have demonstrated their shell-like distributions. The observed results verify the existence of the helium cyclotron waves downstream of supercritical quasi-perpendicular shocks.

Numerical studies have been performed by Xiong et al[47] to interpret the observed ‘‘shock overtaking magnetic cloud (MC)’’ event by a 2.5 dimensional MHD model in the heliospheric meridional plane. Results of an individual MC simulation show that the MC travels with a constant bulk flow speed. The MC is injected with a very strong inherent magnetic field over that in the ambient flow and expands rapidly in size initially. Consequently, the diameter of the MC increases in an asymptotic speed while its angular width contracts gradually. Meanwhile, simulations of MC-shock interaction are also presented, in which both a typical MC and a strong fast shock emerge from the inner boundary and propagate along the heliospheric equator, separated by an appropriate interval. The results show that the shock first catches up with the preceding MC, then penetrates through the MC, and finally merges with the MC-driven shock into a stronger compound shock. The morphologies of shock front in interplanetary space and MC body behave as a central concave and a smooth arc, respectively. The compression and rotation of the magnetic field serve as an efficient mechanism to cause a large geomagnetic storm. The MC is highly compressed by the overtaking shock. Contrarily, the transport time of the incidental shock influenced by the MC depends on the interval between their commencements. Maximum geoeffectiveness results from when the shock enters the core of preceding MC, which is also substantiated to some extent by a corresponding simplified analytic model. Quantified by the Dst index, the specific result is that the geoeffectiveness of an individual MC is largely enhanced with 80% increment in maximum by an incidental shock.

In Ref. [48], Xiong et al continue the Numerical studies of the interplanetary ‘‘shock overtaking magnetic cloud (MC)’’ event. Interplanetary direct collision (DC)/oblique collision (OC) between an MC and a shock results from their same/different initial propagation orientations. OC is investigated in contrast with the results in DC[47]. The shock front behaves as a smooth arc. The cannibalized part of MC is highly compressed by the shock front along its normal. As the shock propagates gradually into the preceding MC body, the most violent interaction is transferred sideways with an accompanying significant narrowing of the MC’s angular width. The opposite deflections of MC body and shock aphelion in OC occur simultaneously through the process of the shock penetrating the MC. After the shock’s passage, theMCis restored to its oblate morphology. With the decrease of MC-shock commencement interval, the shock front at 1 AU traverses MC body and is responsible for the same change trend of the latitude of the greatest geoeffectiveness of MC-shock compound. Regardless of shock orientation, shock penetration location regarding the maximum geoeffectiveness is right at MC core on the condition of very strong shock intensity. An appropriate angular difference between the initial eruption of an MC and an overtaking shock leads to the maximum deflection of the MC body. The larger the shock intensity is, the greater is the deflection angle. The interaction of MCs with other disturbances could be a cause of deflected propagation of interplanetary coronal mass ejection (ICME).

4 Interaction of the Solar Wind With the Magnetosphere

Using a recently developed PPMLR-MHD code[49], Guo, Hu and Wang[50] and Wang et al[51] carried out a global numerical simulation of the interaction between interplanetary shocks and the Earth's magnetosphere. The initial magnetosphere is in a quasi-steady state, embedded in a uniform solar wind and a spiral Interplanetary Magnetic Field (IMF). An interplanetary (IP) shock interacts in turn with the bow shock, the magnetosheath, the magnetopause, and the magnetosphere, and changes the magnetosphere in shape and structure, and the distribution of the electric current and potential in the ionosphere as well. A preliminary comparison is made between two IP shocks of the same solar wind dynamic pressure and a vanishing IMF B_z on the downstream side, but with different propagation directions, one parallel and the other oblique to the Sun-Earth line. The numerical results show that both shocks cause a compression of the magnetosphere, an enhancement of magnetic field strength and field-aligned current in the magnetosphere, and an increase of the dawn-dusk electric potential drop across the polar ionosphere. Moreover, the magnetosphere-ionosphere system approaches a similar quasi-steady state after the interaction, for the downstream states are very close for the two shocks. However, the evolution processes of the system are remarkably different during the interaction with the two shocks of different orientations. The shock with the normal oblique to the Sun-Earth line results in a much longer evolution time for the system. This demonstrates that the shock orientation plays an important role in determining the associated geophysical effects and interpreting multisatellite observations of IP shock-magnetosphere interaction events.

Wang et al[52] made a statistical survey of IP shocks and Storm Sudden Commencements (SSCs) observed between 1995 and 2004. They found that 75% of SSCs are associated with shocks, consistent with previous work. They used this survey to investigate the effect of the interplanetary shock strength and orientation on the SSC rise time. They found that the higher the speed of an IP shock, the less time it takes to sweep by the magnetosphere, and thus the shorter the rise time of the corresponding SSC. The orientation of an IP shock also affects the SSC rise time. Generally speaking, a highly oblique shock causes asymmetric compression of the magnetosphere with respect to the noon-midnight meridian, takes more time to sweep by magnetosphere, and thus results in a longer rise time of the SSC.

5 Magnetic reconnection: numerical study and observations

Magnetic reconnection plays a fundamental role in space plasma phenomena by enabling a fast release of magnetic energy and a rapid topological rearrangement of magnetic field lines. While the occurrence of reconnection is well established, the underlying microphysics and mechanism are still poorly understood.

Turbulent reconnection process in a one-dimensional current sheet is investigated by Fan, Feng and xiang[53] by means of a two-dimensional compressible one-fluid MHD simulation with spatially uniform, fixed resistivity. Turbulence is set up by adding to the sheet pinch small but finite level of broadband random-phased magnetic field components. To clarify the nonlinear spatial-temporal nature of the turbulent reconnection process the reconnection system is treated as an unforced initial value problem without any anomalous resistivity model adopted. Numerical results demonstrate the duality of turbulent reconnection, i.e., a transition from Sweet–Parker-like slow reconnection to Petschek-like fast reconnection in its nonlinear evolutionary process. The initial slow reconnection phase is characterized by many independent microreconnection events confined within the sheet region and a global reconnection rate mainly dependent on the initially added turbulence and insensitive to variations of the plasma beta and resistivity. The formation and amplification of the major plasmoid leads the following reconnection process to a rapid reconnection stage with a fast reconnection rate of the order of 0.1 or even larger, drastically changing the topology of the global magnetic field. That is, the presence of MHD turbulence in large-scale current sheets can raise the reconnection rate from small values on the order of the Sweet–Parker rate to high values on the order of the Petscheck rate through triggering an evolution toward fast magnetic reconnection. Meanwhile, the backward coupling between the small- and large-scale magnetic field dynamics has been properly represented through the present high resolution simulation. The undriven turbulent reconnection model established here expresses a solid numerical basis for the previous schematic two-step magnetic reconnection models and a possible explanation of two-stage energy release process of solar explosives.

A possible two-step solar magnetic energy release process attributed to turbulent magnetic reconnection is investigated by Fan, Feng and xiang[54] using MHD simulation for the purpose of accounting for the closely associated observational features including canceling magnetic features and different kinds of small-scale activities such as ultraviolet explosive events in the lower solar atmosphere. Numerical results based on realistic transition region physical parameters show that magnetic reconnections in a vertical turbulent current sheet consist of two stages, i.e., a first slow Sweet–Parker-like reconnection and a later rapid Petschek-like reconnection, where the latter fast reconnection phase seems a direct consequence of the initial slow reconnection phase when a critical state is reached. The formation of coherent plasmoid of various sizes and their coalescence play a central role in this complex nonlinear evolution. The “observed” values of the rate of cancellation flux as well as the approaching velocity of magnetic fragments of inverse polarity in present simulation are well consistent with the corresponding measurements in the latest observations. The difference between our turbulent magnetic reconnection two-step energy release model and other schematic two-step models is discussed and then possible application of present outcome to solar explosives is described.

The Hall effects are suggested to be responsible for the decoupling of electrons and ions of magnetic plasma in the process of magnetic reconnection. However, the process that ultimately causes the electrons to diffuse from the magnetic field in the very small diffusion region remains one of the main unsolved problems in magnetic reconnection theory. Huang, Wei and Feng[55] theoretically studied the structure of the Hall electric field in the diffusion region in the coordinate system located on the magnetic line. They also gave a numerical simulation result for this problem. The main result is that electrons can be generated in the diffusion region due to the Hall effects. Therefore the role of the Hall effects in the decoupling of electrons and ions of a magnetic plasma can be clarified in the structure of the Hall electric field.

Two-dimensional particle-in-cell simulations are performed by Fu, Lu and Wang [56] to study electron acceleration in collisionless magnetic reconnection. The process of electron acceleration is investigated by tracing typical electron trajectories. When there is no initial guide field, the electrons can be accelerated in both the X-type and O-type regions. In the X-type region, the electrons can be reflected back and enter the acceleration region several times before they leave the diffusion region. In this way, the electrons can be accelerated by the inductive electric field to high energy. In the O-type region, the trapped electrons can be accelerated when they are trapped in the magnetic island. When there is an initial guide field, the electrons can only be accelerated in the X-type region, and no obvious acceleration is observed in the O-type region. In the X-type region, the electrons are not demagnetized and they gyrate with the force of the guide field. Although no electron reflection is observed in this region, the acceleration efficiency can be enhanced through staying longer time in the diffusion region due to their gyration motion.

Developing new numerical methods suited to MHD simulation is an important area in space physics. A new numerical scheme of 3rd order weighted essentially non-oscillatory (WENO) type for 2.5D mixed GLM-MHD in Cartesian coordinates is proposed by Feng, Zhou and Hu[57]. The MHD equations are modified by combing the arguments as used formerly to couple the divergence constraint with the evolution equations using a generalized Lagrange multiplier (GLM). With this modification, the MHD part of the GLM-MHD system is still in conservation form. Meanwhile, this method is very easy to add to an existing code since the underlying MHD solver does not have to be modified. To show the validation and capacity of its application to MHD problem modelling, interaction between a magnetosonic shock and a denser cloud and magnetic reconnection problems are used to verify this new MHD code. The numerical tests for 2D Orszag and Tang's MHD vortex, interaction between a magnetosonic shock and a denser cloud and magnetic reconnection problems show that the third order WENO GLM-MHD solvers are robust and yield reliable results by the new mixed GLM or the mixed EGLM correction here even if how the divergence errors are transported as well as damped can not be shown as done before for one dimensional ideal MHD.

The third order accurate upwind compact difference scheme has been applied by Wei, Feng and Hu[58] for the numerical study of the magnetic reconnection driven by a plasma blob impacting the heliospheric current sheet, under the framework of the two-dimensional compressible MHD. The results show that the driven reconnection near the current sheet could occur in about 10-30 minutes for the interplanetary high magnetic Reynolds number, R_M=2000~10000, a stable magnetic reconnection structure can be formed in hour-order of magnitude, and there appear some basic properties such as the multiple X-line reconnections, vortex structures, filament current systems, splitting and collapse of the high-density plasma blob. These results are helpful in understanding and identifying the magnetic reconnection phenomena possibly occurring near the heliospheric current sheets.

A Space–Time Conservative method is applied by Feng et al[59] to 2.5 dimensional resistive MHD equations in Cartesian coordinates, with the purpose of modeling the magnetic reconnection study. To show the validity and capacity of its application to MHD reconnection problem, spontaneous fast reconnection and magnetic reconnection in multiple heliospheric current sheets are studied, which show good consistency with those obtained formerly by other authors. In order to assess the $\nabla\cdot\mathbf{B}=0$ constraint numerically, the contours and evolution of $\nabla\cdot\mathbf{B}=0$ are analyzed. The numerical results show that the CESE numerical scheme not only has good numerical resolution but also can keep the divergence-free condition for magnetic fields in the reconnection problems during the evolutionary process without any special treatment.

In Ref.[60] spontaneous fast reconnection in a neutral current sheet which is initially perturbed by a localized resistivity is studied by the newly developed Space-Time Conservation Element and Solution Element (CESE) method. After the initial perturbation is switched off, an anomalous resistivity is allowed to occur if a threshold of the local electron-ion drift velocity is exceeded. For a given threshold value, the amount of the reconnected magnetic flux introduced by the initial perturbation is very crucial for the onset of the anomalous resistivity. The numerical results indicate that fast reconnection can develop self-consistently with slow shocks extending between the diffusion region and a large-scale plasmoid-like structure, which is pushed forward by the reconnection outflow. A Petscheklike configuration is then built up, but it can not be sustained as a quasi-steady state. In fact, during the reconnection evolution, the diffusion region undergoes an elongation process so that after the dynamic process is nonlinearly saturated secondary tearing is subject to occur at the center of the system. This leads to enhanced and time-dependent reconnection. The reconnection evolution is further studied in various physical situations, also confirming the bursty nature of the spontaneous fast reconnection mechanism.

An interplanetary magnetic diffusion region was detected by WIND during 0735~0850 UT on May 15, 1997 when the front boundary layer of a magnetic cloud passed through the spacecraft about 190 earth radii upstream of the earth. The main signals of magnetic reconnection processes proposed by Wei et al [61] are: (1) Flow reversal was detected at about 0810 UT. The counter-streaming flows have the speeds of about 65 and 41 km/s, respectively, with an angle of about 140 degree between them. (2) Hall magnetic field was detected. The Hall fields $-B_y$ and $+B_y$, perpendicular to the x-z plane, with their magnitude up to about 7.0 nT, are superposed upon a guide field about 12 nT. (3) Alfvenic fluctuations are obviously intensified inside the reconnection region; at the front boundary of the reconnection region, a slow-mode-like discontinuity was detected. (4) Ions are heated intensively inside the reconnection region, with their temperature three times higher than that ahead of the boundary layer; electrons are also heated, with a little enhancement in their temperature. The above observations indicate that magnetic reconnection processes could take place in interplanetary space.

Zhong et al[62] analyzed the WIND data of an interplanetary magnetic cloud on 2 November 2001, and found new evidences for magnetic reconnection in the tail of this MC. In the MC's tail, the largely dip and the large change of the orientation of the magnetic field occurred simultaneously, $\triangle\theta\approx45^\circ$, and $\triangle\Phi$changed from 90º to 320º. Correspondingly, the number density of ions increased, and the superthermal electrons were heated and accelerated, however, its number density decreased. Meanwhile, inverse jets and Hall term were observed. The pitch angle's distributions of the electrons with lower energy and higher energy showed strong turbulence and bi-direction flow, respectively; the plasma wave activity enhanced near the electron plasma frequency, f_{pe} and $2f_{pe}$. These important physical characteristics are new evidences for magnetic reconnection existing in interplanetary space.

6 Space Weather Study

A so-called "ISF" prediction method for geomagnetic disturbances caused by solar wind storms blowing to the Earth is suggested by Wei and Feng[63]. The method is based on a combined approach of solar activity, interplanetary scintillation (I) and geomagnetic disturbance observations during the period 1966–1982 together with the dynamics of solar wind storm propagation (S) and fuzzy mathematics (F). It has been used for prediction tests for 37 geomagnetic disturbance events during the descending solar activity phase 1984–1985, and was presented in 33rd COSPAR conference. Here, it has been improved by consideration of the three dimensional propagation characteristics of each event, the search for the best radio source and the influence of the southward components of interplanetary magnetic fields on the geomagnetic disturbances. It is used for prediction tests for 24 larger geomagnetic disturbance events that produced space anomalies during the period 1980–1999. The main results are: (1) for the onset time of the geomagnetic disturbance, the relative error between the observation, T_{obs}, and the prediction, T_{pred}, $\triangle T_{pred} / T_{obs} \leq 10\%$ for 45.8% of all events, $\leq 30\%$ for 78.3% and >30% for only 21.7%; (2) for the magnetic disturbance magnitude, the relative error between the observation, $\sum Kp_{obs}$, and the prediction, $\sum Kp_{pred}$, $\triangle\sum Kp_{pred}/\sum Kp_{obs} \leq 10\%$ for 41.6% of all events, $\leq 30\%$ for 79% and $\leq 45\%$ for 100%. This shows that the prediction method described here has encouraging prospects for improving predictions of large geomagnetic disturbances in space weather events.

In late October and early November 2003, a series of space weather hazard events erupted in solar-terrestrial space. Aiming at two intense storm (shock) events on 28 and 29 October, Xie[64] presented a Two-Step method, which combines synoptic analysis of space weather–'observing' and quantitative prediction – 'palpating', and uses it to test predictions. In the first step, 'observing', on the basis of observations of the source surface magnetic field, interplanetary scintillation (IPS) and ACE spacecraft, we find that the propagation of the shock waves is asymmetric and northward relative to the normal direction of their solar sources due to the large-scale configuration of the coronal magnetic fields, and the Earth is located near the direction of the fastest speed and greatest energy of the shocks. Being two fast ejection shock events, the fast explosion of extremely high temperature and strong magnetic field, and background solar wind velocity as high as 600 and 1000 km/s are also helpful to their rapid propagation. According to the synoptic analysis, the shock travel times can be estimated as 21 and 20 h, which are close to the observational results of 19.97 and 19.63 h, respectively. In the second step, 'palpating', we adopt a new membership function of the fast shock events for the ISF method. The predicted results here show that for the onset time of the geomagnetic disturbance, the relative errors between the observational and the predicted results are 1.8 and 6.7%, which are consistent with the estimated results of the first step; and for the magnetic disturbance magnitude, the relative errors between the observational and the predicted results are 4.1 and 3.1%, respectively. The comparison among the predicted results of our Two-Step method with those of five other prevailing methods shows that the Two-Step method is advantageous in predicting such strong shock event. It can predict not only shock arrival time, but also the magnitude of magnetic disturbance.

In order to predict the arrival time at 1AU of interplanetary shocks, a simple model called shock propagation model is established by Gao and Feng[65]. In this model, the travel time is assumed to be a function of energy that is released from solar explosives, and input pulse longitudinal width, input pulse duration, the interaction of interplanetary shock and background solar wind are also taken into account. In order to verify the prediction efficiency, 27 interplanetary shock events from January 1979 to June 1982 and 68 interplanetary shock events from February 1997 to January 2000 are used for testing. Comparing the results of our shock propagation model with those obtained by STOA and ISPM models, we find that our disturbance propagation model is as good as the other two models, and in some cases even better. The shock propagation model can give the prediction for all the 95 shock events, while STOA model works for 89 events and ISPM model for only 72 events. They have 25.26% percentage of all the 95 events with the relative time error less than 10%, 50.53% of all the events with the relative time error less than 20%, 65.26% of all the events with the relative time error less than 30%。

Using 80 CME-ICME events during 1997.1–2002.9, based on the eruptive source locations of CMEs and solar magnetic field observation at the photosphere, a current sheet magnetic coordinate (CMC) system is established by Zhao and Feng[66] in order to study the propagation of CME and its geoeffectiveness. In context of this coordinate system, the effect of the eruptive source location and the form of heliospheric current sheet (HCS) at the eruptive time of CME on the geomagnetic storm intensity caused by CME and the CME's transit time at the Earth is investigated in detail. Our preliminary conclusions are: 1) The geomagnetic disturbances caused by CMEs tend to have the so-called "same side-opposite side effect", *i.e.* CMEs erupt from the same side of the HCS as the earth would be more likely to arrive at the earth and the geomagnetic disturbances associated with them tend to be of larger magnitude, while CMEs erupting from the opposite side would arrive at the earth with less probability and the corresponding geomagnetic disturbance magnitudes would be relatively weaker. 2) The angular separation between the earth and the HCS affect the corresponding disturbance intensity. That is, when our earth is located near the HCS, adverse space weather events occur most probably. 3) The erupting location of the CME and its nearby form of HCS will also affect its arrival time at the earth. According to these conclusions, in this context of CMC coordinate we arrive at new prediction method for estimating the geomagnetic storm intensity (Dst_{min}) caused by CMEs and their transit times. The application of the empirical model for 80 CME-ICME events shows that the relative error of Dst is within 30% for 59% events with $Dst_{min} \leq -50$ nT, while the averaged absolute error of transit time is lower than 10 hour for all events.

Using 180 interplanetary (IP) shock events associated with coronal mass ejections (CMEs) during 1997–2005, Xie et al[67] investigate the influence of the heliospheric current sheet (HCS) upon the propagation and geoeffectiveness of IP shocks. The preliminary results are: (1) The majority of CME driving IP shocks occurred near the HCS. (2) The numbers of shock events and related geomagnetic storms observed when the Earth and the solar source are located on the same side of the HCS, represented by f_{SS} and f_{SG}, respectively, are obviously higher than those when the Earth and the solar source are located on the opposite sides of the HCS, denoted by f_{OS} and f_{OG}, with f_{SS}/ f_{OS} = 126/54, f_{SG}/ f_{OG} = 91/36. (3) Parameter jumps across the shock fronts for the same-side events are also higher than those for the opposite-side events, and the stronger shocks ($\triangle V \geq 200$ km s−1) are mainly attributed to be same-side events, with f_{SSh}/ f_{OSh} = 28/15, where f_{SSh} and f_{OSh} are numbers of stronger shocks which belong to same-side events and opposite-side events, respectively. (4) The level of the geomagnetic disturbances is higher for the same-side events than for the opposite side events. The ratio of the number of intense magnetic storms (Dst < −100) triggered by same-side events to those triggered by opposite-side events is 25/10. (5)We propose an empirical model to predict the arrival time of the shock at the Earth, whose accuracy is comparable to that of other prevailing models. These results show that the HCS is an important physical structure, which probably plays an important role in the propagation of interplanetary shocks and their geoeffectiveness.

By analyzing 8 great geomagnetic storms (Dst<-200 nT) during 2000-2001, the interplanetary causes of great geomagnetic storms are summarized by Xue et al[68]. Almost all of the storms were caused by compressed solar wind plasma formed due to the shock compression or multiple magnetic clouds. Only one storm was caused by an isolated MC.

Interplanetary magnetic clouds (MCs) are one of the main sources of large nonrecurrent geomagnetic storms. With the aid of a force-free flux rope model, the dependence of the intensity of geomagnetic activity indicated by Dst index on the axial orientation (denoted by θ and φ in GSE coordinates) of the magnetic cloud is analyzed theoretically by Wang, Ye and wang[69]. The distribution of the Dst values in the (θ,φ) plane is calculated by changing the axial orientation for various cases. Their resuts are: (1) geomagnetic storms tend to occur in the region of $\theta<0°$, especially in the region of $\theta\leq-45°$, where larger geomagnetic activity could be created; (2) the intensity of geomagnetic activity varies more strongly with θ than with φ; (3) when the parameters B_0 (the magnetic field strength at the flux rope axis), R_0 (the radius of the flux rope), or V (the bulk speed) increase, or |D| (the shortest distance between the flux rope axis and the x-axis in GSE coordinates) decreases, a flux rope not only can increase the intensity of geomagnetic activity, but also is more likely to create a storm, however the variation of n (the density) only has a little effect on the intensity; (4) the most efficient orientation (MEO) in which a flux rope can cause the largest geomagnetic activity appears at φ□0° or □180°, and some value of θ which depends mainly on D; (5) the minimum Dst value that could be caused by a flux rope is the most sensitive to changes in B0 and V of the flux rope, and for a stronger and/or faster MC, a wider range of orientations will be geoeffective. Further, through analyzing 20 MC-caused moderate to large geomagnetic storms during 1998–2003, a long-term prediction of MC-caused geomagnetic storms on the basis of the flux rope model is proposed and assessed. The comparison between the theoretical results and the observations shows that there is a close linear correlation between the estimated and observed minimum Dst values.

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MAGNETOSPHERIC PHYSICS IN CHINA: 2003-2006

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Abstract:

Their brief report presents the advances of the magnetospheric physics researches in China during the period of 2003.01-2006.04. During the past three years, China-ESA cooperation DSP (Double Star Program) satellites were successively launched. In addition, China also participated in the scientific research of ESA's Cluster mission. The DSP and Cluster missions provide Chinese space physicists high quality data to study multiscale physical process in the magnetosphere.

1 Geomagnetic storms

Fu et al [2003] further studied the dependence of the ring current ions and its position to the solar and geomagnetic activity. The solar-cycle and geomagnetic dependence of the ring current ion composition and their maximum positions have been studied by using the energetic particle data [1]obtained by MICS instrument on board CRRES satellite and other research results of AMPTE. Observations s[2]how that the number density ratio and energy density ratio of O+, He++ and He+ ions to the total ring current all show an increase during geomagnetic active times, whereas that of H+ ions exhibits an obvious decrease. Compared with AMPTE observations in the solar minimum, the abundance of the ring current H+ is apparently lower in the solar maximum than during solar minimum. In contrast, the abundance of both O+ and He++ ions are higher. CRRES data also show that, in addition to the inward motion of the position of the maximum flux of O+ and He+ during a geomagnetic storm, the location of the maximum number density of the energetic ions is about 0.5 R*E* lower in solar maximum than in solar minimum.

Xie et al.[2004] studied ring current injection and intensification of the storm-time symmetric ring current with three-dimensional (3-D) test particle trajectory calculations (TPTCs). TPTCs reveal more accurately the process of ring current injection. The main results are the following: (1)

[1] Supported by NSFC 40025413

an intense convection electric field can effectively energize and inject plasma sheet particles into ring current region within 1-3 hours. (2) Injection ions often follow chaotic trajectories in non-adiabatic regions, which may have implications in storm and ring current physics. (3) The shielding electric field, which arises as a consequence of enhanced convection and co-exists with injection and convection electric field, leads the original open trajectories to change into closed ones thus may play an important role in the formation of the symmetric ring current.

Fu et al.[2005] report energetic ion behavior and its composition variations observed by the Cluster/RAPID instrument when the spacecraft was travelling in the high latitude magnetospheric boundary region on the day of the 31 March, 2001, strongest magnetic storm in the past 50 years. The Dst index reached 360 nT at about 09:00 UT. During its early recovery phase, large amounts of oxygen and helium ions were observed; the ratio of oxygen to hydrogen in the RAPID energy range reached as high as 250%, which suggests that the observed energetic particles might be of magnetospheric origin. The observations further show that enhanced energetic electron fluxes are confined in a very narrow region, while protons have occupied a larger region, and heavy ions have been observed in an even larger region. The flux of energetic electrons show a slight enhancement in a region where the magnetic field magnitude is around zero. These observed energetic ions could be quasi-trapped by the current sheet in the stagnation region of the cusp.

Li and Xu.[2005] simulated The morphology of the plasmasphere during a geomagnetic storm by considering the two dimensional $E \times B$ drift motion of plasmaspheric charged particles in the equatorial plane. Assuming a time-independent dipolar magnetic field and a corotation electric field plus, a spatially uniform dawn–dusk convection electric field varying with Kp index, the spatial distributions of charged particles at different time during a geomagnetic storm are obtained. Their results show that if Kp increases with time, some particles inside the original plasmapause will convect into the magnetopause, forming a long tail that stretches from the plasmasphere to the magnetopause in the afternoon region. The particle convection weakens as Kp decreases, and as Kp returns to its normal value, the plasmasphere develops a thin tail that wraps around the Earth.

Tian et al.[2005] developed a method to predict geomagnetic storm by using the data of solar wind. Intense geomagnetic storms ($Dst < -100$ nT) usually occur when a large interplanetary duskward electric field (with $Ey > 5$ mV/m) lasts for more than 3 h. In their work, a self-organizing map (SOM) neural network is used to recognize different patterns in the temporal variation of hourly averaged Ey data and to predict intense storms. The input parameters of SOM are the hourly averaged Ey data over 3 h. The output layer of the SOM has a total of 400 neurons. The hourly Ey data are calculated from solar wind data, which are provided by NSSDC OMNIWeb and ACE spacecraft and contain information on 143 intense storms and a fair number of moderate storms, weak storms and quiet periods between September 3, 1966 and June 30, 2002. Their results show that SOM is able to classify solar wind structures and therefore to give timely intense storm alarms. In their SOM, 21 neurons out of 400 are identified to be closely associated with the intense storms and they successfully predict 134 intense storms out of the 143 ones selected. In particular, there are 14 neurons for which, if one or more of them are present, the occurrence probability of intense storms is about 90%. In addition, several of these 14 neurons can predict big magnetic storm (Dst ≤ - 180 nT). In summary, their method achieves high accuracy in predicting intense geomagnetic storms and could be applied in space environment prediction.

The energetic ion injection and formation of the storm-time symmetric ring current are also studied by Xie et al.[2006], who is conducted an extensive study of ring current injection and intensification of the storm-time ring current with three-dimensional (3-D) test particle trajectory calculations(TPTCs). The TPTCs reveal more accurately the processof ring current injection, with the main results being thefollowing: (1) an intense convection electric field can effectivelyenergize and inject plasma sheet particles into thering current region within 1–3 h. (2) Injected ions often followchaotic trajectories in non-adiabatic regions, which mayhave implications in storm and ring current physics. (3) Theshielding electric field, which arises as a consequence of enhancedconvection and co-exists with the injection and convectionelectric field, may cause the original open trajectoriesof injected ions with higher energy to change into closedones, thus playing a role in the formation of the symmetricring current.

Wang et al.[2006] made a statistical survey of interplanetary (IP) shocks and storm sudden commencements (SSCs) observed between 1995 and 2004. They find that 75% of SSCs are associated with shocks, consistent with previous work. They use this survey to investigate the effect of the interplanetary shock strength and orientation on the SSC rise time. They find that the higher the speed of an IP shock, the less time it takes to sweep by the magnetosphere, and thus the shorter the rise time of the corresponding SSC. The orientation of an IP shock also effects the SSC rise time. Generally speaking, a highly oblique shock causes asymmetric compression of the magnetosphere with respect to the noon-midnight meridian, takes more time to sweep by magnetosphere, and thus results in a longer rise time of the SSC.

The study of Wang and Lur et al. [2006] concentrates on the characteristics of field-aligned currents (FACs) in both hemispheres during the extreme storms in October and November 2003. High resolution CHAMP magnetic data reflect the dynamics of FACs during these geomagnetic storms, which are different from normal periods. The peak intensity and most equatorward location of FACs in response to the storm phases areexamined separately for both hemispheres, as well as for the dayside and nightside. The corresponding large-scale FAC peak densities are, on average, enhanced by about a factor of 5 compared to the quiet-time FACs' strengths. And the FAC densities on the dayside are, on average, 2.5 times larger in the Southern (summer) than in the Northern (winter) Hemisphere, while the observed intensities on the nightside are comparable between the two hemispheres. Solar wind dynamic pressure is correlated with the FACs strength on the dayside. However, the latitudinal variations of the FACs are compared with the variations in Dst and the interplanetary magnetic field component Bz, in order to determine how these parameters control the large-scale FACs' configuration in the polar region. They have determined that (1) the equatorward shift of FACs on the dayside is directly controlled by the southward IMF Bz and there is a saturation of the latitudinal displacement for large value of negative Bz. In the winter hemisphere this saturation occurs at higher latitudes than in the summer hemisphere. (2) The equatorward expansion of the nightside FACs is delayed with respect to the solar wind input. The poleward recovery of FACs on the nightside is slower than on the dayside. The latitudinal variations on the nightside are better described by the variations of the Dst index. (3) The latitudinal width of the FAC region on the nightside spreads over a wide range of about 25_ in latitude.

Based on a large dataset of ion drift velocity measurements board on DMSP satellite, a study is made on the plasma bulk upflowing in the topside polar ionosphere [Huo et al 2006]. The emphasis is put on the storm-time changes in distribution of upflow occurrence and intensity versus MLT (mainly dawn and dusk) in comparison with that during quiet period, as well as the relationship between the ion upflow with the plasma convection and its shear. The results show that the storm-time occurrence frequency of upflow events is nearly two times higher than that during quiet period; the dawn- dusk asymmetry for occurrence frequency inversed from favoring dusk-side to favoring dawn-side. On an average, the storm-time velocity of the ion upflow in the dawn sector is larger than that in the dusk, with maximum upflowing velocity much larger than that in dusk sector. The ion upflow is closely related to the plasma convection and its shear, with strong upflow accompanied usually by large convection shear or abnormally large convection itself.

2 Magnetospheric substorms

Cao et al. .[2004] analyze the characteristics of Pi2s in Beijing from January 1 to March 26 in 1998 and from April 24 to June 13 in 1998, and compare them with AE indexes. In Beijing near the noon time, the occurrence rate .of Pi2 is less and the amplitudes of Pi2s smaller. Not all substorms can excite the cavity oscillation modes. The amplitudes of Pi2 usually increase with the increase of AE index,. However there remain some exceptions which may be due to the fact that Beijing is sometimes very far from the substorm current wedge. Pi2s in Beijing are throughout the whole substorm stages. However for some substorms, no Pi2 is found in Beijing. The AE indexes of theses substorms range from 200 nT to 800 nT. Although Beijing is classified as low latitude region, the characteristics of Pi2s in Beijing is more analogous to that of the Pi2s in middle latitude region. So it is not very credible to use the Pi2s in Beijing to predict and monitor substorms

Ma et al.[2005] studied the Bursty Bulk Flow events (BBFs) observed by CLUSTE during the quite time of the magnetotail. By studying the data of multi-satellites of CLUSTE, they got some results about the time scale of BBFs which is different from that obtained from single satellite. The temporal scale of multi-satellites is about twice that of single satellite. Flapping of BBFs in the dusk-dawn direction mainly determined temporal order of observation of BBFs of three CLUSTE satellites. The localization of BBFs is also confirmed by multi-satellites observations simultaneously. The longer duration of BBFs during the quiet time of magnetotail enhances the earthward transport of mass and energy and changes the onset of the substorm. Their study also provided a new idea to solve the Pressure Balance Inconsistency (PBI).

Cao et al.[2006a], using the observations of three satellites of Cluster (C1, C3 and C4) during the periods July-Oct 2001 and July-Oct 2002, studied 209 active time BBFs, the difference between single satellite observations and multi satellite observations, and the difference among three selection criteria (two about BBFs and one about rapid convection event). Single satellite observations show that the average duration of BBFs selected by the criterion of Angelopoulos et al. is 604s, while multi satellite observations show that the average duration of BBFs is 1105s. Single satellite sometimes misses the BBFs. The missing ratio of single satellite is 22.4% for the criterion of Angelopoulos et al. and 44.9 % for the criterion of Raj et al.. Therefore the single satellite observations can't tell the true number of BBFs. The multi satellite observations are more important for the criterion of Raj et al. The single satellite observations also show that 22% of substorms are not accompanied by BBFs, while multi satellite observations show that only 4.5% of substorms are not accompanied by BBFs. Thus it seems possible that all substorms are accompanied by BBFs. The occurrence frequency of RCEs in the central plasma sheet obtained by multi satellites is 12.2%. The occurrence frequency of BBFs in the central plasma sheet is 9.5% for single satellite observations and 19.4% for multi satellite observations. So BBFs may contribute more to the transport of magnetic flux, mass and energy than what was estimated by previous studies based on single satellite observations.

Xie et al. [2006] studied the Auroral Equatorward Boundary Observed by the NOAA 17 Satellite. Precipitating energetic electrons and protons measured by the TED and MEPED instruments on the NOAA-17 satellite have been investigated. The equatorward boundary of the aurora, defined by the cutoff in the energy fluxes of precipitating particles, is highly coincident with the last closed equipotential line (LCE), which closely represents the plasmapause location (PPL) when the plasmapause moves toward the Earth. This coincidence exists for both low-energy and high-energy (>300keV) ions and electrons. The correlation of the equatorward boundary of the aurora with the LCE suggests that the depth which plasmasheet particles can be transported into the inner magnetosphere is well determined by the PPL. The pitch angle scattering which leads to the precipitation of energetic particles is most effective outside the PPL where strong chorus waves are generated by plasmasheet electrons. Further, the observations indicate that the movement of the auroral equatorward boundary and auroral activity are strongly related to the geomagnetic Kp index, which is determined by the solar wind conditions. During the period of intense geomagnetic activity, such as during the Oct-Nov 2003 magnetic storm, the auroral equatorward boundary can move to magnetic latitudes as low as 40^0- 45^0.

With a favorable constellation of spacecraft and ground stations, a study is made on the global manifestations of a substorm onset [Wang and Ma et al., 2006]. The onset occurred simultaneously and conjugately in both hemispheres, confirmed by observations of the auroral breakup from IMAGE FUV-WIC and a sudden intensification of a westward electrojet from ground-based magnetometers. Concurrently with the onset, field-aligned and Hall currents in the auroral ionosphere are observed by CHAMP, which are consistent with the signature of a Harang discontinuity. Immediately after the onset a magnetic field dipolarization is clearly observed by Double Star TC-1, located near the central magnetotail and subsequently, by the Cluster quartet. The observations can be explained by a dawnward propagation of the substorm current wedge at a speed of about 300 km/s.

3 Magnetic reconnection

Cui et al.[2003] studied flux rope structures at the dayside magnetopause by both observation and simulation. The signatures of flux ropes with obvious core magnetic field are detected by Cluster II at the dayside magnetopause during 11:00—11:15UT on Mar. 2, 2001. The similar characteristics can be found from the magnetic field variations recorded by the four spacecraft (Cluster II C1—C4). All the three (-/+) bipolar signatures in the B_N component are accompanied with enhancements of B_M and magnetic field strength B in the boundary normal coordinates (LMN coordinates). A MHD simulation with two-dimensions and three-components is performed to explore the reconnection process driven by the incoming flow of solar wind at the dayside magnetopause. The numerical results illustrate recurrent formation of magnetic structures with a core magnetic field. The time histories of magnetic field B and three components B_x , B_y and B_z at a given point of the current sheet can reproduce the observational features of the events mentioned above.

Zhou et al.[2003] analyzed the hot ion (~5eV/e-32keV/e) and magnetic field data observed by Cluster II-C1 CIS/HIS and FGM during the magnetotail plasma sheet crossing on September 15, 2001. In the interval of 0340UT-0440UT, fast tailward ion flows ($V_{xGSM} < 0$) were observed, which were associated with the enhancements of southward and dusk-downward magnetic fields ($B_{zGSM} < 0$ and $B_{yGSM} < 0$ or > 0). It can be inferred from these observations that magnetic reconnection events took place at $X_{GSE} > -18.6 R_E$ within the plasma sheet in the interval of 0340UT-0440UT on September 15, 2001. The characteristics for these events are consistent with the physical pictures of theory for a quasi-collisionless magnetic reconnection. Hence these events should be called as a quasi-collisionless magnetic reconnection event.

Jin and Cui [2004] studied the driven reconnection processes at the dayside magnetopause through two-dimensional magnetohydrodynamics (MHD) simulation with three components. The numerical results show significant enhancements of the magnetic field strength B and the B_y component at the centers of the recurrent plasmoid-like structures. Such features are in line with the signatures of flux transfer events (FTEs) which are envisaged as passages of magnetic flux tubes. The evolution of the topological structure in reconnected flux tubes is investigated in terms of the principle of magnetic helicity. It is found that the total magnetic helicity in the domain increases as time elapses due to the transportation of magnetic helicity flux through the system boundaries and a peak value of the magnetic helicity density $h(=AB_y$ where A is the magnetic flux function) always occurs in the central region of the reconnected flux tube. Furthermore, the gradual accumulation of h in the current sheet is associated with the accumulated magnetic flux A which is carried into this region by the plasma inflow. The concentration of the helicity density h in the core of a flux tube arises from the enhancement of the axial field B_y, which is associated with the continuous addition of B_y flux to the domain. The present results indicate that the occurrence of the flux rope structure in the vicinity of the magnetopause might be related to the solar wind plasma flow.

Based on the previous two-dimension and three-components MHD numerical simulation, Cui and Jin [2004] analyses the evolution of magnetic helicity of various magnetic structures in the magnetotail. The results indicate that, in the driven magnetic reconnection process generated by the dawn-dusk electric field in the magnetotail, the transportation of magnetic helicity flux via the boundaries of system is the direct cause of the change of the total magnetic helicity in the system. The various initial distributions of magnetic helicity density and the transportation of magnetic helicity flux may lead to various evolutions of magnetic helicity density in the neutral sheet region, and could result in the formation of various magnetic structures.

Jin and Yang [2004] studied the core field enhancement caused by pressure loss in the flux rope structures in the magnetotail. The plasmoids in the Earth's magnetotail, which are closely correlated with magnetospheric substorm, might be the structures with various magnetic topologies. Most plasmoids are flux rope like structures with large core fields. It is shown in the MHD simulations that the occurrence of various magnetic structures in the magnetotail might be related to different distributions of the cross-tail component B_y. However, the core field strength of flux rope structures shown in the previous simulations is much lower than the ambient lobe field strength. In this paper, they consider that the pressure loss caused by extension of helical field lines to the flank regions and introduce the modificative terms $\left.\frac{\partial \rho}{\partial t}\right|_{loss}$, $\left.\frac{\partial T}{\partial t}\right|_{loss}$ and $\left.\frac{\partial B_y}{\partial t}\right|_{inc}$ to the MHD equations. In two cases with uniform initial B_y distribution, the recurrent formation and successive ejection of flux rope structures is illustrated under the action of plasma inflow caused by the dawn-dusk electric field. It is noticeable that in the cases with the modificative terms, a reduction of the averaging magnitude of peak pressure values and a considerable enhancement of the averaging strength of core magnetic field is exhibited for the multiple magnetic structures. Moreover, In case 1 with a lower background B_y (B_{y0}=1nT) the relative amplitude of core field B_y enhancement is larger than that in case 2 (B_{y0}=2nT).

Zuo et al. [2004] perform A study of the characteristics for the flux transfer events occurred on March 2nd, 2001. Three flux transfer events (FTEs) were detected in magnetosheath near the south cusp of the dawn side by Cluster II during the interval from 11:00 to 11:15 UT on March 2, 2001. In this paper, they analyze the magnetic morphology and the plasma characteristics of these events using the magnetic field and plasma data observed by the four spacecrafts of Cluster II. And the electric current density in the region Cluster II passed were estimated from the Ampere's law in terms of measured spatial gradients of the magnetic field detected simultaneously by four spacecrafts of Cluster II at different places. The results are as follows: (1) The magnetic reconnection at the dayside magnetopause can occur near the cusp when the IMF By component is dominant; (2) The difference of p+B^2/8π (the sum of magnetic and plasma pressure) measured inside and outside the events may not be balanced with the tension of the helical magnetic field at the initial stage when a flux tube is forming, it needs a growing time to reach an equilibrium; (3) The size of the section of the FTEs flux tubes in L-M plane is about 1.89 Re; (4) The plasma inside the flux tubes flows dominantly along the axis-aligned field, at the same time the flux tubes move southward to the tail and its velocity is more slowly than the ambient medium; (5) There are not only axis-aligned current inside the flux tubes but also annular current, the axis-aligned current flows basically along the axis-aligned magnetic field. Because both axis-aligned and annular current distribute in the whole flux tubes, thus the annular magnetic field produced by the axis-aligned current will decrease to zero gradually near the center of the flux tube, and the axis-aligned magnetic field produced by annular current will increase to its extremum by degrees; (6) An enhancement of magnetospheric energetic particle flux was observed inside magnetosheath portion of the flux tubes, this implied that the flux tubes connect the magnetosheath with the magnetosphere through the magnetopause.

Xiao et al. [2004] calculated the current density during multiple flux rope events at the high-latitude magnetopause on January 26, 2001. A systematic comparison is carried out for three Methods of current density calculating based on simultaneous magnetic field measurements of four-spacecraft Cluster mission. Analytically and numerically demonstrated that within the linear approximation, all these methods lead to the exactly the same results. As a case study, the current density of multiple flux rope events at the high-latitude magnetopause on January 26, 2001is investigated. It is showed that an intense current flows inside the ropes with the current density reaching as high as $\sim 10^{-8} A/m^2$. The current inside rope is valuable for the small relative calculating error. It is also found that the directory of current is almost parallel the axis of flux rope gotten by magnetic minimum variance analysis (MVA). It is supposed the current MVA method is useful and simply for the rope axis orientation.

Deng et al. .[2004] analyzed multiple X-lines collisionless reconnection observed by Geotail. On 11 December 1994 the Geotail spacecraft encountered an active reconnection diffusion region around the X line in the Earth's magnetotail. Three interesting features were observed. One is quadrupole pattern of the out-of-plane By magnetic field component during the passage of magnetic islands and the crossing of the neutral sheet. The second is a direction reversal of the electron beams in the vicinity of the separatrix of the magnetic topology of reconnection. The third is a clear plasma flow reversal. By combining the observations of plasma, magnetic field, particles, and waves, their report may provide evidence of multiple X lines collisionless reconnection in the magnetotail at the microscopic level.

Huang et al .[2004] studied the multiple flux rope events at the high-latitude magnetopause observed by Cluster. From 11 :40 to 11 :40UT on January 26, 2001 four Cluster-II spacecrafts were located in the duskside, high latitude regions of the magnetosheath and the magnetosheath boundary layer. During this time interval the interplanetary magnetic field (IMF) had a negative B-z component. A detailed study on the multiple flux ropes (MFRs) observed in this time period is conducted in their paper. It is found that the MFRs in the high latitude magneto heath boundary appeared quasi-periodically with a repeated time period of about 78s, which is much shorter than the averaged occurrence period (about 8-11 minutes) of the flux transfer events (FTEs) at the dayside magnetopause. All the flux ropes observed in this event had a strong core magnetic field. The principal axis of the most flux ropes are found to lie in the direction of the minimum magnetic field variation. A few flux ropes had their axes lying in the direction of the middle magnetic field variation; while for the remainders their principle axes could not be determined by the method of Principal Axis Analysis (PAA). The reason that causes this complexity relays on the different trajectories of the spacecraft passing through the flux ropes. Each flux rope had a good corresponding HT frame of reference in which it was in a quasi-steady state. All flux ropes moved along the surface of the magnetopause in a similar direction indicating that these flux ropes were coming from the dawnside low latitude. Their radial scale is found to be 1-2R(E), comparable to the normal diameter of FTEs. The energetic ions originated from the magnetosphere were flowing out to the magnetosheath on the whole, while the solar wind plasma was seen to flow into the magnetosphere along the axis of the flux ropes. The flux ropes offered channels for the transport of the solar wind plasma into the magnetosphere and the escape of the magnetospheric plasma into the interplanetary space. Each event was accompanied by an enhanced reversal of the dusk-dawn electric field, which could be identified to be the convective electric field in nature.

The effects of Hall Current in the Driven Reconnection with Various Scales are studied theoretically by Yang et al.[2004]. In the driven reconnection process with various scales, the effect of Hall current is studied numerically using a Hall magnetohydrodynamics (MHD) code derived from multi-step implicit scheme. In the cases with $L_c/d_i \leq 1.0$ (L_c is the half-thickness of initial current sheet layer, d_i is the ion inertial length), the features of Hall MHD reconnection are shown as follows: a quasi-steady single X-line reconnection is obtained, the B_y component with a quadrupolar structure is generated and the maximum reconnection rate is larger than 0.11. For the cases with $L_c/d_i > 1.0$, the effect of Hall current on the reconnection dynamics weakens and Hall MHD reconnection is gradually transformed into resistive MHD reconnection as L_c/d_i increases.

Du et al.[2004] studied plasmoid-like structures in the magnetotail. In view of the distribution features of the temperature and density across the different regions of the quiet magnetotail, the same non-uniform distributions of the temperature and density are used as the initial state of the simulation study. In their report, three cases with the different distributions of initial B_y component are investigated. The numerical results illustrate the characteristic evolution of three kinds of magnetic structures. For the varying magnetic field at a given point in the neutral sheet, the hodograms of the typical events are performed. From another point of view, the hodograms of three cases show the features of flux rope structure, plasmoids with complex closed magnetic field lines and two-dimension “magnetic island”, respectively. It was demonstrated from the observations that most plasmoids in the magnetotail are the flux rope structures with a large core field. Monitoring the development of a flux rope structure, the profiles of the directional velocity V_x, V_y, V_z and magnetic field strength B in it as a function of the distance x are given. The computing values of V_x and B are approximately consistent with the observed values in the near and middle tail by Geotail. Moreover, in comparison with Jin et al.’s simulation with a constant initial temperature, in the present work the temperature of plasmoids increases and the density of plasmoids decreases notably, and so the difference between the numerical results and observation is reduced.

Using MHD simulations, Jin et al. [2004] studied the core field enhancement caused by pressure loss in the flux rope structures in the magnetotail. The plasmoids in the Earth’s magnetotail, which are closely correlated with magnetospheric substorm, might be the structures with various magnetic topologies. Most plasmoids are flux rope like structures with large core fields. It is shown in the MHD simulations that the occurrence of various magnetic structures in the magnetotail might be related to different distributions of the cross-tail component B_y. However, the core field strength of flux rope structures shown in the previous simulations is much lower than the field strength in the ambient lobe. In their paper, they consider that the pressure loss caused by extension of helical field lines to the flank regions and introduce the modificative terms $\partial\rho/\partial t|_{loss}$, $\partial T/\partial t|_{loss}$ and $\partial By/\partial t|_{inc}$ to the MHD equations. In two cases with uniform initial B_y distribution, the recurrent formation and successive ejection of flux rope structures is illustrated under the action of plasma inflow caused by the dawn-dusk electric field. It is noticeable that in the cases with the modificative terms, a reduction of the averaging magnitude of peak pressure values and a considerable enhancement of the averaging strength of core magnetic field is exhibited for the multiple magnetic structures. Moreover, In case 1 with a lower background B_y ($B_{y0} = 1nT$) the relative amplitude of core field B_y enhancement is larger than that in case 2 ($B_{y0} = 2nT$).

Also Jin et al. [2004] studied the driven reconnection processes at the dayside magnetopause by using a two-dimensional magnetohydrodynamics simulation with three components. The numerical results show significant enhancements of the magnetic field strength *B* and the *By* component at the centers of the recurrent plasmoid-like structures. Such features are in line with the signatures of flux transfer events which are envisaged as passages of magnetic flux tubes. The evolution of the topological structure in reconnected flux tubes is investigated in terms of the principle of magnetic helicity. It is found that the total magnetic helicity in the domain increases as time elapses due to the transportation of magnetic helicity flux through the system boundaries and a peak value of the magnetic helicity density *h* always occurs in the central region of the reconnected flux tube. Furthermore, the gradual accumulation of *h* in the current sheet is associated with the accumulated magnetic flux which is carried into this region by the plasma inflow. The concentration of the helicity density *h* in the core of a flux tube arises from the enhancement of the axial field *By* , which is associated with the continuous addition of *By* flux to the domain. The present results indicate that the occurrence of the flux rope structure in the vicinity of the magnetopause might be related to the solar wind plasma flow.

Pu et al [2004] studied the Magnetic reconnection at the high-latitude magnetopause iby using 2.5-dimensional Hall-MHD simulation. Concentric flow vortices and magnetic islands appear when both Hall effect and sheared flow are considered. Plasma mixing across the magnetopause occurs in the presence of the flow vortices. Reconnected structure generated in the vicinity of the subsolar point changes its geometry with increasing flow shear while moving to high latitudes. In the presence of flow shear, with the Hall-MHD reconnection a higher reconnection rate than with the traditional MHD is obtained. The out-of-plane components of flow and magnetic field produced by the Hall current are redistributed under the action of the flow shear, which makes the plasma transport across the boundaries more complicated. The simulation results provide some help in understanding the dynamic processes at the high latitude magnetopause.

Cluster satellites observed the flux rope events at the magnetopause. The accuracy in flux rope orientation inference from both the traditional magnetic field based minimum variance analysis

(BMVA) technique and the current-based MVA (CMVA) approach is examined by Xiao et al [2004]. Four different flux rope models are used in the MVA test. It is found that the directions of eigenvectors of MVA are critically dependent on the spacecraft path relative to the flux rope axis and structure of the flux rope encountered. For force-free flux ropes, the M direction of BMVA best fits the axial orientation, while for non-force-free flux ropes the BMVA may fail as the orientation inference tool. Magnetic field data from a single satellite path through non-force-free flux ropes are often insufficient to determine the rope orientation. Uncertainty may appear, as neither the N nor the M eigenvector is close to the axial direction. On the other hand, the CMVA based on multiple spacecraft measurements may help to eliminate such an uncertainty and shows great effectiveness for study of structures and geometries of the observed flux ropes.

Also Xiao et al [2004] calculated the current density of multiple flux rope events at the high-latitude magnetopause observed by Cluster On January 26, 2001. A systematic comparison is carried out for three Methods of current density calculating based on simultaneous magnetic field measurements of four-spacecraft Cluster mission. Analytically and numerically demonstrated that within the linear approximation, all these methods lead to the exactly the same results. As a case study, the current density of multiple flux rope events at the high-latitude magnetopause on January 26, 2001 is investigated. It is showed that an intense current flows inside the ropes with the current density reaching as high as about 10^{-8} A/m^2. The current inside rope is valuable for the small relative calculating error. It is also found that the directory of current is almost parallel the axis of flux rope gotten by magnetic minimum variance analysis (MVA). It is supposed the current MVA method is useful and simply for the rope axis orientation.

Zhou et al [2004] studied the linear dispersion properties and waves in the collisionless plasma current sheet at small scales by using 2.5- dimensional, collisionless and incompressible magnetohydrodynamic (MHD) models with the full electron pressure tensor. General dispersion relations are very complex. Two special cases, i.e., the central region of current sheet and the electron Beta = 0, are analytically studied here. The main results are as follows. (1) In the ion-inertial region ($kd_i > 1$), there are fast magnetosonic kinetic Alfven waves and obliquely Alfven-whistler waves, and the electron magnetohydrodynamic (EMHD) model is a precise MHD model. In the long wavelength region ($kd_i < 1$), there are Alfven waves and ion acoustic waves, and the ideal MHD model is valid. (2) When electron Beta = 0, the results drop off some modes, e.g., the fast magnetosonic-kinetic Alfven wave and ion acoustic wave. This case is not exactly valid for the current sheet plasma. (3) At central region of current sheet, results from both of physical models have fast magnetosonic-kinetic Alfven waves.

Cao et al [2005] studied the continuous lobe reconnection in the mid-tail and its relationship to substorms. When the IMF turns southward, a great amount of magnetic energy is stored in the magnetotail, and the electric field across the magnetotail substantially enhances. As long as magnetic reconnection (MR) in the magnetotail initiates and continues, the magnetic field and plasma in the central plasma sheet are carried away to the near-Earth and down to the tail, the magnetic field and plasma in the lobe region enter the CPS and are involved in MR. They call this process "Continuous Lobe Reconnection (CLR)". In their paper a detailed analysis of Cluster observation of MR through 2001-2003 is made. Plenty of CLR events are found that led to considerable changes of tail configuration, appearance of BBF, as well as large-scale bubbles in which both plasma temperature and number density substantially decrease. It is shown that in general CLR events last for dozens of minutes and have good correspondence to substorm initiation under the condition of continuous southward IMF.

Using a 2.5 dimensional Hall magnetohydrodynamics (MHD) code developed from a multi-step implicit scheme, Jin et al [2005] studied numerically the hall effect and fine structures in magnetic reconnection with high plasma β. The initial state of the Hall MHD simulation is an equilibrium Harris sheet with L_c=0.5di (where L_c is the half-width of the equilibrium current layer, and d_i is the ion inertial length) and a zero guide field (i.e., B_{y0} =0 at t=0). Driven by a constant boundary inflow a quasi-steady fast reconnection occurs in the plasma with a low uniform resistivity. The out-of-plane magnetic field component B_y is then spontaneously generated and its quadrupolar structure is shown around the X-point. It is demonstrated by the comparing studies that the reconnection dynamics is controlled by the Hall effect and the effect of scalar electron pressure gradient is negligible in the generalized Ohm's law. It is also found that the openness of the magnetic separatrix angle and associated quadrupolar B_y structure is enlarged as β increases. When β>2.0 fine structures of B_y contours with reversed sign emerge. The numerical results indicate that the variations in electron velocity V_e are greater than those in ion velocity V_i and the decoupling of electron and ion occurs in a larger scale lengths than d_i as β increases. Clearly, the reserve current, which is associated with the relative motion between electrons and ions, generates the fine structures of B_y contours in the outflow region. Then the corresponding profile of B_y component exhibits a static whistler wave signature. Enhanced wave activities observed during a Cluster crossing of the high-β exterior cusp region [Y. Khotyaintsev *et al.*, Ann. Geophys. **22**, 2403 (2004)] might be related to the Hall effects of magnetic reconnection shown in the present simulation.

Pu et al. [2005] analyzed the multiple flux rope events at the high-latitude magnetopause observed by Cluster/RAPID on January 26,2001. The observations of high latitude magnetopause boundary by Cluster on 26 January, 2001 confirm that the cusp is a dynamic region full of energetic charged particles and turbulence. An energetic ion layer at high-latitudes beyond and adjacent to the duskside magnetopause exists when the Interplanetary Magnetic Field (IMF) has a southward orientation. Multiple energetic ion flux bursts were observed in the energetic ion layer. Each energetic ion flux burst was closely related to a magnetic flux rope. The axes of the flux ropes lie in the direction pointing duskward/tailward and somewhat upward. An intense axis-aligned current flows inside the ropes, with the current density reaching similar to 10(-8) A/m(2). The main components of the energetic ions are protons, helium and CNO ions, which originate from the magnetosphere, flowing out into the magnetosheath along the axis of the flux ropes. The velocity of the magnetosheath thermal plasma relative to the deHoffman-Teller (DHT) frame is found to be basically along the axis of the flux ropes also, but towards the magnetosphere. These flux ropes seem to be produced somewhere away via magnetic reconnection and move at similar DHT velocities passing over the spacecraft. These observations further confirm that the high-latitude magnetopause boundary region plays an important role in the solar wind-magnetopause coupling.

Zhou et al. [2005] studied numerically the whistler wave instabilities in the collisionless current Sheet. Whistler wave instabilities in the collisionless current sheet have been studies in the present paper by solving general dispersion relation obtained from the 2.5-dimenssional and incompressible MHD model. In their MHD model, the electron pressure tensor is used in the generalized Ohm's law. The results show that whistler waves can be directly excited by the collisionless current sheet. At the neutral sheet (z/d_i=0), whistler waves are basically stable in a broad range of wave number. Inside the ion inertial region ($z/d_i < 1$), obliquely propagating whistler waves are unstable. At the edge of ion inertial regian (z/d_i=1), obliquely propagating whistler waves have larger growth rate and higher frequency range. Besides, waves propagating to- wards the neutral sheet (z/d_i= <0) have larger growth rate than that propagating away from the neutral sheet

(z/d_i >0). There are two kinds of whistler waves: one with the parallel wave number larger and the other with the parallel wave number smaller than the perpendicular wave number.

Three flux transfer events (FTEs) were detected in magnetosheath near the south cusp of the dawn side by Cluster II during the interval from 11:00 to 11:15 UT on March 2nd, 2001. Zuo et al [2005] analyzed these events. In their paper, they analyze the magnetic morphology and the plasma characteristics of these events using the magnetic field and plasma data observed by the four spacecrafts of Cluster II. And the electric current density in the region Cluster II passed were estimated from the Ampere's law in terms of measured spatial gradients of the magnetic field observed simultaneously by four spacecrafts of Cluster II at different places. The results are as follows: (1) The magnetic reconnection at the magnetopause can occur near the cusp when the IMF *By* component is dominant; (2) The difference of $p+B^2/8\pi$ (the sum of magnetic and plasma pressure, measured inside and outside the events) may not be balanced with the tension of the helical magnetic filed at the initial stage when a flux tube is forming, it needs a growing time to reach an equilibrium; (3) The size of the section in L-M plane of the FTEs flux tubes is about 1.89 Re; (4)The plasma inside the flux tubes flows dominantly along the axis-aligned field, at the same time the flux tubes move southward to the tail and its velocity is more slowly than the background plasma; (5) There are not only axis-aligned current in the FTEs flux tubes, but also annular current. The axis-aligned current flows basically along the axis-aligned magnetic field. Because both axis-aligned and annular current distribute in the whole flux tubes, thus the annular magnetic field produced by the axis-aligned current will decrease to zero gradually near the center of the flux tube, and the axis-aligned magnetic field produced by annular current will increase to it's extremum by degrees; (6) An enhancement of magnetospheric energetic particle flux was observed inside magnetosheath portion of the flux tubes, this implied that the flux tubes connect the magnetosheath with the magnetosphere through the magnetopause.

Sun et al. [2005] studied the reconnection layer structure with a shear flow perpendicular to the antiparallel magnetic field component. A one-dimensional resistive magnetohydrodynamic (MHD) simulation of the Riemann problem is carried out for the structure of reconnection layer, i.e., outflow region of quasisteady magnetic reconnection, in the presence of a sheared flow tangential to the initial current (*Jy*) sheet. Unlike previous studies, the shear flow is in the *y* direction, perpendicular to the antiparallel component of the magnetic field *Bz*, with a total change of flow

Vy 0 across the current sheet. Cases with symmetric or asymmetric current sheet and various guide magnetic fields *By* are investigated. The simulation shows that in the reconnection layer, the structure of MHD discontinuities changes significantly with the strength of the shear flow. The main findings are the following: (1) In the case initially with a zero guide field (*By*=0, for the so-called "antiparallel reconnection"), the shear flow in *Vy* produces a finite *By* in the reconnection layer and two time-dependent intermediate shocks with rotation angle of tangential magnetic field less than 180°. (2) For initial $By \neq 0$ (the "component reconnection") the sheared *Vy* leads to very different magnetic field structures in the two outflow regions on the two sides of the *X* line. (3) In the cases with the initial *By*Þ0, the existence of the sheared *Vy* can lead to the reversal of the rotation sense of tangential magnetic field through the reconnection layer. The critical value of *Vy* for the occurrence of this field reversal is discussed. The general simulation results can be applied to space and laboratory plasmas.

In spring 2004 Double Star TC-1 measured a number of reconnection signatures at the dayside low-latitude magnetopause (MP) when there was a notable By component in the magnetosheath. In a number of events, Pu et al. [2005c] show that reconnection was operating nearby TC-1 in the subsolar MP region. In this paper we describe three representative events: (a) event on 21 March 2004 in which the reconnection site can be remotely monitored, the spacecraft was passing by the X-line; (b) event on 12 March 2004 in which TC-1 observed the magnetospheric part of the quadrupolar field, together with a consistent flow reversal; (c) event on 26 March 2004 which occurred for northward IMF, TC-1 observed a reversal of v_y across the equatorial MP. In these events the shear angles across the MP were considerably smaller than 180_; a noticeable guide field was present. These observations are consistent with near equatorial component merging, suggesting that component reconnection preferably occurs at the dayside low-latitude MP. There is evidence that when a pronounced magnetic shear across the MP exists in the By component, reconnection may operate at the dayside low-latitude MP for northward IMF Bz.

From 23:10 to 23:50 UT on 18 March 2004, the TC-1 satellite of Chinese-ESA joint Double Star Mission detected seven flux ropes and one FTE event at the outbound crossing of the southern dawnside magnetopause [Xiao et al., 2005] . Its GSM position was (7.5, -5.5, -5.4) *RE*. In the mean time the Cluster spacecraft were staying in the magnetosheath at (18.0, -3.1, -6.2) *RE* (GSM) which worked as a good monitor of the interplanetary magnetic field and plasma states. Seven flux ropes and one FTE event occurred under the condition of southward IMF *Bz* and noticeably negative IMF *By*. The anterior six flux ropes appeared quasi-periodically with a repeated period being approximately 2 minutes. Notable guide field existed inside all ropes. This event is quite similar to the multiple flux rope event observed by Cluster on 26 January 2001 at the northern duskside high-latitude magnetopause (Pu et al., 2005c). A detailed comparison of these two events is made in the paper. Preliminary studies imply that both of these multiple flux ropes observed by Double Star/TC-1 and Cluster seem to be produced by component reconnection at the dayside low latitude magnetopause.

Zhang et al. [2006] have studied the data from Cluster/HIA and Cluster/FGM during the period from July to October of 2001~2003. According to the characteristics of CLR (Continuous Lobe Reconnection) suggested by Cao Xin et al. [2005] [1], we confirm this reconnection process exists in plasma sheet of mid. Magnetotail; We also find almost all of these CLR events happen during substorms marked by Dipolarization, Electron Injection, Aurora sudden brightening and AE index observed by GOSE, LANL, IMAGE, and ground based observatory respectively and that is the clue indicates CLR and Substorm expansion onset are correlative with each other. The timing analysis of these two processes reveals that CLR is the basic cause for substorm expansion onset during continuous southward IMF (Interplanetary Magnetic Field) since they are correlated and CLRs almost always begin several minutes ahead of substorm expansion onset.

The characteristics of dayside ionospheric convection are studied using Northern Hemispheric SuperDARN data and DMSP particle and flow observations when the interplanetary magnetic field (IMF) was strongly northward during 13:00–15:00 UT on 2 March 2002 [Hu et al., 2006a]. Although IMF Bx was positive, which is believed to favour Southern Hemisphere high-latitude reconnection at equinox, a four-cell convection pattern was observed and lasted for more than 1.5 h in the Northern Hemisphere. The reconnection rate derived from an analysis of the Northern Hemisphere SuperDARN data illustrates that the high-latitude reconnection was quasi-periodic, with a period between 4–16 min. A sawtooth-like and reverse-dispersed ion signature was observed by DMSP-F14 in the sunward cusp convection at around 14:41 UT, confirming that the high-latitude reconnection was pulsed. Accompanying the pulsed reconnection, strong antisunward ionospheric flow bursts were observed in the post-noon LLBL region on closed field lines, propagating with the same speed as the plasma convection. DMSP flow data show that a similar flow pattern and particle precipitation occurred in the conjugate Southern Hemisphere.

Density depletions were detected by Wind, Cluster, and Polar spacecrafts in the observations of diffusion region encounters at the Earth's magneto-tail and magnetopause. Yang et al. [2006] investigate the layers of density depletion in magnetic reconnection using a 2.5-dimensional Hall MHD code developed from a multi-step implicit scheme. The numerical results at the quasi-steady state of the Hall MHD reconnection with di/Lc≥1.0, where di is the ion inertial length and Lc is the half thickness of the initial current sheet, show not only the density depletions along the magnetic separatrices but also a density dip in the x direction near the X Neutral line. The comparative tests with various Hall terms demonstrate that the density depletion in the magnetic reconnection is a peculiar feature of the case with a strong Hall effect (di/Lc≥1.0). The layers of low density following the shape of separatrices are in coincidence with the regions of high magnetic pressure. In the spatial profile of density ρ along z, which is in quantitative agreement with Cluster observation, the obvious dips located at the separatrices coincide with the peak and valley in the profile of $K_H(\vec{J}\times\vec{B})_z/\rho$ for the case with di/Lc=2.0.It indicates the major role of the Hall term in the formation of the density depletion layers near the separatrices. On the basis of the comparison between Wind observation and simulation results, They argue that the density dip observed by Wind would be distributed around the reconnection X-line, rather than along the magnetic separatrix. In the case with a strong Hall effect, the in-plane ion flows go around the diffusion region, and enterable ions in this region are significantly reduced due to the action of the in-plane Lorentz force. A density dip in the vicinity of the X-line is attributed to the hard entry of in-plane ion flow and might be related to an increase of the ion drift velocity in the y direction.

Scalings of Hall magnetohydrodynamics reconnection in high-β plasmas has been studied in steady states [Wang et al., 2006]. It again confirms previous temporal evolution reconnection results that while the width of the reconnection layer is scaled by $(\omega_A/\Omega_{ci})^{1/2}L_c=(d_iL_c)^{1/2}$, where

ω_A is the Alfvén frequency, Ω_{ci} is the ion gyrofrequency, Lc is the typical system length scale, and $d_i = c/\omega_{pi}$ is the ion inertial length, the length of the layer should be scaled by $(\omega_A/\Omega_{ci})^{1/2} L_c = (d_i L_c)^{1/2}$ [X.Wang and A.Bhattacharjee, Phys.Rev.Lett.70,1627(1993)], to yield the fast reconnection rate of $(d_i/L_c)^{1/2} V_A$ with V_A as the Alfvén velocity [X.Wang,A.Bhattacharjee,and Z.Ma,Phys.Rev.Lett.87,265003(2001)]. It is also shown that the reconnection rate is proportional to the perturbed boundary flow. Furthermore it is found that in the high- β plasmas, the reconnection keeps constant in the regime $\beta < 2$, and decays as $\beta^{-1/2}$ for $\beta \geq 2$.©2006 American Institute of Physics. [DOI:10.1063/1.2218815]

Sun et al., [2006] investigate the effects of shear flows on the so-called ‘‘component reconnection,’’ in which the guide field By 6 0, by solving a one-dimensional Riemann problem for magnetopause reconnection using a resistive MHD simulation. Specifically, They consider the existence of a shear flow perpendicular to the antiparallel magnetic field Bz, while a finite shear flow tangential to Bz may also be present. In the cases without a magnetosheath flow and having thus a sheared flow across the reconnection layer, two time-dependent intermediate shocks TDIS and TDIS0 are present on the magnetosheath side and the magnetospheric side, respectively, and the strength of TDIS is much stronger than that of TDIS0. Nevertheless, the existence of the shear flows modifies the structure and strength of the time-dependent intermediate shocks significantly. (1) The perpendicular shear flow Vy0 can lead to the reversal of the rotation sense of the tangential magnetic field in time-dependent intermediate shocks. The critical shear flow speeds, Vc and V0c, for the reversal of field rotations in TDIS and TDIS0, respectively, are calculated. (2) For shear flow speed Vy0 = Vc, the strong TDIS is replaced by a steady intermediate shock (IS), whereas at Vy0 = V0c an Alfve´n wave pulse is present in the reconnection layer. (3) The presence of tangential shear flow Vz0 alters not only the strength of TDIS and TDIS0 but also the critical speeds Vc and V0c. The critical shear flow speeds obtained from our simulation are found to agree very well with those from the ideal magnetohydrodynamics (MHD), in which the time-dependent intermediate shocks are replaced by rotational discontinuities.

Magnetic reconnection is one of the most important processes in astrophysical, space and laboratory plasmas. Identifying the structure around the point at which the magnetic field lines break and subsequently reform, known as the magnetic null point, is crucial to improving our understanding of reconnection. But owing to the inherently three-dimensional nature of this process, magnetic nulls are only detectable through measurements obtained simultaneously from at least four points in space. Using data collected by the four spacecraft of the Cluster constellation as they traversed a diffusion region in the Earth's magnetotail on 15 September 2001, Xiao et al. [2006] report here the first *in situ* evidence for the structure of an isolated magnetic null. The results indicate that it has a positive-spiral structure whose spatial extent is of the same order as the local ion inertial length scale, suggesting that the Hall effect could play an important role in 3D reconnection dynamics.

4 Instabilities in the magnetosphere

Duan et al. [2003], using the two-fluid magnetohydrodynamic（MHD）model to describe ions and electrons motion, studied the properties of solitary kinetic Alfvén waves (SKAWs) in the low-βplasma of the inertial limit region (ILR) based on the undisturbed theory. The solitons were taken as the classical particles and the Sagdeev potential function was derived according to the foundational equations, then the SKAWs solutions were obtained by numerical calculation. The results show that the influence of hot ions on the properties of solitary kinetic Alfvén waves can't be neglected and both dip solitons and hump solitons exist in the ILR. These results agree well with the data detected by Freja satellite over the auroral region. As Alfvén solitary waves accompanied by the parallel electric field, take an important part to accelerate the charged particles. This provides a novel kind of physical mechanic for the acceleration of polar aurora in the auroral region.

Duan and Li [2003a] studied the influence of ion nonlinear polarization drift and warm ions on solitary kinetic Alfvén wave. Considering the effects of ion nonlinear polarization drift and warm ions, they adopt two-fluid model to investigate the character of low-frequency Solitary Kinetic Alfvén Wave (SKAW, hereafter) in a magnetic plasma. The results derived in this paper indicate that dip and hump SKAWs both exist in a wide range in magnetosphere (for the pressure parameter $\beta \sim 10^{-5}$-0.01, where βis the ratio of thermal pressure to magnetic pressure, i.e. $\beta = 2\mu_0 nT / B_0^{\ 2}$). These two kinds of SKAWs propagate at either Super-Alfvénic velocity or Sub-Alfvénic velocity. In the inertial region ($\beta<< m_e/m_i$) , the Sub-Alfvenic velocity dip and hump SKAWs both exist; in the transmittal region ($\beta \sim 2m_e/m_i$) dip and hump SKAWs propagate at Super-Alfvénic velocity or Sub-Alfvénic velocity; Super-Alfvénic velocity hump SKAWs and Super-Alfvénic and Sub- Alfvénic velocity dip SKAWs are in the kinetic region ($\beta>> m_e/m_i$). These results are different from previous ones. That indicates that the effects of ion nonlinear polarization drift and warm ions are important and they cannot be neglected. The SKAW has an electric field parallel to the ambient magnetic field, which makes the SKAW take an important role in the acceleration and energization of field-aligned charged particles in magnetic plasmas. And the SKAW is also important for the heating of local plasma. So it makes a novel physical mechanism of energy transmission possible.

Duan and Li [2003b] further studied the influence of the non-linear term in the ionic polarization drift on solitary kinetic Alfven waves. It is shown that the nonlinear term in the ionic polarization drift has a non-negligible effect on the solitary kinetic Alfven waves (SKAW) of the rarefied type in low-βplasmas (βis the heat to magnetic energy ratio) i.e. the nonlinear term allows the existence of SKAW with both sub- and super-Alfvenic speeds in the low-βregime. This result appears to be in good agreement with satellite observations of the magnetosphere.

Liu et al. [2003] perform conjugate phase studies of the ULF waves in the Pc5 band near the cusp. Conjugation of geomagnetic field lines at magnetic high latitude is variable, depending on solar wind and interplanetary magnetic field conditions. In this paper the geomagnetic conjugate point of a location under closed field lines near the cusp has been determined dynamically by examining the conjugate phase relation of ultra low frequency (ULF) waves in the Pc5 band using magnetometer data from high latitude ground stations at Longyearben (LYR), Hornsund (HOR) and Hopen Island (HOP) in the northern hemisphere and Davis (DAV), Zhongshan (ZHS) and Mawson (MAW) in the southern hemisphere. Cross spectral and coherency analysis methods are used to select conjugate Pc5 events and derive phase relations. The results show that near the cusp the geomagnetic field lines resonate mainly in the odd mode with the D component out of phase and the H component in phase, when observed at the two ends of the field line. Assuming this phase characteristic, the conjugate of LYR is typically located in the DAV/ZHS-region, and mainly east of Davis by about 10° CGM longitude. In a reverse mapping analysis the conjugates of ZHS and DAV are located in the LYR region, mainly west of LYR by 10°. These results are qualitatively consistent with corresponding locations derived from the Tsyganenko 1996 (T96) model. The relationship of the longitude movement of the conjugate of LYR with respect to the variation of IMF By is quantitatively consistent with the T96 model. However, the expected position of the conjugate site of LYR (DAV/ZHS) derived from Pc5 phase for $B_y = 0$ is moved westward (eastward) by about 10° CGM in longitude or ~300 km from that predicted by the T96 model.

Chen et al.[2003] studied the Charging Characteristics and Equilibrium Potential of Dust Grains in Comets. The main compositions of comets are water and dust grains. There is ionosphere around cometary nuclear. The atmosphere of comet is plasma environment mainly make up of water and hydrogen. Dust grains in comet will become charged. As a new composition, charged dust grains will take part in cometary plasma group behaviors.

They consider three main charging mechanisms. First, charged plasma particles spray onto surfaces of dust grains will be collected, this current is presented by J_1; second, photoemission caused by the solar rays, the photoelectron current is J_2; third, J_3, current of secondary electron eject. At a certain stage, dust grains will stop charging and attain an equilibrium-state, i.e., $\sum J_\alpha = 0$, α=1, 2, 3. Considering that comets are plasma environments of H_2O^+, and the main compositions of cometary dust are silicate and carbon, based upon observational data of comet Halley and comet G-Z, the charging characteristics and equilibrium potentials of dust grains are calculated. Fig. 3 is curve of equilibrium potential at different distance R from the nuclear of P/Halley. They find that the equilibrium potential is obviously correlative with electron density. They set up algebraic equations about equilibrium potential and logarithm of electron density, too. Upon the calculations, they find that the equilibrium potential has little relativity with other plasma parameters such as electron temperature. Generally. these conclusions can be suitable for other plasma comets.

Lu and Li [2003] studied K-H instability related to in space dusty plasmas and review also recent development of K-H instability studies. The main results of K-H instabilities for multi-components dusty plasma model and dust charge fluctuation model, as well as their possible applications in cometary tail environments, are concluded, and further prospects of this subject are also discussed. The study of dusty plasma K-H instabilities is so far localized in linear-theory discussion with simple physical model. For strong damping effect, which caused by dust charge fluctuations, the dusty plasma nonlinear-simulation will become more significant. Dust charge fluctuations, as well as the variations of the mass and volume of dusty grains, will make this subject even more challenging. With the accumulation of exploration data by satellites in the space environment, the theoretical model for dusty plasma K-H instabilities will be better approaching the space physical reality.

Cao et al. [2006b] studied the nongyrotropy of newborn ions in solar wind plasmas by means of one-dimensional electromagnetic hybrid computer simulations of homogeneous plasmas. It is found that, contrary to the previous theory of nongyrotropy, the homogeneous injections of newborn ions can also produce the nongyrotropy of newborn ions (partial nongyrotropy). However, the inhomogeneous injections of newborn ions can make the ion nongyrotropy stronger. The newborn ion nongyrotropy is different within different perpendicular velocity range, and is strongest in the velocity range close to the injection velocity of newborn ions V_{in}.

Duan et al. [2005] the kinetic alfven wave driven by density and magnetic field inhomogeneities in plasmas of finite Beta. Basing on the analysis on the drift waves instability caused by the density and magnetic field inhomogeneities in finite plasmas, they find that this instability has an effect on driving kinetic Alfven waves. The kinetic theory deals with the effect of finite Lamor radius and wave-particle interacting effectively and correctly. According to the motion of charged particles in the electromagnetic field, they adopt the Vlasov equation to descript the ion motion and the drift kinetic equation for electron motion. Comparing the effects on the drift instabilities between the density in homogeneity and the magnetic field inhomogeneity, they find that the drift instability easily takes pace under the condition of the density inhomogeneity and the energy transfer much faster in this process. Driven kinetic Alfven waves occur after getting the energy from the instability. The numerical solutions indicate that the kinetic Alfven waves can be driven in magnetosphere widely, especially in the obviously inhomogeneous regions such as the cusp, magnetopause and the plasma sheet boundary layer. The results in their paper imply that the kinetic Alfven waves have great influence on the energy transfer in the magnetosphere.

Duan et al[2005] studied kinetic alfvén wave driven by the density inhomogeneity in the presence of loss-cone distribution function. Kinetic Alfven waves (KAWs) driven by the diamagnetic drift instability that is excited by the density inhomogeneity in low-β plasmas, such as plasmas in the auroral region, are investigated by adopting the particle aspect analysis and loss-cone distribution function. The results obtained in their paper indicate that the propagation and evolution of kinetic Alfven waves decrease and the kinetic Alfven wave exciting becomes not easier with increasing loss-cone index J. But the spatial scales of the perpendicular perturbation driving kinetic Alfven waves have a decreasing tendency with the larger values of J, which perhaps is in relation with the decreasing width of loss-cone. A single hump appears in the plots of the growth rate of the instability when J=2. But the hump cannot emerge when J=0 or J=1. The density inhomogeneity of ions plays an important role in driving KAWs and it cannot be ignored. KAWs can be easier driven and KAWs can propagate and evolve faster with the increasing level of density inhomogeneity. While the range of the perpendicular wave number of the wave instability decrease, namely, the longer the scale of perpendicular disturbance the easier the excitation of KAW. As the density inhomogeneity increases, the tendency of numerical solutions of the dispersion relation is similar to the one that obtained by the kinetic theory and Maxwellian distribution function. But the profiles of the plots of numerical solutions are different. This means that velocity distribution function of particles is important for KAW driven in magnetoplasmas, especially in the active regions of the magnetosphere, such as auroral region, and plasma sheet boundary.

Wei et al. [2005] studied the low-frequency electromagnetic instabilities in a collisionless current sheet by using the 3-dimensional, collisionless and compressible magnetohydrodynamic (MHD) model with the isotropy pressure. The linear dispersion relations are numerically solved at the middle plane and edges of current sheet for modes of 2- and 3-dimensional propagation. The main results are as follows. (1) For 2-dimensional disturbed propagation $(k_z = 0)$, at the middle plane (z=0), the growth rate of Alfven waves is maximum, and the frequency and the wave number region of unstable waves are most wide. The farther the distance from the middle plane, the smaller the growth rate and wave number region. As the ion-inertial length becomes longer, the growth rate of Alfven waves becomes larger. (2) For 3-dimensional disturbed propagation $(k_z \neq 0)$, whistler waves are unstable. At current sheet middle plane, whistler waves have obvious growth rate. Outside the ion-inertial region, the growth rate of whistler waves becomes larger.（3）At the middle plane (z=0), low-frequency waves are mainly excited by the current-driven instabilities. At places far from the middle plane, the gradient instabilities of the current, density and pressure become more important.

Li et al [2006] investigated the shear-flow induced wave transformations and energy exchange between the magnetohydrodynamic waves and mean flow in the magnetopause boundary layer (BL) with the non-modal approach. The magnetopause is assumed to be consisting of three BLs: the inner, outer layers and the transition region with uniform velocity shear and different plasma parameters. It is found that an initially-given Alfvénic perturbation experiences distinct evolution in different region. It is mainly transformed into the slow mode in the outer part of the magnetopause BL and fast mode in the inner part, while in the transition region both modes with comparative amplitudes can be obtained. They also find that the fluctuations with stronger fast mode oscillations can gain more energy from the background shear flow and get amplified as a result. The physical processes described above may be useful in understanding the anomalous transport phenomena of energy and momentum from the magnetosheath to the magnetosphere.

Also in the paper of Li et al. [2006], the nonmodal self-heating phenomenon of linear shear flow is investigated with an initially excited Alfvénic perturbation focusing on the factors determining the efficiency of the heating process. It is found that to get an efficient self-heating process, the initial Alfvén wave must be at least partially transformed into the fast mode. This is because only the fast mode, among the three types of magnetohydrodynamic modes, can get amplified significantly by the shear flow. This requires the initial wave number along the shear to be positive so that the Spatial Fourier Harmonics can pass through the degeneration region, and also puts constraints on the plasma parameter β [$\beta = C_S^2 / V_A^2$, where C_S (V_A) is the sound (Alfvénic) velocity]. It is shown that the self-heating function, which represents the total energy dissipated at a certain time, decreases monotonically with increasing β. In addition, to get efficient heating the viscous coefficient should be in an appropriate range. A smaller viscosity results in an insufficient thermalization of the perturbation energy, while a larger one corresponds to a suppressed nonmodal amplification.

The energy transfer between low frequency waves (LFWs) with frequency range from 0.3 to 10 Hertz (f1) and ions (protons) is observed by Cluster crossing the high-altitude polar cusp [Duan et al., 2006]. The energy transfer between low frequency waves and ions has two means. One is that the energy is transferred from low frequency waves to ions and ions energy increases. The other is that the energy is transferred from ions to low frequency waves and ions energy decreases. Ion gyratory motion plays an important role in the energy transfer processes. The electromagnetic field of f1 LFWs can accelerate or decelerate proton along the direction of ambient magnetic field and warm or refrigerate proton in the parallel and perpendicular directions of ambient magnetic field. And the peak values of protons number density have corresponding peak values of electromagnetic energy of low frequency waves. That implies that the kinetic Alfven waves and solitary kinetic Alfven waves possibly exist in the high-altitude cusp region.

The effects of ultraviolet irradiation on small but finite amplitude dust-acoustic solitons, are studied by the reductive perturbation method [Ren et al., 2006]. The self-consistent dust charge variation is taken into account. It is shown that the ultraviolet irradiation can significantly lower the magnitude of the dust negative charge, and even make the dust grains charged positively. With the growth of the dust charge, the phase velocity and the width of the solitary wave increase, whereas its amplitude decreases. The related physical mechanism is discussed.

5. Cusp

Zhou et al [2006] made a study focusing on a single particle dynamics in the cusp region. The topology of the cusp region in terms of magnetic field iso-B contours has been studied using the Tsyganenko 96 model (T96) as an example, to show the importance of an off-equatorial minimum on particle trapping We carry out test particle simulations to demonstrate the bounce and drift motion. The "cusp trapping limit" concept is introduced to reflect the particle motion in the high latitude magnetospheric region. The spatial distribution of the "cusp trapping limit" shows that only those particles with near 90 pitch-angles can be trapped and drift around the cusp. Those with smaller pitch angles may be partly trapped in the iso-B contours, however, they will eventually escape along one of the magnetic field lines. There exist both open field lines and closed ones within the same drift orbit, indicating two possible destinations of these particles: those particles being lost along open field lines will be connected to the surface of the magnetopause and the solar wind, while those along closed ones will enter the equatorial radiation belt. Thus, it is believed that the cusp region can provide a window for particle exchange between these two regions. Some of the factors, such as dipole tilt angle, magnetospheric convection, IMF and the Birkeland current system, may influence the cusp's trapping capability and therefore affect the particle exchanging mechanism. Their roles are examined by both the analysis of cusp magnetic topology and test particle simulations. pitch-angles can be trapped and drift around the cusp. Those with smaller pitch angles may be partly trapped in the iso-B contours, however, they will eventually escape along one of the magnetic field lines. There exist both open field lines and closed ones within the same drift orbit, indicating two possible destinations of these particles: those particles being lost along open field lines will be connected to the surface of the magnetopause and the solar wind, while those along closed ones will enter the equatorial radiation belt. Thus, it is believed that the cusp region can provide a window for particle exchange between these two regions. Some of the factors, such as dipole tilt angle, magnetospheric convection, IMF and the Birkeland current system, may influence the cusp's trapping capability and therefore affect the particle exchanging mechanism. Their roles are examined by both the analysis of cusp magnetic topology and test particle simulations.

6. Radiation belt and ring current

Li et al. [2004] studied the acceleration of seed electrons by whistler Turbulences near the geosynchronous orbit in quasi-linear approximation, A part of lower energy electrons decrease while the higher ones increase after distribution function of electrons evolve with time via momentum diffusion, which suggest that "seed electrons" are accelerated effectively by the whistler turbulence. The larger the energy of whistler turbulence is, the higher the acceleration efficiency is. In addition, the lower the frequency of the whistler, the higher the energy of remnant electrons and the wider the frequency range of the whistler, the wider the energy range of resonant electrons and the more the accelerated electrons. Electron acceleration by the whistler turbulence can markedly increase the number of relativistic electrons within about 30 hours, which is consistent with the observation of relativistic electron flux enhancements during most magnetic storms.

Cao et al.[2004]studied Relation between magnetic shell parameter L, Dst and IMF. It is new trend to use the magnetic coordinate L－Λ to describe space particle features and position of spacecraft. They use T96 model to calculate magnetic shell parameter, and compare the difference between L values calculated from Dipolar model, IGRF and T96. The difference between L values calculated from Dipolar model and IGRF, begin to increase when magnetic latitude is larger than 30°. Also，the difference between L values calculated from IGRF and T96, begin to increase when magnetic latitude is larger than 50° . The L values are therefore dependent on the IMF(interplanetary magnetic field) and have also the dependence of local time. Our work is meaningful to radiation belt dynamic model and understanding of magnetic position of satellite.

Once again in the quasi-linear approximation, Li et al. [2005a] studied electron acceleration process generated by whistler-mode and compressional ULF (fast mode waves) turbulences near the Earth's synchronous orbit. The results show that the whistler-mode turbulence ($0.1f_{ce} \le f \le 0.75f_{ce}$) can accelerate substorm injection electrons with several hundreds of keV through wave-particle gyroresonant interaction, and hence may play an important role in the electron acceleration during substorms. The compressional ULF turbulence (2-15mHz) can accelerate both lower-energy background electrons (<30keV) and substorm injection electrons (~30-300keV) through the transit-time damping mechanism. So the compressional ULF turbulence acceleration mechanism is important during both substorms and quiet times. The compressional ULF turbulence accelerates substorm injection electrons more effectively than whistler-mode turbulence. The combined electron acceleration by whistler-mode and ULF turbulences is most effective and can cause the number density of the relativistic electrons increase largely within about 8 hours. Substorms can offer both substorm injection electrons and strong turbulences, therefore large flux enhancement events of relativistic electrons (≥1MeV) always occur during substorm time. For magnetic storms that are composed of a series of substorms, extremely large flux enhancement events of the relativistic electrons can thus occur.

In addition, Li et al[2005] studied electron 'transit-time acceleration' by compressional ULF turbulence near the geosynchronous orbit. The frequency range of compressional ULF turbulence is from 2mHz to 15 mHz. When compressional ULF waves resonate with the background electrons (E<30keV) and substorm injection electrons (30~300keV), the higher-energy electrons increase while the lower-energy electrons decrease, which showed that resonant electrons are accelerated effectively by compressional ULF turbulence. The efficiency of the electron acceleration depends on the character of ULF waves, the larger the amplitude of ULF waves are, the higher the acceleration efficiency is, and the bigger the spectral index is, the lower the acceleration efficiency is. In addition, the more substorm injection electrons are, the more relativistic electrons produced by 'Transit-time acceleration' are. Since substorms can offer substorm injection electrons, therefore large flux enhancement events of relativistic electrons ($E \geq 1$MeV) always occur during substorm time. For magnetic storms that are composed of a series of substorms, extremely large flux enhancement events of relativistic electrons can thus occur.

Based on the energetic particle measurements obtained by CRRES/MICS, variations of the third most important ion species, N^+, in the ring current region have been investigated in detail by Liu et al. [2005]. The ratio of N^+/O^+ during geomagnetic quiet times is found to be about 0.314 ± 0.043 and decreases with enhanced solar radiation, as indicated by the F10.7 index. Through a statistic study, the ratio of N^+/O^+ has been demonstrated to decrease with enhanced geomagnetic activity for strong storms, whereas for small storms, there is no obvious correlation found for this ratio. It is worthy to note that not all the values during active times are higher than those at quiet times. The quite different ratios of N^+/O^+ (up to 50%) in the ring current region found between quiet and storm times in their paper, together with the different combination rates of atomic oxygen and nitrogen, suggest that the ionospheric nitrogen ions may play a crucial role during some magnetic storms and should have a strong impact on the magnetic storm simulation works on the build-up and/or decay processes of the ring current.

Pu et al. [2005] studied the drift shell tracing and secular variation of inner zong high energy proton environment in the SAA. To investigate long-term variations of the inner zone high-energy proton environment at low orbits, they developed the drift shell tracing (DST) approach by using the adiabatic approximation of charged particle motion with the NASA standard radiation models as reference states. The DST results show that over the past three decades fluxes of high-energy protons at altitudes similar to 1000 km in the South Atlantic Anomaly (SAA) noticeably increased and the centre region of the proton SAA apparently moved westward and expanded. Calculations of the L-averaged lifetime of high-energy protons indicate that the DST approach provides a reasonable means for estimation of the secular variation of the inner zone proton environment.

Xie et al. [2005] studied the secular variation of inner zone high energy proton environment in the SAA. A long-term variation of the inner zone high-energy proton environment at low orbits was investigated by DSTM using the adiabatic approximation of charge particle motion with NASA standard radiation models as reference states. The DST results show that over the past three decades the fluxes of high-energy protons at similar to 1000 km in the South Atlantic Anomaly (SAA) noticeably increased, the center region of proton SAA apparently moved westward and expanded.

Calculations of the L-shell averaged lifetime of high-energy protons indicate that the DST provides a reasonable means for estimation of the secular variation of inner zone proton environment.

Li et al [2006] studied the relations among the interplanetary magnetic field (IMF), solar wind, *Dst* index, *AE* index and flux of the relativistic electrons ($E \geq 1\,\mathrm{MeV}$) .Geomagnetic storms/substorms can occur when B_Z component of the IMF is southward and velocity of the solar wind increases to above $500\,\mathrm{km/s}$. The flux of the relativistic electrons decreases during the main phase of the storms, and then it increases during the recovery phase of the storms. However, the flux of the relativistic electrons can increases and exceeds the prestorm level just during recovery phase of the storms including many prolonged substorm activities. Furthermore, the larger the flux of the electrons with energy being less than $300\,\mathrm{keV}$ is, the larger the flux of the relativistic electron is, which shows the substorm-injection electrons with energy being less than 300 keV may be a important source of the relativistic electrons.

7 The plasma sheet

Shen et al. [2003] analyze the geometrical structure of magnetic field in the current sheet based on cluster measurements. The geometrical structure of the magnetic field is a critical character in the magnetospheric dynamics. Using the magnetic field data measured by the Cluster constellation satellites, the geometrical structure including the curvature radius, directions of curvature and normal of the osculating planes of the magnetic field lines within the current sheet/neutral sheet have been investigated. The results are: (1) Inside of the tail neutral sheet (NS), the curvature of magnetic field lines points towards Earth, the normal of the osculating plane points duskward, and the characteristic half width (or the minimum curvature radius) of the neutral sheet is generally less than 2Re, for many cases less than 1600km. (2) Outside of the neutral sheet, the curvature of magnetic field lines pointed northward (southward) at the north (south) side of NS, the normal of the osculating plane points dawnward, and the curvature radius is about 5Re~10Re. (3) Thin NS, where the magnetic field lines have the minimum of the curvature radius less than $0.25\,R_E$, may appear at all the local time between LT 20hr and 4 hr, but thin NS occurrs more frequently near to midnight than that at the dawnside and duskside. (4) The size of the NS is dependent on substorm phases. Generally, the NS is thin during the growth and expansion phases and grows thick during the recovery phase. (5) For the one-dimensional NS, the half thickness and flapping velocity of the NS could be quantitatively determined. Therefore, the differential geometry analyses based on Cluster 4-point magnetic measurements open a window for visioning the three-dimensional static and dynamic magnetic field structure of geomagnetosphere.

Zong et al. [2004] studied earthward flowing plasmoid in the tail. The energetic electrons and ions embedded in Earthward-moving plasmoid structures have been observed by Cluster. These plasmoids are associated with a rotational local Bz component (bi-polar) signature. Energetic electrons are found to be confined in a smaller spatial region than ions inside the plasmoid. Energetic ions and electrons seem to be a good indicator for the structure boundary. The fleet of Cluster spacecraft cross the plasmoid structure in a ‘‘first entry, last out’’ order (Note: when spacecraft cross a planar discontinuity, e.g. magnetopause, they will be in ‘‘first entry, first out’’ order). This documents the fact that the plasmoid has a non-planar nested structure. The large separation distance (around 1 RE) of the Cluster satellites in October 2002 is an advantage to provide constraints on the size and shape of the plasmoid structure of interest. In addition, the plasmoid (with closed field lines) should preserve the ion composition information where it is formed. The ion composition observed in the plasmoid shows significantly lower O and He than in the ambient plasma. This implies few heavy ions are involved in the reconnection process where the plasmoid is formed. Multiple flux ropes/plasmoids observation presented in their paper can be interpreted as strong evidence for multiple X-lines.

Based on the energetic particle measurements obtained by Cluster/RAPID, ion composition variations in the plasma sheet have been investigated by Ruan et al[2005]. By comparing observations during quiet and storm intervals, it is found that, in addition to the enhanced energy density for all ion species, the ratio of energetic O+ ions to protons shows an increase during geomagnetic active periods in the near- Earth plasma sheet (-15 RE < X <-12 RE). However, the ratio shows a decrease in the middle plasma sheet (-19 RE < X < -15 RE). These observation results have been further confirmed by a statistical study of all the plasma sheet crossing events from 2001 to 2003. Observations also show that energetic particles embedded in the earthward high-speed streams observed in the plasma sheet have an obvious low abundance of heavy ions compared with surrounding plasmas. It is implied that energetic O+ ions could be distributed in a limited region in the plasma sheet and much less ionosphere origin particles could reach the region beyond X = _15 RE. Bursty Bulk Flows (BBFs) could not supply more energetic O^+ ions to the near-Earth plasma sheet, whereas the ionospheric supplement, together with local acceleration processes, leads to an enhanced oxygen abundance during active times.

Yang et al[2005] studied the spatial distribution of energetic ion compositions in the plasma sheet observed by Cluster/RAPID. The RAPID spectrometer (Research with Adaptive Particle Imaging Detectors) onboard Cluster provided us an opportunity to investigate the distribution of energetic ions in the plasma sheet in the energy range of 40 keV-1500 keV for protons, and 10 keV-1500 keV for helium and oxygen ions. Totally about 600 hours data have been surveyed when the spacecrafts cross the plasma sheet in the mid magnetotail at *X*=-7~ -19 *Re* (GSE). The dependence of ion energy density on different geomagnetic activity level indicated by *Kp* indices has been studied. A linear correlation of energy density with *Kp* has been found. The profiles of different ion energy density distributions in GES-*Z* direction with low *Kp* and high *Kp* are presented, respectively. The reason for the positive correlation and the profile may lie on the fact that the energy density increase more near the current sheet, and heavier ions enhance more intensely. A simplified current sheet model has been employed to demonstrate that current sheet acceleration mechanism could be a plausible explanation for these observational results that heavier ions can remain more in the site near the central plasma sheet and obtain more energy at the same time

Tang et al. [2006] studied the bifurcated current sheet structure in quiet-time by Cluster. In their paper they analyzed the vertical structure of the magnetotail current sheet for two intervals during which Cluster crossed the neutral sheet in quiet-time. In the intervals, the current sheet moved slowly, and the value of the AE index was relative small, about 40-130 nT. They found examples of current sheet, with the current density maximum at the magnetic equator (Bx = 0), as well as examples of off-center or bifurcated current sheets. The bifurcated current sheet is probably associated with instabilities in the current sheet.

8 Magnetopause

. Chen et al.[2003] describe how a local plasma structure can be changed by a transverse shear flow using numerical simulation to investigate the disturbance process near the magnetopause. The results show that magnetic field lines are bent by transverse shear flow disturbance near the current sheet region. There are multiple bipolar structures of the normal magnetic field in the numerical simulation. They term this new feature as K point magnetic reconnection, realistic for discussing space observations.

Cao et al [2005] proposed a preliminary model to describe quantitatively the position and movement of cusp equatorward boundary. This integrated model, consisting of an empirical model of the magnetopause and a compressed dipolar model of Open/Closed field line, connects quantitatively the solar wind conditions, subsolar magnetopause and cusp equatorward boundary. It is shown that the increasing solar wind dynamic pressure and the increasing southward interplanetary magnetic field (IMF) component drive the magnetopause to move inward and the cusp equatorward. They adopt this model to interpret quantitatively the cusp movement of August 14, 2001 observed by Cluster. The results show that the subsolar magnetopause moved earthward from 10.7 R_E to 9.0 R_E during the period of 00:23:00 – 00:28:00 UT, and correspondingly the cusp equatorward boundary shifted equatorward. The observations of Cluster C1 and C4 show the cusp equatorward boundary that Cluster C1 and C4 were crossing during same interval moved equatorward by 4.6°. The cusp equatorward boundary velocity computed in the theoretical model (10.7 km/s) is in good agreement with the observed value (9.4 km/s) calculated from the data of CIS of Cluster C4 and C1.

Shi et al. [2005] studied the magnetic reconnection at the high-latitude magnetopause using 2 dimensional (2 1/2-D) Hall-MHD simulation. Concentric flow vortices and magnetic islands appear when both Hall effect and sheared flow are considered. Plasma mixing across the magnetopause occurs in the presence of the flow vortices. Reconnected structure generated in the vicinity of the subsolar point changes its geometry with increasing flow shear while moving to high latitudes. In the presence of flow shear, with the Hall-MHD reconnection a higher reconnection rate than with the traditional MHD is obtained. The out-of-plane components of flow and magnetic field produced by the Hall current are redistributed under the action of the .flow shear, which makes the plasma transport across the boundaries more complicated. The simulation results provide some help in understanding the dynamic processes at the high-latitude magnetopause.

9 Magnetic structure in the magnetosphere

Shi et al. [2005] proposed a new method which can be used to analyze the dimensional character of observed structures using multipoint magnetic field measurements of four or more spacecraft. The technique can provide three directions along which the magnetic field has the minimum, intermediate, and maximum derivatives if the magnetic gradient tensor $G = \nabla B$ at every moment has been estimated by multipoint measurements. It follows that the structure's dimensionality and the variation direction can be directly determined. Both Cluster observations and simulations have shown that it is feasible to obtain the invariant axis orientation for two dimensional structures such as flux tubes, and to find the normal directions for one-dimensional structures such as discontinuities. One advantage of this method is that these directions can be determined instantaneously, point by point in the time series, and so can be tracked through each observed structure. The analysis tool provides us a new perspective of the observed structures in the space.

Moreover, Shi et al. [2006] studied the motion of observed structures based on multi-point magnetic field measurements. They proposed a a new method to calculates the velocity of observed, quasi-stationary structures at every moment in time from multi-point magnetic field measurements. Once the magnetic gradient tensor $G = \nabla B$ and the time variation of the magnetic field have been estimated at every moment, the velocity can then be determined, in principle, as a function of time. One striking property of this method is that they can calculate the velocity of structures for any dimensionality: for three-dimensional structures, all three components of the velocity vector can be calculated directly; for two-dimensional (or one dimensional) structures, they can calculate the velocity along two (or one) directions. The advantage of this method is that the velocity is determined instantaneously, point by point through any structure, and so they can see the time variation of the velocity as the spacecraft traverse the structure. In their paper, the feasibility of the method is tested by calculating the motion velocity of a three-dimensional, near cusp structure and a two-dimensional magnetotail current sheet. The results for one-dimensional structures in the magnetopause and cusp boundaries are compared to calculations for the standard techniques for analyzing discontinuities.

Lei et al. [2006] studied the structure and motion of current sheet. Multiple crossings of the neutral sheet were observed by the FGM and CIS experiments onboard the Cluster at -19 R_E (GSM coordinate system was used throughout their paper) from 04:30 to 05:15 on September 15, 2001 (). The high-speed proton flow, which reversed from tailward to Earthward, was detected during the multicrossings. Using a linear gradient/curl estimator technique the cross-tail current was obtained and the peak of the current density was $28nA/m^2$. A large-scale wave propagating duskward and the thin current sheet flapping in the vertical direction were investigated. The velocity of the proton bulk flow in the X direction exceeded 1000 km/s during the magnetic field reconnection. By using the multi-point timing analysis and Minimum Variance Analysis, the structure and motion of the magnetotail current sheet were estimated.

Using the data of the FGM instrument onboard of Cluster II, Ren et al. [2006] can calculate the velocity of the magnetic structure. Data observed by Cluster II in the plasma sheet were analyzed during the storm (1 and 2 August, 2002) and the geomagnetism quiet (6 and 7 August, 2002) in GSM (Geocentric Solar Magnetospheric System) coordinates. After analyzing the statistical characteristics and the spectral character of the velocity, they conclude the followings: 1) The variation of the velocity is an irregular, long-period oscillations. 2) The width of the distribution of V_z is nearly equal to that of V_y and they are both bigger than that of V_x. This may be caused by the windsock mechanism. 3) On the dawn side of the plasma sheet, the average of V_x and V_z are nearly equal to 0， but the average of V_y is in the order of -10 km/s. It may be caused by the compressed Pc 5 wave which moves in the plasma sheet. 4) All the spectrum of V_x, V_y, V_z have apices between 0.033 min^{-1} and 0.035 min^{-1}.

Another approach (Multiple Triangulation Analysis, MTA) is presented to determine the orientation of magnetic flux rope, based on 4-point measurements [Zhou et al. , 2006a]. A 2-D flux rope model is used to examine the accuracy of the MTA technique in a theoretical way. It is found that the precision of the estimated orientation is dependent on both the spacecraft separation and the constellation path relative to the flux rope structure. However, the MTA error range can be shown to be smaller than that of the traditional MVA technique. As an application to real Cluster data, several flux rope events on 26 January 2001 are analyzed using MTA, to obtain their orientations. The results are compared with the ones obtained by several other methods which also yield flux rope orientation. The estimated axis orientations are shown to be fairly close, suggesting the reliability of the MTA method.

In order to avoid the ambiguity of the application of the Triangulation Method (multi-spacecraft timing method) to two-dimensional structures, another version of this method, the Multiple

Triangulation Analysis (MTA) is used, to calculate the velocities of these structures based on 4-point measurements [Zhou et al. 2006b]. We describe the principle of MTA and apply this approach to a real event observed by the Cluster constellation on 2 October 2003. The resulting velocity of the 2-D structure agrees with the ones obtained by some other methods fairly well. So we believe that MTA is a reliable version of the Triangulation Method for 2-D structures, and thus provides us a new way to describe their motion.

10 Space dust plasma

Li et al. [2004] studied the charging process of space dust. Dust grains immersed in plasma will be charged. Of various charging currents, their paper considers three main currents due to the relative velocity between the dust grains and the plasma: the primary ions, the primary electrons, and the secondary electrons. The surface potentials of silicate and carbon dusts grains in H^+ and H_2O^+ plasma environments are calculated using universal plasma parameters, these plasma conditions are common in space environments, such as comets, planetary rings, and interplanetary media. They get a conclusion that the equilibrium potential of dust grains have close correlation with the plasma temperature. At low temperatures, the surface potential will become lower while the temperature rises. The dust can reach a positive potential when the temperature is high enough. The potential of carbon grains is lower than that of silicate grains. The component of plasma may affect the potential, too. For both silicate and carbon grains, potential in H^+ plasma is higher than that in H_2O^+ plasma.

Yao et al. [2005] investigated 13 FTEs, which were detected by Cluster II in magnetosheath near the cusp region during February to March 2001. The orientation of the FTE tube axis is derived by virtue of minimum variance analysis (MVA) using magnetic field data from the four Cluster spacecraft. Of 13 events, 6 axis directions are determined reliably, most of them are more close to L axis than to M axis in the boundary normal coordinate system LMN. This implies that there are some differences between them and those events observed at low-latitude magnetopause, whose axes tend to lie in east-west directions. The DeHoffmann-Teller (HT) frame for 13 events are also obtained, and there are good HT frames for all FTEs, the correlation coefficients between the convection electric field and the HT electric field are larger than 0.96 except two of them are about 0.9. This means the event pass spacecraft as a moving quasi-static structure at V_{HT} (velocity of the HT frame). The FTE moving in the direction perpendicular to its axis is not convected with the ambient magnetosheath plasma, the velocity of FTE tube may be slower or faster than the ambient plasma. The motion direction of FTE tube is about the same with the ambient plasma, but there may be a small angle between them. The plasma velocity in HT frame approximate to zero for ten FTEs, and is only about 14% of the local Alfven speed for the others, they are all not satisfied with the Walen relation. The slope of Walen plot is positive in northern hemisphere and negative in southern hemisphere, this implies the plasma flow along the magnetic field into the magnetosphere (parallel magnetic field in the northern hemisphere and anti-parallel magnetic field in the southern hemisphere).

11 Solar wind-Magnetosphere-Ionosphere Coupling

Wang and Cao [2003]studied the Ionospheric Feedback Instability inthe Coupling of the magnetosphere-ionosphere. Through a positive magnetosphere-ionosphere coupling feedback instability, the ionospheric conductivity has been invoked as a possible mechanism responsible for the generation of discrete auroral arcs. Several physical issues about the ionospheric feedback instability are discussed by using the conductivity argument. They give an exact quantitative description to show that the free energy for this instability comes from the reduction of the Joule dissipation produced by the pre-existing convection electric field through self-consistent changes in ionization and conductivity due to Alfvenic perturbations in the ionosphere. By the over-reflection of Alfven waves, the energy in the active ionosphere is pumped into the magnetosphere, which is opposite to the usual case whereby energy carried by Alfven waves is deposited in the ionosphere by Joule dissipation. The feedback of the ionosphere not only enhances the electron $E \times B$ drift by a factor of γ (γ-1 is the ratio of secondary pair-produced electrons due to ionization from energetic precipitating electrons to that produced directly by cold electrons in the field-aligned current) but also means that the electron conductivity is controlled by the ion Perdersen conductivity rather than by the electrons Pedersen conductivity. The second issue, at first time as our knowledge, provides a qualitative theoretical explanation to the intense aurora favoured by a lower ambient ionospheric conductivity in the ionospheric feedback instability since its first being noticed in 1996 (Newell et al., 1996).

Hu et al. [2006b] studied quantificationally the dependences of the high-latitude postnoon auroral intensity upon solar wind-magnetosphere coupling functions by using auroral observations at Zhongshan Station, Antarctica with a multi-channels scanning photometer, and Interplanetary Magnetic Field (IMF) and solar wind parameters observed by Wind Satellite at the upstream of the bow shock in 1997 and 1998. It shows that the intensity of the postnoon 630 nm emission is highly dependent on the solar wind electric field and the solar wind energy density flux, the postnoon auroral emission has larger correlation coefficients with the solar wind electric field functions than with the solar wind energy density flux functions, which is consistent with Liou's result derived from images acquired by the ultraviolet imager on board Polar satellite. The dependences of 630 nm emission on the different solar wind electric field functions related to the clock angle are varied, which implies that the clock angle of the interplanetary field is also a very important factor on postnoon aurora. The dependences of the postnoon auroral emission on solar wind-magnetosphere coupling functions and trans-polar potential functions are also studied. The intensity of the 630 nm emission depends on these functions more directly than that of the 557.7 nm emission.

The occurrence rates of the cross correlations of the inter-hemispheric geomagnetic field variations are studied statistically with the magnetic data observed at Zhongshan Station, Antarctica and at Ny-Alesund, Longyearbyen, Hopen Island, Bear Island and Tromso in the Arctic during Sept. 2000 to Mar. 2003, in which the criterion is that the correlation coefficient within sliding 20 min bin is larger than 0.9 [Hu et al., 2006c]. It is shown that the occurrence rates of correlations of geomagnetic field variations between Zhongshan and Arctic stations are related to locations of the Arctic stations, season, local time and geomagnetic active level. Among the 5 stations in the Arctic, Longyearbyen is correlated most frequently with Zhongshan (17 %), Ny-Alesund or Hopsen take the second place. In the equinox, the occurrence rate of correlations is higher than other seasons. In the daily variation of the occurrence rate of correlations, there is a peak in the evening and a valley at noon. The occurrence rate of correlation increases as geomagnetic activities increase.

Chen et al [2006] carried out a simulation study on the effects of particles precipitation on the polar ionosphere. It was studied with the aid of a one-dimensional time-dependent ionospheric model self-consistently in the continuity, momentum and energy equations. With the model, flux tubes of plasma were followed in response to convection electric fields. The trajectories, which had been adopted to follow convecting plasma flux tubes was different from each other. When they convected through cusp region, the time that precipitating particle acting on the plasma flux tube was different. The result of simulation draw a conclusion that when the plasma flux tube was enough long time in cusp region the electron density of ionospheric F layer would remarkable increase, while when the plasma flux tube was short time in cusp region the electron density of ionospheric F layer would not remarkable increase. The other result is given by this paper from the other view. The assumption was that the precipitating electrons would act on a plasma flux tube, which convect through cusp region, or not. In the two situations the difference will come into being between time transformation of electron density in the ionospheric F layer.

Zhang et al. [2006] studied magnetic field disturbances caused by FACs in the mid-altitude cusps by using the data from the four Cluster spacecraft during the mid-altitude cusp crossings on 10 September 2002 are presented. The encounters occur under conditions of weak and steady southward Interplanetary Magnetic Field (IMF). The data show that there are the field-aligned currents (FACs) in the cusp causing large magnetic field disturbances. The boundary structures of the cusps are characterized by the FACs interfaces. A method for calculating the velocities of the interface based on multi-point measurements of spacecraft are introduced. Results show that the interfaces are roughly parallel to magnetic field lines, and their velocities are almost dawnward for the southerly crossing, are almost duskward in the northerly pass. The velocities have small values (0.36~0.80km/s) with respect to satellite's velocity in the cusp crossings.

12. Space Plasma Dynamics

Liu et al., [2006] develop the nonlinear theory of dust voids [Phys. Rev. Lett. 90(2003) 075001], focusing particularly on effects of the ionization to investigate numerically the void evolution under cylindrical coordinates [Phys. Plasmas 13(2006) 064502]. The ion velocity profile is solved by a more accurate ion motion equation with the ion convection and ionization terms. It is shown that the differences between the previous result and the one obtained with ionizations are significant for the distributions of ion and dust velocities, the dust density, and etc., in the void formation process. Furthermore, the ionization can slow down the void formation process effectively.

The resistive wall mode generated by plasma-wall relative rotations is studied numerically in a slab model with a compressible plasma flow parallel to the magnetic field [Cui et al., 2006]. The linear growth of the mode is investigated with different parameters in numerical simulations. The critical plasma flow velocities for the instability are calculated as the wave number of the mode and other parameters vary. It is found that in the long wavelength regime, the critical velocity is in the range of the sound speed *cs*, as predicted in theory. In the short wavelength regime however, the critical velocity increases to a level of Alfvén velocity *VA* and a second stable region is found. This region eventually merges with the first stable region as the wave number increases and stabilizes the mode. The growth rate of the mode decreases with the wave number of the mode and the plasma viscosity. The critical wave number for the instability is also calculated as the plasma velocity changes.

Liu et al. [2006] built a sheath model in an oblique magnetic field which has one-dimension coordinate space and three-dimension speed space. The effects of magnetic field on the structure of RF sheath and parameter characteristics are discussed. The numerical simulation result shows that magnetic field has great effects on the sheath structure, especially in the region near the edge of sheath. Also, the magnetic field affects ion energy in the direction vertically to the board and incidence departure angle.

Vibrational mode in taw o-dimensional dust monolayer is investigated by considering the finite size of dust grains [Wang et al., 2006]. Each dust grain is assumed to be a negative point charge and a dipole moment due to the inhomogeneous charge distribution on its surface. The dispersion relation of the vibrational mode is derived. Both the self-excited and externally excited cases are discussed. It is shown that the mode is sensitive to the direction of the dipole moment.

A time-dependent, self-consistent nonlinear model with the convective term for the void formation in dusty plasmas is given [Liu et al., 2006]. Furthermore, the cylindrical configuration is applied instead of the Cartesian system, considering the device geometry in experiments. The nonlinear evolution of the dust void is then investigated numerically. It is shown that, similar to the slab model, the ion drag plays a crucial role in the evolution of the void. However, the effect of the convective term slows down the void formation process and the void size obtained in the cylindrical coordinate is larger than that obtained in the Cartesian coordinates.

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PROGRESS IN IONOSPHERIC RESEARCH IN CHINA, 2003-2006

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Abstract This paper reviews the progress in the ionospheric research in China from 2003 to 2006 as a national report for IAGA/IUGG 2007. The main contents include five divisions: the ionospheric variability and disturbances, the ionospheric storms, the annual and semiannual ionospheric variations, Solar Cycle Ionospheric Variations, and up-flowing ions and ionosphere - magnetosphere coupling.

1. Ionospheric Variability and Disturbances

1.1 Ionospheric variability，disturbances and irregularity

The topside electron density profile is studied by Luan[1] using incoherent scatter radar (ISR) measurements. The results reveal that the shape factor shows a general departure from the typically used values of 0.5 (Chapman layer) except during the night, and also undergoes appreciable variation with local time, season, solar activity and latitude. Over Arecibo, the averaged shape factor is characterized by a daytime maximum of 0.55 - 0.75, a nearly constant nighttime value close to 0.5, and a marked morning decline; Over Millstone Hill, the shape factor shows pronounced seasonal variations, and the diurnal variation in summer is opposite to that in other seasons. Over both stations, the shape factor exhibits a high correlation with the F2 layer peak electron density NmF2 and it has strong solar cycle dependence during the late morning hours. It seems clear that the temperature structure of the topside ionosphere can explain much of the variation of the shape factor when the plasma density is low, especially during nighttime.During daytime hours, the topside shape factor is thought to be associated with ion-neutral drag during periods of large plasma density.

Zhao et. al.[2] applied the empirical orthogonal function (EOF) analysis to examine the climatology of the total ion density at 840km during the period 1996---2004, obtained from the Defense Meteorological Satellite Program (DMSP) spacecraft. Results show that the dominant mode that controls the Ni variability is the solar EUV flux. The second EOF, associated with the solar declination, presents an annual (summer to winter) asymmetry that is caused by the trans-equatorial winds. The semiannual variation that appears in the third EOF for the evening sector is interpreted as both the effects of the equatorial electric fields and the wind patterns. Both the annual and semiannual variations are modulated by the solar flux, which has a close relationship with the O+ composition. The quick convergence of the EOF expansion makes it very convenient to construct an empirical model for the original data set. The modeled results show that the accuracy of the prediction depends mainly on the first principal component which has a close relationship with the solar EUV flux. Diurnal, seasonal, and solar activity variations of the bottom-side electron density profile parameters B0 and B1, representing the F2 layer thickness and shape, are studied by Lei et.al.[3] using a large incoherent scatter radar dataset for Millstone Hill covering the period 1976-2002. These results are compared with the latest IRI model. Our statistical study is characterized by morning and afternoon falls in the diurnal variation of B0 for seasons other than summer and a 15% change in B1 over a solar cycle, features not fully well represented by the standard IRI model. The standard IRI B1, however, is very close to observations in terms of the diurnal variation.

Using the observation data（Jul. 2003-Jun. 2005）from GPS scintillation monitor at CSSAR Hainan station, a morphological analysis for L-band ionospheric scintillations over Hainan region in the fall phase of solar cycle has been performed (Shang et.al.[4]). The main results are the following. Scintillations mainly occur from postsunset to near midnight. The onset time of scintillations is clearly earliest with the peaks on near 22LT in equinox months, and has some time delay in winter months, and has an obviously time delay which mainly takes place near midnight in summer months. The occurrence rate and intensity of scintillations are evidently enhanced in equinox months, and are evidently reduced in winter and summer months. The scintillations mainly occur on the magnetic quiet days, which mainly take place near the two equinoxes. The scintillations may also occur in magnetic disturbance/ storm days, which mostly appear in winter and summer months. Compared with the geomagnetic activity, the solar activity does not evidently affect the scintillation occurrence.

Chen et.al.[5] studied the diurnal, seasonal, and solar activity variations of the bottomside ionospheric profile parameters B0 and B1 using electron density profiles measured over Wuhan of China with a DGS-256 during 1999---2004. Comparisons are made with the International Reference Ionosphere model (IRI-2001) using both the standard option (B0-Tab and B1-Tab) and the Gulyaeva's option (B0-Gul and B1-Gul). The results show that: (1) observed B0 has distinct diurnal and seasonal variations, while observed B1 changes little with season. The value of B0 is larger in summer than that in equinox and winter, especially for daytime. In winter and equinox, B0 also presents morning and afternoon collapses as reported by Lei et al,[16]. (2) B0 increases about 18.6km from Low Solar Activity (LSA) to High Solar Activity (HSA). B1 in HSA is smaller than that in LSA before 1000LT and with an opposite tendency during the rest time. (3) Observed B0 is in better agreement with B0-Gul than with B0-Tab, though the B0-Gul overestimates during 0900-1700LT in equinox and summer. B0-Tab is 12-20km larger than the observations over Wuhan almost all the time. Meanwhile, B1-Tab is in good agreement with the observations.

Lei et.al.[6] conducted theoretical calculations of the ionospheric lower transition height (LTH), a level of equal O+ and molecular ion densities. This paper included the AE-C data of ion composition analysis and by detailed quantitative studies of the LTH simulation, and by creating a new LTH empirical model based on the simulations. Results show that: (1) the calculated LTH, in general, is lowest near 1100-1300LT and reaches the diurnal maximum after midnight. The local time asymmetry becomes more evident in summer, when the time of minimum shifts to 1600LT. (2) The simulated LTH presents a dominant, semiannual variation during nighttime, and a pronounced annual variation during daytime. (3) The simulated LTH increases with solar activity at night and decreases by day, while the standard IRI option has an opposite tendency at night in summer and equinox. Therefore, the day-night difference of simulated LTH significantly increases with solar activity. (4) Both daytime and nighttime LTHs, tend to increase with the increasing geomagnetic activity Ap index, with a mean slope about 0.1455km per Ap unit. (5) The diurnal variation of LTH is found to be more than 20 km, which is much larger than the seasonal variation under F10.7=100 and Ap=10. Thus, the diurnal and solar activity variations of LTH are more pronounced than its seasonal and magnetic activity variations.

The ionospheric sounding in China has a long history and has a well spread network, which is still keeping routine operation. Liu et.al.[7,8] used an autocorrelation method for the short-term forecasting of ionospheric characteristics. The performances of the forecasts at Chongqing have been examined for different combination of parameters and algorithms by estimating the prediction errors. Preliminary results show that for predictions of more than 10 hours ahead the ‘at once" method with f0F2 is preferable. For predictions of less than 10 hours ahead the “iterations" method is the best. A corrected method of the International reference Ionosphere used in China region (the CRI model) is described in this paper. By introducing an effective ionospheric index Ice into the CRI model the regional forecasting could be realized.

Zhang et. al.[9] and Liu et. al.[10] use a one-dimensional high-latitude ionospheric model, in which the continuity equations, as well as momentum and energy equations are solved self-consistently, to study the conductivities in auroral regions where electrojets exist. The heating effect from the Farley-Buneman instability, which possibly occurs in the electrojet regions, is considered. Electrojet-related Joule heating and frictional heating are also taken into account. Thermal processes are analyzed in response to the electrojet current. As a result of changes in the thermal structure, we demonstrate the response of the conductivities due to changes in the chemical reaction rate, which results in a higher electron density. The response of altitude profiles of the conductivities is determined by changes in the collision frequency of ions and electrons with neutral components, while an enhancement in the conductance is mainly caused by the electron density. The results show that both the Hall and Pedersen conductances, i.e., the height-integrated conductivities, increase significantly. The ratio between Hall and Pedersen conductances also changes considerably.

Wang et.al. [11,12] ana1yzed the ionospheric drift data observed with DPS-4 in Hainan region. The results show that variation of daytime vertical drift is regular and generally the vertical plasma drift is about(0-20)m/s, nighttimevertica1 plasma drift is usually downward and its variation is very complicated，which varies with season． Horiaonta1 plasma drift is about(50- 100)m/s and at sunset and sunrise increasing up to about(150-200)m/s, even as high as 300 m/s, and the meridian and zonal plasma drifts are different, Compared with plasma drift observation in Jieamarea ionospheric observatory, ionospheric drift in Hainan shows distinct territorial features.

Zuo et.al.[13] deal with both the statistical study and the computer simulation of sporadic E-layers at mid-latitude regions. The Fourier transformation of the foes sequence shows that the observational data have a strong 24 h and 12 h periodic component, which means strong correlation of Es with the atmospheric tides. The sporadic E occurrence has one peak at higher latitudes while has double peaks at lower latitudes, which suggests that the sporadic E occurrence is associated with the diurnal and semi-diurnal tides. The simulation work is based on the continuity equation and momentum equation. Method of characteristic curve is adopted. According to the widely studied wind shear theory, simulation for the convergence of metal ions to form a thin layer induced by the tidal wind has been carried out. In conclusion, the strong correlation between the sporadic E-layers and the tide is confirmed not only from the statistical analysis of observational data but also from the computer numerical simulation work.

With the statistical analysis of the monthly medians from 1995 to 2002 of the DPS-4 ionospheric sounder at Zhongshan Station,Antarctica, main features of the ionospheric critical frequency （f oF2 ） are revealed by Xu et.al.[14]. The result shows that the frequency foF2 has obvious diurnal and annual variations. There is a " magnetic noon anomaly " of the diurnal variation. The " winter anomaly " of the annual variation does not occur at local noon at solar minimum, while the " semi-annual anomaly " occurs at solar maximum, which means foF2 is larger at equinoxes than at solstices. The physical mechanisms of these phenomena are discussed according to ionization of solar radiation, the driven factors from magnetosphere and variations of neutral components of the atmosphere at the location of Zhongshan Station.

Ke et.al.[15] discusses chaotic properties of ionospheric total electron content （TEC） based on the TEC data from 1996 to 2004, and analyzes possibility to predict it by using the chaos theory. Calculation shows that the TEC chaos properties over a specified area exist. The correlation dimension is 3. 6092 and the Lyapunov exponent is 0.3369. It is successful to predict TEC by using the weighted one-rank local-region forecasting model. Analysis of the forecasting error indicates that the error is lesser comparatively among 1 - 144 forecasted points, while the standard deviation is about 7.6438 TECU and the correlation coefficient is about 0.9172.

Adopting the autocorrelation method in the ionospheric short-term forecasting, Liu et.al.[16] forward a simple and practical forecasting method-- the sectional autocorrelation method, that is, for predictions of one hour to four hours ahead the autocorrelation coefficient of RDF with the " iteration " method is selected, for prediction of more than four hours ahead, the autocorrelation coefficient of f0F2 with the " at once " method is used. The prediction precisions have been quantitatively estimated based on the data from Chongqing and Guangzhou Ionosonde Stations. It is shown that the method is much improved for the predictions of one hour to four hours ahead. For the predictions of more than four hours ahead the prediction error reaches a saturation value, which is still lower than that of the " median " method. This new method could also be applied to the short-term forecasting of other ionospheric parameters.

Georgiadiou ionospheric model was adopted to determine satellite-plus-receiver differential delay. The satellite-plus-receiver differential delay was estimated as constant values for each day (Cai et.al.[17]). Dual-frequency GPS pseudo-ranges observables were used to compute vertical TEC （VTEC）. All the monthly mean VTEC profiles were presented using GPS data of Beijing IGS site between 2000 and 2004. All the monthly averaged values and amplitudes of VTEC were also presented. The results indicate that the VTEC has seasonal dependency. The maximum VTEC values are observed in March and April, the minimum VTEC values in December. The seasonal variations trend is found to be the same after polynomial fitting be tween 2000 and 2004.

Usually, the ionosphere delay models can be sorted as three types--the forecast model, the real-time model and the post-processing model. Different purpose for the application of these models is required to choose one that can be used to correct the ionospheric delay efficiently. Here Zhang et.al.[18] we compare several ionosphere delay models often used, such as the functional modcl uscd for Wide Area Augmentation System （WAAS） trigonometric series function, polynomial model, and low degree spheric harmonics function. The three models are roughly equivalent to each other in the ionosphere delay correcting for WAAS. The TEC harmonic expansion trend function can be used to analyze the long-trend variations of thc ionosphere. The International Ionosphere Reference（IRI）model, as an empirical one, can reach 60 percent of the correcting effect. The Klobuchar model as the CPS broadcast model can also achieve same effect although there are some shortcomings in the parameters setting. This model will be discussed here and some improving methods are presented.

Wei et.al.[19] presents theoretical models for the formation of HF-induced ionospheric irregularities under both homogeneous and stratified ionosphere backgrounds. It proves theoretically that pondermotive force and thermal pressure play a lead role in the evolution of artificial irregularities during ionospheric heating. Based on the physical model for homogeneous ionosphere, spatial structures of HFinduced ionospheric irregularities are numerically obtained. The results demonstrate that electron density turbulences exhibit a typical scale of more than one kilometer in the pump field direction and of 10 to 20 meters in its perpendicular direction. These results match well with the experimental observations that artificial ionospheric irregularities usually hold a transverse scale of 10 meters and a longitudinal scale of one kilometer. The numerically obtained alternant structure of electron depletion and enhancement can also interpret self-focusing effect of radio waves during ionospheric heating processes.

A real-time GPS ionospheric scintillation monitoring system for measuring and display ionospheric scintillation is presented by Li et.al.[20] The system can measure the amplitude and phase scintillation index of GPS signals, and the raw amplitude and phase data can be saved automatically at the time when ionospheric scintillation occurs. A detailed discussion about scintillation index computation and the principles of ionospheric scintillation monitoring are discussed. The design method presented may have some guidance meaning for designing the similar ionospheric scintillation monitoring system using Beidou satellite signals.

Shi et.al. [21] studied the nonlinear waves observed by the Freja satellite in the upper ionosphere. The amplitudes of magnetic disturbances associated with observed density solitons are only several 10^{-2} nT or less. These very weak magnetic disturbances can be neglected against the ambient magnetic field of 0.2 Gauss in Freja's orbit region. They establish an electrostatic model for the nonlinear waves observed on board of Freja. The fluid equations are used and the “Sagdeev potential” is derived to study the nonlinear waves. The results show the existence not only of solitons with a density hump and solitons with a density dip, but also of periodic density waves and density shock waves. The theoretic amplitudes of the solitons may vary between 20% and a factor of 2, which is consistent with the observations on board of Freja. Some waveforms of the solitons with a density dip are very similar to the observed ones. They also studied the electrostatic shock in the upper ionosphere (Shi et.al. [22]).

Zhang et.al. [23] compare the ionogram-derived total electron content (ITEC) obtained at the low latitude station Hainan, China with that derived from GPS signals produced by the

International GPS Services for Geodynamics (TECigs) and the TEC data obtained by the altimeter on TOPEX satellite when it passed over nearby Hainan. They also compare them with the results produced by the current International Reference Ionosphere model (IRI2001) TECiri. Data used for the present comparison study are both the daily hourly and monthly median values for the 12 months of the descending solar activity year 2003.

According to the observation waved in the ionosphere, Qureshi et.al. [24] studied Landau damping of electron plasma (Langmuir) waves and ion-acoustic waves in a hot, isotropic, unmagnetized plasma is studied with the generalized (r ,q) distribution function. The results show that for the Langmuir oscillations Landau damping becomes severe as the spectral index r or q reduces. However, for the ion-acoustic waves Landau damping is more sensitive to the ion temperature than the spectral indices.

Shang et.al. [25] investigate the equatorial ionospheric scintillation morphology and the relevant physica1 processes: One GPS ionospheric scintillation monitor was installed at CSSAR Hainan station. The monitor is built on Plessey GPS Builder. 2 development system with its software modified to log signal strength from up to 1 channels at a high data rate(50 samples/s) . It is suits the high time resolution studies of scintillation spectral and temporal characteristics and also can be used to perform the statistic analysis of scintillation signals.

Using the SF data observed by DPS-4 digisonde at Hainan ionospheric observatory station between March 2002 and February 2003, Wang et.al. [26] studied the properties of starting time of four type SF, i. e., frequency, range, hybrid, and strong SF statistically. The results show that the starting time of most of the frequency SF and the hybrid SF was between 0200LT -0800LT and 0000LT -0600LT, respectively. The starting time of the range SF and the strong SF mainly happened between 2000LT-0200LT and 2000LT-2200LT, respectively.

1.2 Sudden ionospheric disturbances

Using the GPS data from as many as 114 GPS stations of the International GPS Service for Geodynamics (IGS), Zhang et.al.[27,28] studied the morphological features of the ionospheric TEC variations on the sunlit hemisphere during the 4B solar flare on 28 October 2003. It is found that the strongest sudden increase of TEC (SITEC) happened during the flare, and the magnitudes of

SITEC vary at regions with different local Solar Zenith Angle (SZA). In the northern hemisphere, the TEC enhancement is approximately symmetrical to the local noon, and its value is usually greater than 14 TECU°if the SZA is less than 60°. On the whole, as the SZA increases, the value of TEC enhancement in the northern hemisphere decreases.

Wan et.al.[29]studied SITEC of the ionosphere caused by a very intense solar flare on July 14, 2000. TEC data observed by a global GPS network were used to calculate the TEC increment, TEC, and variation rate, dTEC/dt, at different places with different solar zenith angle *X*. It is found that both dTEC/dt and deltaTEC are close related with *X*. A simple relationship between the partial derivative of TEC, which is a good approximation for dTEC/dt, and *X* as well as the effective flare radiation flux If is derived to explain the observation results. It shows that GPS observation is a powerful tool in the observation and investigation of solar flare effects on the ionosphere.

Chen et.al.[30] statistically studied both deltaTEC and dTEC/dt during X-class solar flares occurred from 1996 to 2003 by using the data from a global GPS network. It is found that both deltaTEC and dTEC/dt are close closely related with the flare's maximal X-ray flux and its locations on solar disc. The results also showed that there is a negative correlation between deltaTEC and the sun-earth distance. It was also found that dTEC/dt correlates with the duration of the flares.

Hao et.al.[31] found a sudden ionospheric disturbance detected by the Doppler shift sounding equipment at Beijing, about 25 min later after the outbreak of the Sumatra earthquake on 26 December 2004. This ionospheric disturbance appeared less than lOmin after the earthquake was first recorded at Beijing seismological station by the arrival of the seismic Rayleigh wave. The analysis shows that about 18rain is the time necessary for the seismic Rayleigh wave to propagate from the epicentre to Beijing and then about 5-10min for acoustic waves to propagate from the surface of the Beijing area to the altitude of the ionosphere. Also, a report was made as another example to show the ionospheric response of Doppler shift observation at Beijing area during the Mount Pinatubo eruption of 1991. These two examples show clear evidence of the lithosphere-atmosphere-ionosphere coupling. The former case is in the frequency domain of infrasonic waves of the Earth surface oscillation due to the Rayleigh waves caused by the earthquake, while the latter is in the acoustic-gravity wave category directly excited in the atmosphere by the mass and energy eruptions of Mount Pinatubo.

1.3 Traveling ionospheric disturbances

Lu et.al.[32] investigate the characteristics of TIDs associated with two severe magnetic storms occurring on March 31 and April 11, 2002 using the data from a GPS array. Wavelet technique is used to eliminate the long trend change of TEC and noise to pick out effectively weak ionospheric disturbances. The statistical angle of arrival and Doppler method for the GPS array and the maximum entropy cross spectral method are used in determining the propagation parameters of TIDs. The analyzing results indicated that, during the main phases of two magnetic storms, all appeared TIDs last several hours and travel from polar region to the equator. Its' main periods ranges from 37 to 41 minutes and horizontal propagation velocity is about 372m/s. Ding et. al.[33] present a 7-year climatology describing medium-scale gravity waves observed in the menopause region covering the years from 1995 to 2001. The data they used comes from the OI and OH airglow observations of the three-field photometer employed at the University of Adelaide's Buckland Park, Australia. About 1300 Gravity Wave events (AGW) are identified during the years 1995-2001. These AGW events usually persist for between 40 min and 4 hours. The magnitudes range from 1% to 14% of the background intensities and peak at 2% for OI observations and at 3% for OH observations. The observed periods range from 10 to 30 min, and the horizontal phase speeds range from 20 to 250 ms, with dominant wave scales of 17min, 70m/s for OI observations and 20min, 40m/s for OH observations. The intrinsic parameters are obtained by using Medium-Frequency (MF) wind data observed at the same place. The occurrence frequency of AGW events peaks at 13 min, 40 m/s for both OI and OH observations. The occurrence rate of gravity waves has a major peak in summer and a minor peak in winter. There is an obvious dominating southeastward direction for gravity waves, with azimuths of 160°S in summer and 130°S in winter. Studies for gravity waves observed in various locations show a similar tendency of propagating meridionally toward the summer pole. This implies that the tendency of propagating toward the summer pole may be a global trend for medium-scale gravity waves observed in the mesopause region. During summer, gravity waves propagate against winds measured by MF radar in their dominating direction. Using the ray tracing method, we found that the seasonal variation of winds limits the access of gravity waves to the observation height through reflection and critical coupling, which is one of the causes leading to the seasonal behavior of gravity waves observed over Adelaide.

The total number of 189 ionospheric absorption spike events was identified in the imaging riometer′s data from 2000 to 2001 at Zhongshan station, Antarctica by Deng et.al.[34] All events are divided into two groups, the nightside events （69 samples） and the dayside events （120 samples） according to their occurring time. The whole features are found with regard to their occurrence, duration, intensity, shape, size, movement and the relationship with Kp by using statistical methods. The occurrence peak of the nightside spike event is around magnetic per-midnight and in April, while the occurrence peak of the dayside spike event is around magnetic noon and in August. It is suggested that the nightside spike events are closely related to the aurora substorm activities, while the dayside spike events are affected by the solar wind conditions. The typical duration of the spike events is 2 - 3 minutes. The maximum intensities of absorption are usually less than 1 dB. The shape of the spike is most like elliptic with the major axis along the geomagnetic east-west direction. Comparisons have been made on the occurrence of the spike events between Zhongshan station and arctic stations. The possible mechanisms which cause the spike events are suggested in the paper.

1.4 Influence of typhoon on the ionosphere

Liu et.al.[35] studied Influence of typhoon on the ionosphere and the results are as follows. During the period of typhoon, especially when typhoon is approaching the mainland, violent interaction between the wind and the sea surface, the wind and the mainland will greatly strengthen the turbulence in the lower atmosphere, and it will possibly raise the turbopause in altitude. Thus it will change the structure of the earth′s atmosphere and influence the photochemical process of the upper atmosphere, and consequently influence the ionosphere. Based on the assumption that typhoon will raise the turbopause in altitude, the response of F2 layer of the ionosphere over the middle latitude of Japan was simulated, by using the one dimensional ionospheric model. The results of the simulation can qualitatively explain the following phenomena very well: f0F2 of the ionosphere will decrease while the reflecting surface in the ionosphere of the radio wave with a certain frequency will increase during the time of typhoon, hmF2 increases due to the raise of turbopause in this simulation. These results suggest that the rising in altitude of turbopause by typhoon is a very reasonable mechanism of typhoon effects on the ionospheric F2 layer.

Xiao et.al.[36] present a case study to reveal the detailed process of ionospheric responses to strong disturbances in the lower atmosphere when a strong typhoon lands or approaches the mainland. The ionospheric HF Doppler shift data during the periods of two strong typhoons which occurred in 1988 and 1990 respectively are analyzed in detail.The results show that except the appearance of significant wave-like disturbances （in general, medium scale acoustic-gravity waves AGWs） there are some new phenomena worth noticing： the temporal evolution of these waves in the two cases show clearly the change elapses the frequency was getting lower and lower and phenomena appeared, showing the role of seeding of comparison is made for the above phenomena with the linear numerical simulation of the dynamic features of of both wave main frequency and amplitudes, as time amplitudes enhanced gradually. After sunset, Spread-F the AGWs for exciting of ionospheric irregularities. A linear theory of TIDs propagation and also with a nonAGWs propagation in the atmosphere. All these results are in good agreement.

2. Ionospheric Storms

The responses of Equatorial Ionization Anomaly (EIA) to the superstorms of October/November 2003 were investigated by Zhao et. al.[37]. Based on the TEC data measured with receivers in China, Southeast Asia, Australian (CSAA), and the American regions.Enhanced EIA was seen to be correlated with the southward turning of the interplanetary magnetic field Bz. In both the CSAA and American regions, EIA was intensified, corresponding to a large increase in the F-layer peak height (hmF2) measured by ionosonde and digisonde at middle and equatorial latitudes. However, the enhanced EIA was shown to be more significant during the daytime in the American region, which was associated with a series of large substorms when Bz was stable southward. The prompt penetration electric field and the wind disturbance dynamo electric field are suggested to be responsible for this observation. Both the ionogram and magnetometer data show the existence of a weak shielding effect whose effect still needs further study. A clear asymmetric ionospheric response was shown in the TEC observations. The southern EIA crest was totally obliterated on 29 and 30 October in the CSAA region and on 31 October in the American region. Ion temperatures from the Defense Meteorological Satellite Program (DMSP) spacecraft revealed that the unequal energy injection at the polar region might be the reason for this effect. It was pointed out that different physical processes have varying degrees of importance on the evolution of EIA in the CSAA and American regions.

Wang et.al.[38] studied statistically 1829 well-defined substorm onsets in the Northern Hemisphere based on a 2-year period observation by the FUV Imager on board the IMAGE spacecraft. From the combination of solar wind parameter observations by ACE and magnetic field observations by the low altitude satellite CHAMP, the location of auroral breakups in response to solar illumination and solar coupling parameters are studied. Furthermore, the correspondence of the onset location with prominent large-scale field-aligned currents and electrojets are investigated. Solar illumination and the related ionospheric conductivity have significant effects on the most probable substorm onset latitude and local time. In sunlight, substorm onsets tend to occur 1 hour earlier in local time and 1.5° more poleward than in darkness. The solar wind input, represented by the merging electric field, integrated over 1 hour prior to the substorm, correlates well with the latitude of the breakup. Most poleward latitudes of the onsets are found to range around 73° magnetic latitude during very quiet times. Field-aligned and Hall currents observed concurrently with the onset are consistent with the signature of a westward travelling surge evolving out of the Harang discontinuity.The observations suggest that the ionospheric conductivity has an influence on the location of the precipitating energetic electron which causes the auroral break-up signature.

The characteristics of Field-Aligned Currents (FACs) were investigated by Wang et. al.[39,40]in both hemispheres during the extreme storms in October and November 2003. High resolution CHAMP magnetic data reflect the dynamics of FACs during these geomagnetic storms, which are different from normal periods. The peak intensity and most equatorward location of FACs in response to the storm phases are examined separately for both hemispheres, as well as for the dayside and nightside. The corresponding large-scale FAC peak densities are, on average, enhanced by about a factor of 5 compared to the quiet-time FACs' strengths. And the FAC densities onthe dayside are, on average, 2.5 times larger in the Southern (summer) than in the Northern (winter) Hemisphere, while the observed intensities on the nightside are comparable between the two hemispheres. Solar wind dynamic pressure is correlated with the FACs strength on the dayside. However, the latitudinal variations of theFACs are compared with the variations in Dst and the interplanetary magnetic field component Bz, in order to determine how these parameters control the large-scale FACs' configuration in the polar region. We have determined that (1) the equatorward shift of FACs on the dayside is directly controlled by the southward IMF Bz and there is a saturation of the latitudinal displacement for large value of negative Bz. In the winter hemisphere this saturation occurs at higher latitudes than in the summer hemisphere. (2) The equatorward expansion of the nightside FACs is delayed with respect to the solar wind input. The poleward recovery of FACs on the nightside is slower than on the dayside. The latitudinal variations on the nightside are better described by the variations of the Dst index. (3) The latitudinal width of the FAC region on the nightside spreads over a wide range of about 25 in latitude.

A theoretical ionospheric model is employed by Lei et.al.[41] to investigate the ionospheric behavior as observed by the Incoherent-Scatter Radar (ISR) at Millstone Hill during the September 21-27, 1998 storm. The observed NmF2 presented a significant negative phase on September 25, and a *g* condition was also observed. The model results based on the standard input parameters are in good agreement with the observed electron densities under quiet conditions, but there are large discrepancies during disturbed periods. The exospheric temperature Te, neutral winds, atomic oxygen density and molecular nitrogen density, and solar flux are inferred from the ISR ion temperature profiles and from the electron density profiles. Our calculated results show that the maximum Tex is higher than 1700K, and an averaged decrease in [O] is a factor of 2.2 and an increase in [N2] at 300km is about 1.8 times for the disturbed day, September 25, relative to the quiet day level. Therefore, the large change of [N2/O] ratio gives a good explanation for the negative phase at Millstone Hill during this storm. Furthermore, at the disturbed nighttime the observations show a strong NmF2 decrease, accompanied by a significant hmF2 increase after the Sudden Storm Commencement (SSC). Simulations are carried out based on the inferred Tex. It is found that the uplift of F2 layer during the period from sunset to post-midnight is mainly associated with the large equatorward winds, and a second rise in hmF2 after midnight results from the depleted Ne in the bottom-side of F2 layer due to the increased recombination, while the “midnight collapse" of hmF2 is attributed to the large-scale traveling atmospheric disturbances.

Lei et.al.[42] examined the physical mechanism of the negative and positive storm at middle latitude in August 1992, based on Incoherent Scatter Radar (ISR) observations over Millstone Hill

(42.6°N, 288.5°E) and a first-principles ionospheric model. The exospheric temperature Te, thermospheric composition and neutral winds, inferred from the ion temperature profile using the ion energy balance calculation and from the electron density profile using an ISR data assimilation method, are employed to investigate the storm effects. The derived thermospheric information shows that the negative phase on August 5 is attributed to both the large poleward wind and the reduced [O/N2] and [O/N2] ratio at F2-layer. For the daytime positive storm on August 4, the thermospheric composition perturbation, in addition to the enhanced equatorward wind, plays a significant role. This study also suggests that the data assimilation technique can provide useful information to understand some physical mechanisms of the ionospheric storm when direct experimental data are not available.

Liu et.al.[43] report the responses of the low latitude ionosphere near the longitude 120°E to the April 2000 geomagnetic storm using Digisonde data measured at Chungli, Wuhan, and Kokubunji. At these three stations, the significant ionospheric responses are near-simultaneous height disturbances after the SSC on April 6, 2000 and wave-like disturbances in the daytime on April 7. The ionospheric height disturbances in the nighttime after the SSC at these stations are suggested to be caused by the storm related perturbed electric fields, and the followed wave-like disturbances may be caused by storm induced atmospheric gravity waves. The vertical effective winds derived from Digisonde measurements imply the existence of significantly large vertical drifts during this storm, which are in agreement with the perturbed zonal electric fields predicted by the model of Fejer and Scherliess and Scherliess and Fejer. Finally,the storm time derivations of f0F2 from its monthly median level at these stations are used to validate the predication ability of the empirical model of Araujo-Pradere, which has included in the International Reference Ionosphere model IRI 2000.

Li et.al.[44] studied the characteristics and development of the ionospheric storm between Nov. 6 and Nov. 12, 2004 using the total electron content （TEC） derived from GPS data observed by globally-distributed GPS stations under International GPS Service for Geodynamics （IGS）. It was found that when magnetic storm was in its main phase on Nov. 8, the ionospheric positive storm occurred over a large region of mid-and low latitude in the day time. And during the recovery phase on Nov. 10, when Dst index reached its minimum, the global ionosphere was intensely disturbed and both positive and negative effects appeared. During this storm, negative effects appeared more intensely in the southern hemisphere（the summer hemisphere）than in the northern one, which is consistent with previous statistic results that negative storms have a proneness to appear in the summer hemisphere. It has been also observed that during the storm the value of night time TEC is low comparing the night TEC with no storm period, for which many mechanisms has been proposed. Because of the complex evolution process of ionospheric storm, more data including from other observation methods during other large ionospheric storms needs to be collected and analyzed.

The parameters of the upper atmosphere and ionosphere, such as the neutral wind and conductance, deduced from widely accepted empirical models are used to calculate the distribution of the electric field and current between geomagnetic latitudes ±72° and 00：00 - 24：00 MLT on June- and December-solstices during strong storms in terms of the ionospheric current continuity equation by Shen et.al.[45] The deviation of geomagnetic and rotation axes of the earth is considered in the calculation. Except the dynamo effect induced by the neutral wind, the driving electric field across the polar cap and the region 2 field-aligned current, caused by the magnetospheric coupling, are also taken into account. The results show that on the June-solstice the penetration of magnetospheric disturbances from the auroral zone to mid- and low-latitude areas is similar between the southern and northern hemispheres, but is a bit little stronger in the northern one. On the December solstice, however,obvious asymmetry appeared. The penetration of disturbed current is much stronger in the southem hemisphere than that in the northem one, meanwhile the penetration of the electric field is stronger in the northern one. Independent of the southern or northern hemisphere, in the moderate high latitude areas the existence of a eastward electric field in the midnight-dawn region is an expected mechanism, which can be used to explain phenomena found many times in our previous works, due to its g x B upper-ward drift effect.

3. Annual Variations of the Ionosphere

Yu et. al.[46]]investigated the annual and semi-annual variations of the ionosphere by using the daytime F2 peak electron concentration observed at a global ionosonde network with 104 stations. The main features are obtained as:(1) The annual variations are most pronounced at magnetic latitudes of 40°-60°in both hemispheres, and usually manifest as winter anomalies, below magnetic latitude of 40° as well as in the tropical region they are much weaker and winter anomalies that are not obvious; (2) The semi-annual variations, which are usually peak in March or April in most regions, are generally weak in the near-pole regions and strong in the far-pole regions of both hemispheres;(3) Compared with their annual components, the semi-annual variations in the tropical region are more significant. In order to explain the above results, they particularly analyzed the global atomic/molecular ratio of [O/N2] at the F2 layer peak height by the MSIS90 model. The results show that the annual variation of [O/N2] is closely related with that of NmF2 prevailing in mid-latitudes and [O/N2] annual variation usually may lead to the winter anomalies of NmF2 occurring in the near-pole region. Moreover, NmF2 semi-annual variations appearing in the tropical region also have a close relationship with the variation of [O/N2]. On the other hand, the semi-annual variations of NmF2 in the far-pole region cannot be simply explained by that of [O/N2], but the variation of the solar zenith angle may also have a significant contribution. Yu et.al.[47] also simulated semi-annual variations ionospheric variation related with that of ionospheric electric field.

Xu et. al.[48] statistically analyzed the ionospheric date from 1995 to 2002 observed at Zhongshan Station, Antarctica. Several primary characteristics of the ionospheric critical frequency (f0F2) were obtained: f0F2 has obvious diurnal and annual variations; there is a ‘magnetic noon anomaly” of diurnal variation; the “winter anomaly" of annual variation does not occur at local noon at solar minimum, but the “semi-annual anomaly" occurs at solar maximum, which means f0F2 is larger at equinox than at solstice. The mechanism of them are discussed by the ionization of the solar radiation, the driven factors from magnetosphere and the variations of the neutral components of atmosphere according to the location of Zhongshan Station.

With the Fourier analysis method, the daytime ionosphere total electron concentration （TEC） are investigated by Yu et.al.[49] using a high solar activity years（2000）global GPS data series from IGS, the main features are outlined as follows： the annual variation of daytime TEC are strong in the middle latitudes for the northern and southern hemispheres, and weak in the low latitudes and equatorial region. The amplitudes of semiannual variation are much larger in the ′far-pole′ region （far away from the northern or southern magnetic pole, i.e. north-east Asia and South American） than those in the ′near-pole′ region （North American and Austria）. Further studies also show that daytime TEC maximize at equinox days in most regions, and maximize in winter in the northern ′near-pole′ region. In South America and Austria, daytime TEC reaches its max value in summer. The atomic/molecular ratio [O/N2] in the neutral atmosphere calculated by the MSIS90 model are also treated with Fourier method, results indicate that the annual amplitudes of the [O/N2] ratio are large in the northern and southern middle and high latitudes, and the winter anomaly are noticeable very much. According to Rishbeth′ s opinion, we suggest that the [O/N2] may have important contribution to the TEC annual variation, as well as the winter anomaly in the 'near-pole' region. As for the daytime TEC semiannual variations, we should comprehensively consider the contribution of [O/N2] and the electron production rate associate with the solar zenith angle.

With a theoretic ionospheric model, Yu et.al.[50] we simulate semiannual variations of the ionospheric F2 region peak electron density （NmF2） at mid- and low latitudes under the low solar activity and quiet geomagnetic conditions, and focus on how electric fields modify the semiannual component of NmF2. The result indicates that when the input electric fields have no semiannual variation, the NmF2 at the geomagnetic equator still exhibits some semiannual component, and the amplitudes of the semiannual component become smaller as the latitude increase. When the input electric fields have a semiannual component to some extent, the amplitudes of the Nm F2 semiannual component is strongly modified, and this influence seems to be much different at different magnetic latitudes. It is also found that the modification of electric fields on the NmF2 may have a close relationship with the 'fountain effect' in the equatorial ionosphere.

Huge efforts have been made to search for the greenhouse effects in the ionosphere. Main efforts have been directed towards the analysis of the F2 region parameter long-term trends[51]. An Artificial Neural Network (ANN) method is first used by Yue et.al.[52]for deriving long-term trends of the F2-layer critical frequency (f0F2) at 19 ionospheric stations in the Asia/Pacific sector. It is found that the ANN method can eliminate the geomagnetic activity effect on f0F2 more effectively than usual regression methods. Of the selected 19 stations, there are significant long-term trends corresponding to a confidence level >90% at 14 stations and 12 of these stations present negative trends. An average trend of -0.05% per year in the selected area can be obtained if the 12 stations with significant negative long-term trends be considered. No pronounced diurnal and latitudinal effects in trends and no uniform pattern of seasonal variation in most stations are detected. The long-term trends for low latitude and equatorial stations differ from other stations suggest that some special dynamical processes may take effects in the equatorial anomaly region. Many factors which can influence ionosphere, such as the greenhouse effect, solar and geomagnetic activity, and neutral background gas, might contribute to the trend.

4. Influences of the Solar Activity on Ionosphere

Utilizing f0F2 obtained at Wuhan (114.4°E, 30.6°N; 45.2°dip) from 1957 to 1991, Liu et.al.[53] investigated the solar activity dependence of monthly median f0F2 and constructed single-station models using Fourier expansion and cubic-B splines approaches. Statistical analyses show that, monthly median f0F2 over Wuhan has a significantly nonlinear dependence on the present and historical levels of solar activities. Their climatological models are in good agreement with observations.

Later, Liu et.al.[54] used the ionogram derived scale height around the ionospheric F layer peak Hm to study the diurnal, seasonal, and solar activity variations of Hm over Wuhan. Hm is a measure of the slope of the topside electron number density profiles. Their results indicate that the value of median Hm increases with increasing solar flux. Hm is highest in summer and lowest in winter during the daytime, while it exhibits a much smaller seasonal variation at night. A common feature presented at global 13 stations is that, Hm undergoes a yearly annual variation with a maximum in summer during the daytime. The annual variation becomes much weak or disappears from late night to pre-sunrise. In addition, a moderate positive correlation is found between Hm with HmF2 and a strong correlation between the bottomside thickness parameter B0 and Hm. The later provides a new and convenient way for empirical modeling the topside ionospheric shape only from the established B0 parameter set.

Liu et. al.[55] collected the SEM/SOHO EUV data and F0F2 from 20 ionospheric stations in the East Asia/Australian sector to quantify the solar activity dependence and access the saturation effect of NmF2. The SEM/SOHO EUV shows a nonlinear relationship with F107, and can be better represented by a solar activity factor P=(F107+ F107A)/2. Seasonal and latitudinal dependences are found in the solar activity variation of NmF2 in the East Asia/Australian sector. The slope of NmF2 with P in the linear segment further shows similar annual variations as the background electron densities at moderate solar activity. Observations show a nonlinear dependence of NmF2 on solar EUV (the saturation effect of NmF2 for high solar EUV). Based on a simple model of photochemistry, taking the neutral atmospheric consequences into account, calculations at fixed height simulate the saturation effect of NmF2, but the observed change rate of NmF2 with P are inadequately reproduced. Calculations taking into account the influence of dynamics (via a simple model of the solar EUV dependence of the ionospheric height) tend to reproduce the observed change rate of NmF2. Results indicate that, besides solar EUV changes, the influence of dynamics and the atmospheric consequences should substantially contribute to the solar activity variations of NmF2.

Because the influence of dynamics plays an important role in controlling the ionosphere, their variations actually need to be investigated. Dynamic information (neutral winds and electric fields) near the ionospheric F-layer peak can be obtained from ionosonde measurements based on the nature that neutral winds and electric fields strongly control the evolution of the ionosphere, especially the peak height of the F-layer. Approaches, like Liu et. al.[56] are used to investigate the latitudinal feature (Luan et.al.[57]) and the solar cycle variability of thermospheric circulation, which is one of the outstanding questions involving the upper atmosphere. Liu et. al.[58] derived the equivalent winds at the F layer peak from global ionosonde data. They found that, with increasing solar activity, the derived equivalent winds are found of nonlinearly decreased diurnal amplitudes in all seasons at most stations. The diurnal phase of the derived equivalent winds generally shifts later at higher solar activity. It is the first time to explicitly report this striking feature emerged at so many stations. Another pronounced feature is that the diurnal phase has a summer-winter difference. The diurnal phases at most stations in the northern hemisphere are later in winter than in summer at higher solar activity. Furthermore, a decrease in the semidiurnal amplitudes of equivalent winds with increasing solar activity is evident in winter over most stations considered and in other seasons at stations with a lower dip, but it becomes weak in other seasons at stations with a larger dip. However, complicated dependences on solar activity can be found in the diurnal mean and the semidiurnal phases of equivalent winds at stations considered.

Daytime half-hourly values of the critical frequency of the E-layer, f0E, obtained at Wuhan from 1957 to 1991 and from 1999 to 2004 have been used by Yue et.al.[59] to develop an empirical model. The model, including variations with local time, day number and solar cycle, is in agreement with the observations. A comparison between our model and IRI and Titheridge's model has also been made. Statistically, the model gives a better performance than IRI and Titheridge's model because data set is obtained with our own station. Both the IRI and Titheridge's model overestimate f0E especially in May to September months. Combing with past investigations, we suggest that overestimation of ionospheric parameters by IRI may be a common feature in East Asia. This result is very helpful for both the correction of IRI in East Asia and the development of Chinese Reference Ionosphere.

Liao et.al.[60] studied the influences of the solar flux on the ionosphere. The E10.7 index representing the solar EUV irradiance flux has been used to replace the traditional F10.7 index in more and more researches and applications. X-rays are important ionization source of the terrestrial D and E layer. Due to lack of enough observation to the D layer and versatile ionization sources of E layer, it is difficult to study the influence of X-rays to terrestrial ionosphere. The dominant ionization source for the secondary layer of Martian ionosphere is soft X-ray. This makes it possible to study the X-ray influence on the ionosphere. By studying the dependence of Martian ionospheric secondary layer peak density to E10.7, it is found that even after necessary corrections, the dependences are in disagreement for different data sets. After data and theoretical analysis, a new index Xs is introduced to represents the solar soft X-ray irradiance flux. After replacing E10.7 with this Xs index, the peak density dependences upon the solar irradiance are in good agreement for different data sets, indicating Xs index is a better measure of solar soft X-ray irradiance than E10.7 index.

Hu et.al.[61] using auroral observations at Zhongshan Station, Antarctica with a multi-channels scanning photometer, and Interplanetary Magnetic Field （IMF） and solar wind parameters observed by Wind Satellite at the upstream of the bow shock in 1997 and 1998, the dependences of the highlatitude postnoon auroral intensity upon solar wind-magnetosphere coupling functions are studied quantificationally. It shows that the intensity of the postnoon 630 nm emission is highly dependent on the solar wind electric field and the solar wind energy density flux, the postnoon auroral emission has larger correlation coefficients with the solar wind electric field functions than with the solar wind energy density flux functions, which is consistent with Liou′s result derived from images acquired by the ultraviolet imager on board Polar satellite. The dependences of 630 nm emission on the different solar wind electric field functions related to the clock angle are varied, which implies that the clock angle of the interplanetary field is also a very important factor on postnoon aurora. The dependencesof the postnoon auroral emission on solar wind-magnetosphere coupling functions and trans-polar potential functions are also studied. The intensity of the 630 nm emission depends on these functions more directly than that of the 557.7 nm emission.

Using the model of solar irradiance spectrum during large solar flare and MSIS, the electron production rate during flare over sun-lit boundary region is calculated by Zhang et.al.[62] It is found that during large solar flare the obvious increase of electron production rate over sun-lit boundary region occurs that, in turn cause the sudden increase of total electron content observed in this region. From the profile of electron production rate in different solar zenith angle, it can be seen that the largest electron production rate decreases with the zenith angle increasing and the heights of peak electron production rate increase. Calculation shows that the double peaks exist in the profile of electron production rate when the zenith angle less than 90° that correspond to ionospheric E and F region. Nevertheless, the peak value of electron production rate in F region is more larger than that in E region when zenith angle larger than 90°. Considering the feature of recombination of electron and ion in different ionospheric regions, it can be concluded that the sudden increase of total electron content observed by GPS mainly occurs in F region over sun-lit boundary region.

The data from the International GPS Service （IGS） are used to investigate the characteristics of the sudden increase of the ionospheric total electron content（QTEC） response to the solar flare (Shen et.al.[63]). Based on the methods of differential time delay and differential phase advance, research on the solar flare occurring on Oct. 28, 2003 indicated that the largest increase of the QTEC is 17. 7 TECU. When local solar zenith angle is larger than 40°, the increase of QTEC has inversely-proportional relationship to the solar zenith angle. The inversely proportional coefficient can be got by fitting. Compared with the solar flares on Oct. 29, 2003 and Nov. 4, 2003, the relationship between the inversely proportional coefficient and the increase of QTEC caused by the solar flares can be determined. Analyzing the spacial variation of QTEC, as a result, the spacial variation could be ignored while studying the QTEC temporal variation response to the solar flare.

5. Up-flowing ions and Ionosphere-Magnetosphere Coupling

A simulation study on the effects of particle precipitation on the polar ionosphere was carried out By Chen et.al.[64]. It was studied with the aid of a one-dimensional time-dependent ionospheric model self-consistently in the continuity, momentum and energy equations. With the model, flux tubes of plasma were followed in response to convection electric fields. The trajectories, which had been adopted to follow convecting plasma flux tubes was different from each other. When they convected through cusp region, the time that precipitating particle acting on the plasma flux tube was different. The result of simulation draw a conclusion that when the plasma flux tube stayed long enough in cusp region the electron density of ionospheric F layer would remarkably increase, while when the plasma flux tube stayed short in cusp region the electron density of ionospheric F layer would not remarkably increase. The other result was given by this paper from the other view. The assumption was that the precipitating electrons would act on a plasma flux tube, which convect through cusp region, or not. In the two situations the difference would come into being due to time transformation of electron density in the ionospheric F layer.

Based on a large dataset of ion drift velocity measurements board on DMSP satelhte, a study is made on the plasma bulk upflowing in the topside polar ionosphere. The emphasis is put on the storm-time changes in distribution of upflow occurrence and intensity versus MLT （mainly dawn and dusk） in comparison with that during quiet period, as well as the relationship between the ion upflow with the plasma convection and its shear (Huo et.al.[65]) . The results show that the storm-time occurrence frequency of upflow events is nearly two times higher than that during quiet period; the dawn-dusk asymmetry for occurrence frequency inversed from favoring duskside to favoring dawn-side. On an average, the storm-time velocity of the ion upflow in the dawn sector is larger than that in the dusk, with maximum upflowing velocity much larger than that in dusk sector. The ion upflow is closely related to the plasma convection and its shear, with strong upflow accompanied usually by large convection shear or abnormally large convection itself.

Shi et.al.[66] studied the FAC connecting the ionosphere and magnetosphere. The features of the Field Aligned Currents (FACs) distribution in the plasma sheet boundary layer are investigated. The current is calculated with the 4-point measurement of FluxGate Magnetometer (FGM) on board the Cluster in the period of July to October 2001. There are 172 FAC cases/events chosen for statistics. The results show that spatial distribution of the FAC has asymmetry in several aspects. The FACs occurrence is mainly Earthward in dawn side and is mainly tailward in dusk side. The FACs occurrence also has south-north hemisphere asymmetry.

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ADVANCES IN THE STUDIES OF THE MIDDLE AND UPPER ATMOSPHERE IN CHINA: 2004-2006

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Abstract

A substantial progress in the studies of the middle and upper atmosphere in China has been seen in the past three years. The primary achievements are outlined in five aspects, i.e. observational facilities, retrieval methods for remote sensing, mean flow and waves, stratospheric ozone and metallic layers.

Key words: Middle and upper atmosphere; observation; retrieval method; mean flow; wave; stratospheric ozone; metallic layers

1 Introduction

The "middle and upper atmosphere" is the region of our atmosphere extending roughly from 10 km altitude out to several hundred kilometers. This region is subject to long-term changes due to both man-made and solar variability effects. Compared with the lower atmosphere, the middle and upper atmosphere is not well-investigated. However, in the recent years, the science community has made many progresses in this field. Here referring to Chen et al.[1], we present the primary achievements made by Chinese scientists independently or cooperatively since 2004. The readers interesting in the previous advancements are suggested to read Chen and Chen[2].

Scientific requirements in this area include monitoring crucial parameters in the middle and upper atmosphere, monitoring inputs to the middle and upper atmosphere from space above and the lower atmosphere below; understanding atmospheric dynamic phenomena and developing models that correctly depict the processes important for coupling the middle and upper atmosphere with regions above and below; understanding atmospheric composition and photochemical processes. We organize the summarization around these requirements. The achievement of the first requirement relies on observational facilities and retrieves methods, the development and improvement of which are introduced in Section 2 and Section 3, respectively. Section 4 is devoted to the research progresses on atmospheric mean flow and waves. The production on the distribution and variation of the elementary atmospheric composition--stratospheric ozone, is given in Section 5. In Section 6, the outcome about metallic layers in the mesosphere is provided.

2 Observational facilities

Here, we introduce the newly established or improved observational facilities in China and their related academic outcome.

The development of two MST radars, one in Xianghe Observatory (39.6°N, 117.0°E) and the other in Wuhan (30.5°N, 114.4°E), is promoted by a national project funded by the Ministry of

Science and Technology of China, Observation Cluster of Monitoring Space Environment. The former is still under development while the latter has brought into test run. The specifications of these two MST radars have been given in Lu and Chen[3]. They are expected to put into operation with full function in 2008.

A Fe-resonance fluorescence/Rayleigh lidar and a Fe-Boltzmann temperature measuring lidar have been established in Wuhan University in 2004. A simple and fast alignment method is tested by the adjustment of the Fe-resonance fluorescence lidar system of Wuhan University and proved to be effective and convenient. The data from the adjusted lidar system can be used to retrieve the Fe-density profiles with fine spatiotemporal resolution[4]. The temperature profiles in the mesopause region over China can be retrieved by the data from the Fe-Boltzmann temperature measuring lidar. This is the first time that the mesopause temperature is observed in China. An upgraded Rayleigh lidar in Wuhan Institute of Physics and Mathematics has been put into service[5] and its data quality was evaluated by comparing with CIRA86 and HALOE/UARS temperatures. In 2006, A new sodium resonance fluorescence lidar is set up in University of Science and Technology of China[6]. It is expected that the observation campaign with the counterparts in Wuhan can provide us a lot of knowledge about the sodium layer. A Ca/Ca^+ resonance fluorescence lidar is also installed recently by Wuhan University. It has a large power-aperture product. Thus high-accuracy Ca/Ca^+ density profiles are expectably available.

During the past decade, the Xianghe Observatory underwent a substantial development. A series of observational instruments for the middle atmosphere have been setting up, including an MST radar, a Dobson spectrometer for O3, an all-sky imager for cloud detection, and a GPS-ozonesonde launching system. An all-sky imager was established in 2004[7], and its images can be used to analyze macro-scale cloud properties and cloud distributions quantitatively. In the end of 2005, the all-sky imager participated in a campaign observation conducted by Yangbajing Observatory in Tibet and its preliminary results were introduced in Huo et al.[8] Additionally, the GPS-ozonesonde technique was improved substantially[9,10] and continuous measurements of O3 profile up to 35-km altitude are carried through for more than 2 years in Beijing.

Generally speaking, many new facilities put into operation promise a bright and prospective future for Chinese middle and upper atmosphere researches.

3 Retrieval methods for remote sensing

More precise information can be acquired by better retrieval methods from the same observational data. The development and improvement of retrieval methods also concern the Chinese scientists in the field of the middle and upper atmosphere.

For satellite remote sensing, some new retrieval methods are put forward. A new retrieval method for the satellite remote sensing of global sodium during nighttime is proposed by Xu et al.[11] The sodium density is retrieved from satellite limb observations of ozone density, neutral temperature, and Na D-line nightglow volume emission rate. The theoretical study shows that, under the ideal condition of no measurement noise, the retrieval error in the main region of sodium layer is very small (less than 1%). Li et al.[12] introduce a space particle composition detector onboard the FY-1C satellite, and investigate the characteristics of the particle radiation in SAA (South Atlantic Anomy) according to the observed data and analyze the impact of solar proton events and magneto-storm on the particle radiation in the SAA. By using the data of n(He) observed at Perigees by AE-D satellite, Shen et al.[13] estimate the mean altitude of turbopause Z_t and its variations. By detecting the Doppler shifts of airglow (aurora) in the upper atmosphere, He et al.[14] and Tang et al.[15] propose a new method to derive winds, temperature and pressure of the upper atmosphere based on the Lorentzian profile. Wang and Lu[16] propose an improved algorithm to retrieve land surface temperature (LST) by GMS 5/VISSR thermal infrared data, which is called the single time/dual channels split-window algorithm.

Below we present some productions in the retrieval methods for the radio occultation measurements. Dual- and single- frequency inversion techniques, the geometric optics and full spectrum inversion methods, as well as the calibrated TEC inversion technique of the ionosphere radio occultation[17,18,19] are developed in Center for Space Science and Applied Research (CSSAR). A new technique monitoring the lower atmospheric environment, i.e. the mountain-based GPS radio occultation, is also developed in CSSAR[20]. Some new inverse methods to retrieve water vapor profiles in the troposphere from radio occultation measurements are also proposed[21,22].

Some studies are concentrated on the inversion algorithms from MODIS measurements. Tang et al.[23] propose an inversion algorithm to retrieve the optical depth of land aerosol and Earth's surface reflectivity by using jointly TERRA and AQUA MODIS measurements. Wang et al.[24] use MODIS global land surface temperature/emissivity products to calculate the surface long wave radiation of natural objects such as sand, soil, vegetation, etc.

4 Mean flow and waves

4.1 Mean circulation

The data of MF radars can be used to investigate the MLT mean circulation. The simultaneous observations of MLT winds with Wuhan/China and Yamagawa/Japan MF radars are compared to shed a light upon the longitudinal variations of the winds[25]. The longitudinal variations of atmospheric gravity waves forcing may contribute to the differences between the above two sites, as well as their small differences of their geographic locations. The mean flow characteristics can also be investigated by using satellite observations. The long-term mean characteristics of the zonal wind in the middle atmosphere over East Asia are studied by using the HRDI/UARS measurements[26].

4.2 MLT planetary wave type oscillations

Planetary waves are atmospheric oscillations with typical periods of about 2–30 days. Planetary waves such as the quasi 16-day waves in Wuhan are studied using the wind data from the Wuhan meteor radar and compared with those results at Adelaide[27]. Differences are found in wave amplitudes and time of appearance between the two years of 2002 and 2003. Using wind, ionospheric and geomagnetic intensity data observed simultaneously at Wuhan in 2002 and 2003, planetary wave type oscillations (PWTO) in the ionosphere and their relationship with oscillations in the MLT and geomagnetic intensity have been investigated[28]. Two cases of 2- and 5-day oscillations in the ionosphere are analyzed to distinguish MLT drivers and geomagnetic drivers.

4.3 Stationary planetary wave activity

In the recent year, the stationary planetary wave activities have been well studied. It is shown that the oscillation of two wave guides for the quasi-stationary planetary waves was closely related to Arctic Oscillation on the interannual timescale and this oscillation also appears on inter-decadal timescales[29,30]. Since the variability of both the stationary planetary wave activity and the East Asian winter monsoon is strongly associated with the thermal contrast between oceans and landmasses, Chen et al.[31] explore the interannual relationship between the monsoon and the wave activity. It is found that, compared to the winters of low wave activity, the equatorward propagation of planetary waves in the middle and upper troposphere is stronger in the high wave activity winters. During these high activity winters, the upward wave propagation from the troposphere into the stratosphere becomes weaker.

4.4 Atmospheric tides

The studies on atmospheric tides focus on observation research and numerical study. As for the former, Zhang et al.[32] study the spatial and temporal structure of mean winds and tide oscillations in the mid-latitude mesopause region using the data from the Wuhan/China MF radar in winter 2001. It is shown that the diurnal tide is the dominant tidal disturbance at mesopause in winter while the semidiurnal and terdiurnal components are respectively occasionally slightly strong and weak. The temporal variation of tidal amplitudes and their wave kinematical energies illustrates that there may be significant resonant interaction among the diurnal, semidiurnal and terdiurnal tides. By analyzing the same data set, Liu et al.[33] provide comprehensive and powerful observational evidence, e.g., frequency and vertical wavenumber correlation, bicoherence phase correlation and amplitude correlation, and connection between tidal amplitude time variations and height variations, for the tide-tide quadratic nonlinear interactions. Xue et al.[34] use canonical correlation analysis (CCA) method to investigate the mesosphere/low thermosphere (MLT) diurnal tidal winds during 2002 observed by a newly installed meteor radar at Wuhan. On the basis of the first year of neutral wind data measured by the Wuhan meteor radar, Xiong et al.[35] study the tidal structure in the MLT. A comparison of the observed diurnal tide with GSWM00 values shows their similar phase variations with height, but discrepancies in amplitudes. More data from the Wuhan meteor radar are used to investigate the seasonal variations of the tides and some similar results are obtained by Zhao et al[36]. They also investigate the climatology of the terdiurnal tide in the MLT region over Wuhan[37]. Moreover, the semidiurnal lunar tide in Wuhan and Adelaide[38] is compared based on measurements made by the Wuhan meteor radar and the Adelaide MF radar.

There are some outcomes in numerical study on atmospheric tides. Huang et al.[39] developed a 3-D fully nonlinear numerical model in spherical coordinates to simulate the linear and nonlinear propagations of the migrating diurnal and semidiurnal tides. Afterwards, they[40,41] provides the nonlinear quasi-steady solution of the migrating diurnal/semidiurnal tide, which differs from the GSWM-00 result in the MLT region. A quantitative analysis suggests that the main cause for the amplitude difference is the tide-tide and tide-mean flow nonlinear interactions. The comparisons with the GSWMs and some observations of tides suggest that the nonlinearity-induced tidal structure variation could be a possible mechanism accounting for some discrepancies between the GSWMs and observations. Furthermore, they[42] also present amplitude features of the terdiurnal tide excited by nonlinear interaction between the diurnal and semidiurnal tides. Their simulations show that: the migrating terdiurnal tide can be significantly excited by the nonlinear interaction between the diurnal and semidiurnal tides in the MLT region. Simultaneously, the diurnal and semidiurnal tides and the mean flow exhibit evident variations, indicating that the wave-wave and wave-mean flow interactions are the important cause of the tidal variability and background alteration.

4.5 Gravity waves

The achievements on gravity waves are also concentrated in observation research and modeling work. By using the OI and OH airglow observations obtained from the Adelaide three-field photometer, Ding et al.[43] present the 7-year statistical characteristics of the medium-scale gravity waves in the mesopause region. Wu and Xu[44] utilize horizontal velocity measurements observed from 19 chaff rockets and nearly simultaneous temperature measurements collected from 19 falling sphere rockets to study the cause of winter gravity wave spectrum saturation. They[45] also use the data from 64 chaff rockets to study the character and variability of motion spectra and to identify the mechanisms that contribute significantly to the gravity wave saturation.

Some researches by analyzing radiosonde observational data are presented as follow. Bian et al.[46] study the seasonal variation of inertia gravity-wave activity in the lower stratosphere based on the high vertical resolution radiosonde observations of Beijing Observatory. Time series of wave energy show that the largest wave amplitudes occur during the winter and the least during the summer. The background atmosphere and gravity wave activities in the TLS over Wuhan are statistically studied by using the data from radiosonde observations on a twice daily basis in the period between 2000 and 2002[47]. The results strongly suggest that at the observation site, dynamical instability (strong wind shear) induced by the tropospheric jet is the main excitation source of inertial gravity waves in the TLS. And then, gravity wave activities and background dynamical structure in the troposphere and lower stratosphere (TLS) over five stations at latitudes from 10°N to 40°N are statistically studied by using the Radiosonde observations[48]. The observational results indicate that the tropospheric jet is the most important excitation source for gravity waves both in the troposphere and lower stratosphere, and it plays different roles in determining the morphology of gravity waves in the troposphere and lower stratosphere. Further work is the statistical study of vertical wave number spectra of inertial gravity waves in the troposphere and lower stratosphere over six stations at latitudes from 20°N to 40° N[49]. It is found that the spectral characteristics seem to be independent of the local observation time, and the characteristic wave numbers of the spectra also show considerable consistency among the observations at different stations. In addition to the universal characteristics, the spectral structures also exhibit departures and variations, most of which are related to the strong tropospheric jets. Most recently, the radiosonde data obtained in Wuhan are used for studying the behaviors of inertia-gravity waves in the vicinity of the jet stream[50]. It is observed that the wave intensity has a similar seasonal variation with the jet stream intensity with a strong winter maximum and a summer minimum.

In the numerical studies on the dynamic processes of gravity waves, some satisfactory work has been done. By using a full-implicit-continuous-Eulerian (FICE) scheme and taking a set of basic atmospheric motion equations in spherical coordinates as governing equations, Zhang and Yi[51] establish a fully nonlinear numerical model for the dynamics of the middle and upper atmosphere to numerically study the nonlinear global propagations and amplitude growths of large-scale gravity wave packets. Their simulation demonstrates that Earth rotation has little influences on the wave energy propagations and amplitude growths while the primary nonlinear curvature terms play an important role in the growths of gravity wave amplitudes, causing an evident latitudinal dependence of wave amplitude growth. Afterwards, they[52] simulate the nonlinear propagation and evolution of resonant interacting gravity wave packets with small initial amplitudes in a compressible atmosphere. The numerical results show that a downward propagating gravity wave is excited by two up-going gravity waves initially due to the resonant interaction. During the whole nonlinear propagation and evolution, although the total wave energy for the interacting triad is almost conservative, obvious wave energy exchange among the three interacting gravity waves is observed. Wave energy tends to transfer from the wave with larger amplitude to that with smaller amplitude. Yue et al.[53] also present a numerical simulation of nonlinear propagation of gravity wave packet in three-dimension compressible atmosphere and find that: the increase of wave amplitude is faster than the exponential increase according to the linear gravity theory. Additionally, Yue and Yi[54] numerically study the propagation of the gravity wave packet into a mean wind shear. It is shown that the nonlinear effects modify the mean flow markedly, reduce the momentum and energy propagation velocity and drop the elevation of the critical level. The gravity wave packet becomes unstable and breaks down into smaller scales in some regions. Huang et al. [55] investigate the nonresonant interactions of gravity waves in a compressible atmosphere. The numerical results show that the nonresonant interaction of the gravity waves does occur, and an apparent energy exchange among the interacting waves can be observed, which indicates that the gravity waves with different spatial and temporal scales can extensively interact.

Some achievements on the photochemical-dynamical processes have been made in the most recent years. A linear and a nonlinear models are developed to study the response of the sodium layer to gravity waves[56,57,58]. The nonlinear photochemical-dynamical model is composed of 4 modules: a dynamical gravity wave model, a middle atmospheric photochemical model, a sodium layer photochemical model and an ionospheric (IRI) model. A comparison between the linear and nonlinear models displays that their main differences occur for sodium evolution near the peak and the bottomside of the sodium layer. For a large amplitude gravity wave, the nonlinear simulation of the sodium layer evolution is reasonable, while the linear simulation gives an unphysical solution at the bottom side of the sodium layer. Xu et al.[58] study the evolution of the sodium layer in the presence of an overturning (or convectively unstable) gravity wave using the nonlinear photochemical-dynamical gravity wave model of sodium layer and lidar observations. The model and observations indicate that the sodium density perturbation has a more pronounced overturning behavior in the bottomside of the layer than the topside of the layer. Xu and

Smith[58,59] apply the method of the eigenvalue and eigenvector analysis (EEA method) to analyze the photochemical timescale of the sodium layer chemical system to perturbations. This method determines a lifetime that is an excellent estimate of the relaxation time of the sodium chemical system. Their results show that the timescales of three important sodium species, Na, Na^+ and $NaHCO_3$, vary strongly with altitude and are significantly different during day and night. Furthermore, a time-dependent, nonlinear, photochemical-dynamical 2-D model, composed of 3 models: dynamical gravity wave model, middle atmospheric photochemical model and airglow layer photochemical model, is developed[60]. The model is used to study the effect of the gravity wave propagation on the airglow layer.

5 Stratospheric ozone

Modeling and observation are the primary methods to study the distribution and variation of stratospheric ozone. As for the modeling work, Yang and Brsaaeur[61] assess the impact of odd chlorine (Cl_y) and odd nitrogen (NO_y) perturbations (resulting from human activities) and of enhanced H_2O-H_2SO_4 aerosol load (associated with volcanic activity) on stratospheric ozone (25 km altitude, midlatitudes) by using a chemical box model in which key heterogeneous reactions on the surface of sulfate aerosol particles are taken into account.

Compared with modeling work, more efforts are put into observation research. Wang and Yang[62] use a similar method to study the nonlinear response of lower mid-latitude stratospheric ozone to NO_x and ClO_x perturbations and surface area intensity of sulfate aerosol. By using the TOMS data, Zhou and Chen[63] show that in summer an ozone low center also exists over the Iranian Plateau, and the vertical distributions and variation characters of ozone over the Iranian Plateau were discussed along with the analysis of those over the Tibetan Plateauozone by using the TOMS, HALOE and SAGE II data. In Zhou et al.[64], main results concerning ozone over the Tibetan Plateau in the last decade were reviewed. By using the ozone sounding data at Lin An, Kun Ming, and Hong Kong, Zheng et al.[65] study the vertical distributions of ozone at these three sites. Using the same data, Wang et al.[66] analyze the multi-layer structure in the ozone vertical profiles in Spring of 2001 at Kun Ming. The heterogeneous structure of ozone partial pressure profile is also studied by Wang et al.[67]. Zou et al.[68] use the merged TOMS/SBUV ozone data for 1979–2002 to analyze the zonal distribution of ozone variations between 50° and 60°N, the seasonal cycle and trends, and the responses to the solar cycle, quasi-biennial oscillation (QBO), El Niño-Southern Oscillation (ENSO) and Arctic Oscillation (AO). Bian et al.[69] analyze the difference of total atmospheric ozone between TOMS data from Earth Probe satellite and ground-based measurements and an unusual discrepancy between them is found in 2002-2003 in nearly all the stations at the middle latitudes in the Northern Hemisphere. By analyzing the total ozone data from TOMS and ground-based observations, they[70] also find that a large area with extremely low ozone occurs over the Tibetan Plateau during December 14-17, 2003. It is the first time that an ozone mini-hole or an extremely low ozone event is found to occur over the Tibetan Plateau.

6 Metallic layers

The built Na and Fe resonance fluorescence lidars provide us the possibility to study metallic layers in the height range of 80-110 km. Since 2002, some efforts have been made in this field and some characteristics of the mesospheric Fe and Na layers have been revealed[71]. Here we only present the work since 2004. Wan and Yi[72] calculate the chemical lifetime of the mesospheric ferrum and sodium layers using the EigenAnalysis (EA) method. Afterwards, Li and Yi[73] analyze the process of the ablation of meteoroid which radius is less than 100 μm by adopting a continuous evaporation model of micro meteoroid, and the impact on the metallic layer in mesosphere is estimated. In 2007, Yi et al.[74] study the relationship between sporadic Fe (Fe_s) and Na (Na_s) layers through simultaneous and common volume Fe and Na lidar observations using the data from the Wuhan Na-resonance and Fe-resonance fluorescence lidars. 62% of sporadic layering events are characterized by the simultaneous formation of Fe_s and Na_s layers and their most prominent feature is that the Fe_s and Na_s layers occurred in overlapping altitude ranges and moved following almost the same track. These observational results strongly suggest that Fe_s and Na_s layers are formed via the same or very similar mechanisms. Moreover, the undersides of the normal Fe and Na layers follow nearly the exact movements and occur at nearly the same altitude. The nearly persistent underside overlap strongly suggests that on the undersides of these meteoric metal layers there exist some sink mechanisms leading to the concurrent removal of different sorts of free neutral metal atoms.

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DEVELOPMENTS OF GEOMAGNETIC OBSERVATIONS AND STUDIES IN CHINA DURING 2003-2007

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Abstract

The advances of geomagnetic science in China during the period of 2003-2007 is summarized in following aspects: China Meridian Chain of Magnetometers (CMCM)，magnetic survey and compilation of magnetic charts for epochs of 2000 and 2005, the main magnetic field and regional anomaly, magnetic field origin, spatial and temporal characteristics of variable magnetic field and their relationship with solar activity and interplanetary disturbances, and possible correlation between magnetic variations and earthquakes.

Key words: Geomagnetism, Earth’s magnetic field, Main magnetic field, Variable magnetic field, China Meridian Chain of Magnetometers (CMCM), seismomagnetic effect.

1. Intruduction

The magnetic field is one of important properties of the Earth. The main magnetic field originates from hydromagnetic processes in the liquid outer core. In addition, the configuration and secular variations of the main field are largely dependent upon the thermal structure and dynamic processes in the mantle and the core-mantle boundary. Various types of transient variations in the Earth’s magnetic field are caused by currents in the solar-terrestrial system (mainly in the ionosphere and magnetosphere), which are correlated with space weather, especially, disastrous events. Consequently, the Earth’s magnetic field includes important information on the Earth’s interior and space environment.

In this paper the researches in geomagnetism carried out in China during 2003-2007 are briefly summarized in several respects, including magnetic survey and regional magnetic chart compilation, the project of meridian chain of magnetometers, the main magnetic field and its secular variations, the origin of the Earth’s magnetic field and geodynamo, geomagnetic transient variations and their connection with solar activity . Besides, the studies on possible relationship between magnetic variations and earthquake occurrence are also summarized.

2. China Meridian Chain of Magnetometers (CMCM)

More than one hundred magnetic stations are routinely operating in China, among which 15 observatories are assessed as the “first class” stations, they are Beijing, Sheshan (in Shanghai), Lanzhou, Wuhan, Guangzhou, Changchun, Ulumuqi, Manzhouli, Quanzhou, Chengdu, Tonghai, Lahsa, Kashi, Qiongzhong, and Geermu. In the second class there are 19 stations. The data from these observatories have been submitted to World Data Center A in Boulder, USA for international exchange. In addition, there are two permanent stations, Great Wall station and Zhongshan station, operating in Antarctica.

During the 22nd and 23rd solar cycles, the data from these magnetic stations played an important role in studying solar-terrestrial coupling. On the basis of these studies, Chinese scientists proposed a comprehensive project for establishing a system of space environment monitoring.

After more than 10-years preparation, the China Meridian Chain of Magnetometers (CMCM) started to operate. It is a part of the China Meridian Chain Project for Monitoring Space Environment, or shortly “ZIWU” Project (“ZIWU” means meridian in Chinese).

The CMCM includes 9 magnetic observatories along 120°E longitude, starting from Mohe station, the most northern station in China, through Changchun, Beijing, Zhengzhou, Wuhan, Shaoyang, Guangzhou (Zhaoqing), Qiongzhong to Hainan, the most southern station. Moreover, the chain is actually extended to Chinese Zhongshan Station in the Antarctica. In this project are included other two stations at 30°N latitude, Shanghai (Zose) and Chengdu, which, together with the 9 meridian stations, form a crosswise station array.

The stations of the CMCM are equipped mainly with ground-based instruments and networked as a system to coordinately monitor a variety of processes in space environment, especially, during the period of disturbances.

The main task of the CMCM is to continuously record magnetic field variations at mid-low latitudes from the subauroral zone to the equatorial anomaly zone. In addition, the CMCM will accumulate historical data which are necessary supplements for space weather researches. These historical and modern data are used to study and understand the physical mechanism of solar wind-magnetosphere-ionosphere coupling responsible for space weather processes, and to develop regional/global cause-effect models for diagnosing space weather environment. These data are also applied to routine forecasting and nowcasting of space weather events, such as magnetic storms and substorms.

Cooperating with other magnetic meridian chains existing at high latitudes and mid-low latitudes, we have a worldwide network of magnetic stations, continuously monitoring global magnetic activity.

Extending to the western hemisphere, the CMCM connects with magnetic stations around 60°W longitude, forming a closed circle of stations. This international complete meridian chain will greatly enhance the ability of space environment monitoring.

At the initial stage of the CMCM, the existing instruments at the chain stations keep in operation, their performance is going to be improved, and some new instruments will be equipped very soon.

On the basis of the meridian chain data, several research programs have being carried out, such as magnetosphere-ionosphere-thermosphere coupling processes and their responses to solar wind storms, equatorward and poleward transportation of mass, energy and momentum injected into geo-space during space weather events, global 3D semi-empirical background (quiet) model for space environment, time-varying cause-effect model for space weather events, and relationship between regional and global models.

3. Magnetic survey and compilation of magnetic charts for epochs of 2000 and 2005

Magnetic field survey and surface field charting have been a routine work in major nations of the world since the early days of global exploration.

The seventh generation of ChinaGRF for the epoch 2000 was compiled on the basis of data from the magnetic survey carried out during 1998-2001 at 119 repeat stations, 39 permanent observatories. In addition, 20 grid values of the IGRF 2000 are used for improving boundary condition.

In order to compile the eighth generation of China-GRF for 2005, an extended magnetic survey was carried out at a relatively denser network in resent years. In addition, GPS (Global Positioning System) technique was used to positioning of repeat station (longitude, latitude and elevation) and azimuth measurement of the reference mark for determining declination [Gu et al., 2005]. The statistical results of the GPS data at 135 stations indicate that the difference between 2 GPS azimuth measurements is 0.0"~ 5.9" at various stations with an average 1.6", showing accurate and reliable azimuth measurements by GPS. The standard deviation of declination *D* thus obtained based on the GPS azimuth measurement is less than 0.4’.

The magnetic chart compilation, instead of a mere collection and organization of data, concerns many aspects of geomagnetism: selection and reduction of data, estimation and analysis of error, assessment and comparison of methods, establishment and choice of mathematical models, and evaluation of final results. The magnetic charts are essential base for studying magnetic field source and secular variation. Different users need different kind of magnetic charts and models, but what has to be commonly considered in chart compilation is (1) physical reasonableness, (2) accurate values, (3) complete information, and (4) convenience in use.

4. Studies on the main magnetic field and regional anomaly

4.1 Structure of the main magnetic field represented by IGRF model

Wang [2003] analyzed the distribution of the IGRF in China continent, and compared with the observations at 29 observatories in this region. His result shows a root-mean-square error of 146.9nT.

As an alternate type of IGRF model, a NOC model of the main field is established by Xu [2003], using the method of Natural Orthogonal Components (NOC) in analysis of the Earth’s main magnetic field IGRF 1900-2000. The eigen modes of the field are first calculated from the Gauss coefficients of IGRF 1900-2000. And then the magnetic field for each epoch is expanded in a series of the basic eigen mode family. Finally, the intensity coefficients are calculated for each of the eigen modes. Test of the convergency and stability of the NOC model shows that the NOC model has very short series and much rapid convergency in comparison with the conventional spherical harmonic models of IGRF. Comparison of the eigen modes obtained from different IGRF model groups indicates that the low-degree eigen modes are rather stable, whereas the high-degree modes show relatively large variability. An interesting relationship is found between the spatial structure of the main field and its secular variation.

4.2 Secular variation of the main field

Secular variation (SV) is the dynamic characteristics of the main magnetic field, which bring the convection flow and dynamo process in the Earth's core to light.

Although the main magnetic field **B** and its secular variation ($\dot{\mathbf{B}}$-field), originate from the same dynamo process in the outer core, their spatial structure and temporal behaviors are drastically different. Using 'globally averaged unsigned annual rate', $\overline{\dot{X}}$, $\overline{\dot{Y}}$, $\overline{\dot{Z}}$, $\overline{\dot{H}}$, and $\overline{\dot{F}}$, to express the magnitude of the $\dot{\mathbf{B}}$-field, Xu [2006] studied periodicity of the $\dot{\mathbf{B}}$-field. The results show that the $\dot{\mathbf{B}}$-field experienced a three-episode variation during the centennial period from 1900 to 2000. The maximum annual rates occurred respectively around 1910-1920, 1940-1950, and 1970-1980, showing a 30-year period. The governing factor of this periodic variation is proved to be the non-dipole field (mainly the quatrupole field, n=2), instead of the dipole field, although the dipole field is dominative over all other multipoles in the main field.

Important role of the quatrupole part of the non-dipole field in secular variation of the main field is also noted by Wang's analysis [2004]. It is pointed out in his paper that the quadrupole field is the most significant contributor to the geomagnetic secular variation in 20th century.

Continuous decrease in the dipole moment of the main field is a well established fact. Wang [2004], using IGRF models, analyzed characteristics of the dipole declining, and then compared the features of the secular variations in China and for globe.

The secular variations are dependent not only on low-degree harmonics in the main field, but also on the high-degree harmonics. The effects of the unusual behaviors in high-degree Gauss coefficients of IGRF 1945-1955 on the secular variation are studied by using the eighth generation of IGRF [Xu, 2003]. By comparing the original and the revised IGRF models，the errors in the high-degree coefficients are estimated and corrected. Since the magnitudes of high-degree terms increase rapidly with increasing depth, these errors will distort greatly the magnetic field configuration and magnetic energy distribution in the deep interior. Significant effects are also expected in the calculation of the liquid flow pattern at the outer core surface and in the geomagnetic estimation of the core radius.

A comparative analysis of global and regional secular variations is conducted by Xu [2004].

On the basis of the magnetic survey data during 1998-2001, the China Geomagnetic Reference Field Secular Variation model for 2000, China-GRF-SV2000, is established. The model shows a slow and smooth variation of the magnetic field in China area. The unsigned average annual rates are 12.2 nT/a, 8.2 nT/a, 43. 8 nT/a, 11.8 nT/a, 0.96 ’/a, 2.99 ’/a and 22.4 nT/a for seven elements *X, Y, Z, H, D, I* and *F*, respectively. These rates are less than the global rates of IGRF by 1/2 to 1/3. The variations of different elements shows an unified SV pattern in China: the north geomagnetic pole is moving to China, or China is moving toward high latitude at a rate $3'/a$. In addition, the variation of declination D shows that the contrast of *D* between Eastern and Western China is enhanced. As a comparison and test, The 8-th generation of the International Geomagnetic Reference Field (IGRF) models is analyzed. The global SV estimated by IGRF models shows similar characteristics compared with ChinaGRF-SV2000, although the annual rates of IGRF-SV are greater than those of ChinaGRF-SV, and some regional (or local) anomalies are noted.

The rapid convergence of NOC series of the main field suggests an approach to raise the truncation level in historical magnetic field models. Assuming that a historical model with a low truncation level for an epoch just prior to 1900 consists of the same eigen modes as those for 1900-2000, one can derive the additional high-degree Gauss coefficients by means of solving a linear equation system. In this way a little longer model series with a common truncation level $N = 10$ is obtained. Considering the time variation of the eigen modes, the NOC analysis is carried out for this longer model set, when we analyze the field model of next earlier epoch. In this progressive way a set of geomagnetic field models with $N = 10$ can be generated backward to 1550 [Xu, 2003].

4.3 Regional magnetic anomalies

The Eurasian magnetic anomaly is an important feature of the non-dipole part in the main magnetic field, which controls the overall configuration of the regional magnetic field in China. On this large-scale anomaly background are superposed some regional and local anomalies, among which the most dominant ones are the negative Tibet anomaly and the positive Tarimu anomaly.

In resent years, many of the researches made by Chinese were focused on construction and analysis of regional magnetic models for the Eurasian anomaly and for smaller regions in this anomaly. Both spherical cap harmonic model and Legendre polynomial model have been established by means of MAGSAT data and have been widely used to explain the tectonic significance of Tibet and Tarimu anomalies.

On the basis of the data from the present and historical magnetic surveys, An [2003a,b] established a set of spherical cap harmonic models of China magnetic field for 1936-2000 with truncation level n_{max}=8. The standard deviations of these models components are 93.1-128.9nT, 74.8-98.1nT, and 107.5-137.7nT for X, Y, and Z, respectively. These models fairly well illustrate basic features of the magnetic field in this area. A similar model for 2005 is established by Gu et al [2005]. In addition, spline function is also used to modeling regional magnetic field by Gao et al. [2006].

For studying more detailed structures of some regions in China, Gu et al [2004] established a spherical cap harmonic model for the Beijing-Tianjin-Hebei area, on the basis of magnetic data from the survey during 2002-2003. These results can be applied in geological explanation. In the further small spatial scale, information on aeromagnetic anomalies is used to estimation of the Curie point isotherms [Hu et al., 2006].

In determining regional or local magnetic anomalies, the choice of the normal background field is critical. Gao et al [2005] chose two normal fields, one of which is the IGRF, another is Taylor polynomial model for China area, and then respectively calculated the residual fields. The results show that the different normal fields have no essential influence on the overall pattern, although it causes different base values.

5. Dynamic state in the core and magnetic field origin

The westward drift of the non-dipole field is the most important feature in secular variations of the main field, which shed light on fluid flow pattern in the core. The latitudinal dependence of the westward drift is examined by Wei and Xu [2003]. The study reveals the characteristics in the differential rotation of the main field. The results show that the global geomagnetic field drifts westward with an average speed $0.18°/a$ during 1900--2000. The westward drift rate is not symmetrical with respect to the equator. The maximum westward drift rate, $0.31°/a$, occurs at the latitude $\varphi = -15°$, forming a Rapid Westward Drift Belt (RDB) around this latitude. Going northward and southward from this belt, the drift rate decreases and reaches the minimum ($0.12°/a$) at $\varphi = 50°$ and the minimum ($0.14°/a$) at $\varphi = -56°$, forming a Northern Hemisphere Slow Westward Drift Belt (N-SDB) and a Southern Hemisphere Slow Westward Drift Belt (S-SDB). Three phases can be detected in the evolution of the westward drift. In the first phase (1900~1940), the RDB dominates the global drift pattern. The westward drift in this belt is much faster than other areas. In the second phase (1940~1960), the drift rate in the RDB was less than the first phase, while the drifts in the N-SDB and S-SDB were relatively large. In this phase, the differential rotation became less obvious. In the third phase (1960~2000), the westward drift in the RDB increased again and the differential rotation gradually became apparent.

6. Observation and study of transient magnetic variations

Transient variations in the Earth's magnetic field arise from the currents in the ionosphere and magnetosphere, as well as induced currents in the Earth's interior. Consequently, their characteristics depend on both near-Earth space environment and electromagnetic properties in the Earth.

The transient variations include various types and cover a broad frequency spectrum from 11-year solar cycle variation to short period pulsation. Separation of different components in a complicated event is very important to explain physical process and understand physical mechanism.

A technique for separating different components, called “three-step separation”, is developed by Wu et al. [2007]. They used three methods to successive steps: using method of Natural Orthogonal Components (NOC), as the first step, to decompose the storm-time UT-variation (*D*st), and then using correlation analysis, as the second step, to separate disturbance-daily variation (S_D) , and finally, using Fourier analysis to determine solar daily variation (*S*q). Examination of twenty five magnetic storms shows flexibility of this technique. The results reveal characteristic evolutions of the ring current, *Sq* currents and S_D currents.

Magnetic pulsations are considered as a manifestation of ULF wave in the magnetosphere and ionosphere. Du et al. [2003] analyzed Pc5 pulsations during a storm, using ground observations at 22 stations in IMAGE chain. The results show that in initial and main phases of the storm, the principle frequency of PC 5 ULF wave increases with decreasing latitudes. In addition, the principle frequency in the main phase is lower than those in initial and recovery phases. The injection of heavy ions into the ring current during main phase seems to be responsible for these features.

Prediction of magnetic storms and substorms is one of important fields in geomagnetic studies. A routine forcasting and nowcasting of space environment, including magnetic activity, is carried out by several institutions. Various analysis methods and techniques, such as MNOC, linear prediction filtering, neural network, and close degree analysis, are applied in prediction practice, [Wang and Feng, 2006].

7. Exploration of seismomagnetic effects

Geophysicists have long been searching for precursors or harbingers of earthquake occurrence, or more generally, for correlation between the seismic activity and other phenomena. The searches cover very wide fields and many phenomena, including magnetic field variation. Some types of anomalous variations in the geomagnetic field are considered as possible earthquake precursors, being potentially useful for earthquake prediction. This idea leads some researchers to find out the physical connection between earthquakes and magnetic field variations.

Seismomagnetic effects have been extensively studied in recent decades since the great Tangshan earthquakes occurred in northern China in 1976. Most of studies are focused to VLF-ULF signal emission, magnetic storms and abnormal Sq, that is quite different from those conducted at the early stage.

An anomalous emission of ULF signals prior to the great Hotan earthquake (M_L=7.1) in northwestern China on Oct. 19, 1996 is studied by Du et al. [2004]. Three types of ULF anomalies were observed prior the earthquake: drift of the dynamic zero, special orientation of the major axis of the polarization ellipse, and large amplitude of ULF wave. A simplified model of a vertical electric dipole is proposed for explaining the ULF wave anomalies.

Wavelet analysis technique is used by Li et al. [2006] to study precursor prior Zhangbei earthquake (M_s=6.2) occurred at northern China on Jan. 10, 1998. It is found that abnormal frequency structure of Z component appeared before the earthquake, although no similar anomalies were detected in H and D elements.

In addition, some interesting anomalous phenomena in the geomagnetic field and ionosphere have been detected before, during and after earthquakes, typhoon, and volcano eruptions [HaoYong-Qiang et al., 2006, Xiao et al., 2007].

It should be emphasized that the associations between earthquakes and magnetic field variations are still open, although some people claimed that they have definitely found reliable evidences showing a cause-effect relationship between earthquakes and magnetic field variations.

Acknowledgement. This paper is supported by the grant (40436016) from the National Natural Science Foundation of China and the KIP pilot project (kzcx3-sw-144) of the Chinese Academy of Sciences.

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