A critical review on solar cycle variation of interplanetary magnetic flux ropes

*Katsuhide Marubashi[1]

1.Asia Space Environment Research Consortium

The interplanetary magnetic flux rope (IFR) has been a subject of extensive research activity since its discovery in 1981 as a key structure in the solar wind that provide important information on the solar eruption phenomena and on how the southward magnetic fields are carried from the Sun to the Earth. In this review, we discuss solar-cycle variation of occurrence frequency of IFRs that still remains unsettled, based on our own results. First, we have found more than 500 IFRs in the time period from 1995 to 2009, whereas the survey by Lepping et al. (AnnGeo, 2006) identified 82 IFRs during 1995-2003. The difference mainly comes from the fact that their survey was not successful in identifying IFRs when the spacecraft passed only near the surface of IFRs. Our result indicates that the rate of IFR occurrence to the ICMEs should be much higher than those which were suggested by previous evaluation. Secondly, the following trend is clearly seen: namely, the occurrence rate of IFRs increases rapidly after the 1996 solar minimum, reaches maximum in 1998, and then decreases monotonically toward the next solar minimum. This trend seems in concert with the trend of the magnetic butterfly diagram (Hathaway, http://solarscience.msfc.nasa.gov/images/magbfly.jpg). The time of rapid increase of IFR rate coincides with the time when the active regions begin to emerge at mid latitude (Li et al., Solar Phys., 2011). In addition, Marubashi et al. (Solar Phys. 2015) found that 2/3 of IFRs were erupted from neutral lines at the Hale boundaries, using another data base. An important implication is that the IFR occurrence should be closely related with the evolution of large-scale solar magnetic fields. An interesting question arises also: how the Hale boundaries are preferably selected for any instabilities to occur that lead CMEs. In a more general term, interrelationships among the occurrence of IFRs, CMEs, flares, and sunspot cycle seem to be an unsettled problem.

Keywords: coronal mass ejection, solar-cycle variation

Formation of a Quadrupolar Active Region Producing a Magnetic Flux Rope

*Yoshiaki Oi[1], Takaaki Yokoyama[1], Shin Toriumi[2]

1.Graduate School of Science, The University of Tokyo, 2.National Astronomical Observatory of Japan

It is suggested that most of the largest flares in the Sun are produced in active regions hosting delta-sunspots (Sammis et al., 2000). The formation process of delta-sunspots is not clearly understood but some of them may be formed by the merging of two beta-sunspots, which produces a quadrupolar active region. Toriumi et al. (2014) showed that the quadrupolar active region was successfully reproduced in their MHD simulation only when the two merging bipoles were magnetically connected with each other in the convection zone. Toriumi et al. (2014) aimed at reproducing an active region similar to an observed one, NOAA AR 11158, which had produced several flares including one X-class event. However, no flux ropes or eruptions were found in their simulation. Therefore, in this work, we aim to propose a theoretical model which produces not only the quadrupolar active region but also the magnetic flux rope. As a result of MHD simulation, we succeeded in reproducing a flux rope above the polarity inversion line as a consequence of an emergence of a flux tube from the convection zone. Also we found that the flux rope could reach the upper boundary when reconnection-favored coronal magnetic field was introduced above the developing active region. In this presentation, we will discuss the formation process of the flux rope and physical conditions for its ascent.

Keywords: Sun, Flares, Sunspots

Studies on homologous flares at quadrupole magnetic field using force-free field modeling

*Yusuke Kawabata[1,3], Satoshi Inoue[2], Toshifumi Shimizu[3,1]

1.Earth and Planetary Science, The University of Tokyo, 2.Max-Planck Institute for Solar System Research, 3.Institute of Space and Astronautical Science, JAXA

Solar flares are known as abrupt energy release events by magnetic reconnection. The standard 2D model of solar flares, which is called CSHKP model, explains large eruptive flares well. We analyzed three M-class flares occurring on 2 February 2014, which are difficult to understand with the CSHKP model. Our investigations primarily focused on the 3D coronal magnetic field structures formed in the flaring region for attempting to understand why three similar flares (labeled flare 1, flare 2, and flare 3, respectively) are successively produced in the region.
Four flare ribbons were observed at the footpoints of three flaring structures by Atmospheric Imaging Assembly aboard the *Solar Dynamics Observatory*. The observed flare ribbons and coronal flaring structures show similarity in the three flares, which are called homologous flares. The flare ribbons were located in the four magnetic regions (P1, P2, N1, and N2) at the solar surface. We derived the three dimensional magnetic field configuration using force-free field modeling with *Hinode*/Spectropolarimeter data. We used the squashing factor defined by Titov (1999) to identify the location of quasi-separatrix layers, i.e., QSLs. The magnetic field lines from the force-free field modeling give fairly good correspondences among many bright flare kernels in the flare ribbons, although we still need to improve the modeling fidelity. The magnetic field lines rooted on the flare ribbons forms the three-dimensional quadrupole magnetic configuration with an X-shape separatrix structure in the upper atmosphere.
The region of the highest squashing factor is located at the height of 2000~3000km from the photosphere, suggesting that the magnetic reconnection may take place at the lower atmosphere. The magnetic flux in the N1 sunspot appears to be highly twisted, because the QSLs structure derived with the assumption of the potential field is completely different from what obtained with 3D magnetic field configuration from the NLFFF modeling. The QSLs structure derived with the NLFFF results for the SP data taken one day before the occurrence of flare 1 is different from that derived with the data taken one hour before flare 1. This indicates that the QSLs structure was formed during the day due to the emergence or the transverse photospheric motions of the magnetic flux in N1. The temporal evolution of magnetic flux suggests that both the existence of emerging activities and the conversing motions in and around the N1 sunspot region. Focused on homology and differences in the flares, although the spatial distribution of the flare ribbons is similar to each other in the main period of the flares, there is a little difference in the temporal evolution of X-ray flux. Such a difference might attribute to the difference in triggering the onset of these flares. Flare 1 occurred after the occurrence of another flare event at the east side of the flare 1 region, while flare 2 occurred after the upward motion of a dark material. This may indicate that the magnetic field shows a similar topology, but the trigger mechanism can alter the temporal behaviors of the energy release.

Keywords: Solar flare, Magnetic reconnection

Double Arc Instability in the solar corona

*Naoyuki Ishiguro[1], Kanya Kusano[1,2]

1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Japan Agency for Marine-Earth Science and Technology

The stability of flux rope in the solar corona must be related to the occurrence of solar flares and coronal mass ejections (CMEs), which are primary cause of solar weather disturbance. Torus Instability (TI) was recently proposed by Kliem & Toeroek (2006) as the cause of solar eruptions. However, how the instability can be initiated is not yet well understood. On the other hand, one of the most likely scenario for the process causing unstable flux rope is the tether-cutting reconnection suggested by Moore et al. (2001). This scenario suggests that magnetic reconnection between sheared magnetic fields forms a double-arc loop which can erupts. However, the stability of double-arc loop was not analyzed yet.
The objective of this study is to analyze the stability of double-arc loop theoretically. We model double-arc electric current loop using two circular tori connected each other, and numerically calculate the stability of it. As the result, we found that the double-arc current loop can be destabilized even if the external field is uniform in contrast to the TI. The results indicate that the Double-Arc Instability (DAI) is different from the TI. The decay index which is used as a criteria for TI is not applicable to DAI. Furthermore, we found that in order to make the DAI the twist of magnetic field line must be larger than one-half. We also show that the growth of DAI is similar to the observation of flux eruption. These results indicate that the DAI caused by the tether cutting reconnection is a possible scenario, which can well explain how solar eruption can be triggered.

Keywords: Sun, solar flare, instability

Continued Operation of Nobeyama Radioheliograph by the International Consortium (ICCON)

*Satoshi Masuda[1], Kiyoto Shibasaki[1,2], Nat Gopalswamy[3], Yihua Yan[4], Kyung-Suk Cho[5]

1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Solar Physics Research Inc., 3.Goddard Space Flight Center, NASA, 4.National Astronomical Observatories, Chinese Academy of Sciences, 5.Korea Astronomy and Space Science Institute

Nobeyama Radioheliograph (NoRH) is a radio interferometer specially designed to observe the full disk of the Sun at 17 and 34 GHz. Eighty-four antennas with a diameter of 80 cm were installed along a T-shape baseline (North - South: 250 m, East - West: 500 m). The spatial resolution is about 10 arcseconds and 5 arcseconds in 17 GHz and 34 GHz, respectively. The time resolution of NoRH is typically 1 second and 0.1 second for the event mode. NoRH continuously observes the full sun for about eight hours (22:45 - 6:30 UT) every day. The system has been quite stable and NoRH data are available in the period more than 99 % out of the total possible operational window.
The National Astronomical Observatory of Japan (NAOJ) has successfully operated NoRH during these two decades. From April 2015, the Solar-Terrestrial Environment Laboratory (now the Institute for Space-Earth Environmental Research), Nagoya University started the operation of NoRH as a representative of the International Consortium for the Continued Operation of Nobeyama Raidoheliograph (ICCON; http://hinode.stelab.nagoya-u.ac.jp/ICCON/). The current ICCON representatives are N. Gopalswamy (NASA), Y. Yan (NAOC), K. S. Cho (KASI), M. Ishii (NICT), K. Shibasaki (Nagoya University and Solar Physics Laboratory) and S. Masuda (Nagoya University).
In addition to the core members of this consortium, about 30 researchers collaborate the operation of NoRH. Among them, one chief observer is assigned to check the health of the instrument/computers and to verify the data quality every day. These daily tasks can be done via internet from a remote site. This system also works very well for the first one year.
NoRH data are automatically transferred from the observational site (Nobeyama) to Solar Data Analysis System (SDAS; http://hinode.nao.ac.jp/SDAS/index_e.shtml) of NAOJ at Mitaka, and then all of them are automatically mirrored to Hinode Science Center at Nagoya (http://hinode.stelab.nagoya-u.ac.jp/index.shtml.en). Any researcher registered in either system can access all of the NoRH data. The software for the data analysis is supplied as a part of the solarsoft (IDL-based software system mainly maintained by Lockheed Martin Solar and Astrophysics Laboratory) and distributed via internet.

Keywords: Sun, radio

Calculation of solar rotation rate using the magnetic field observation, and its long-term variation

*Masashi Fujiyama[1], Shinsuke Imada[1], Shinobu Machida[1]

1.Institute for Space-Earth Environmental Research

Space environment around Earth have been influenced by solar wind that is plasma which is released from the Sun. The plasma is explosively released by phenomena such as solar flare and CMD, and that exerts a huge damage to our planet and artificial satellite. This is called solar storm. In addition, the entire change in the solar wind is called space weather that has been studied in a variety of fields. There is a study of solar activity mechanism in one of the Solar-Terrestrial Environment prediction research.
The Sun it is known that the magnitude of the activity varies 11 year cycle. When activity is strong, it is called the maximum. Opposite, when weak, it is called the minimum. Along with it also varies the strong of solar wind occur many solar storms during the maximum phases. In addition it is reported that magnitude of the activity is different in every cycle. It is known that there is a correlation in the intensity of pole magnetic field and the solar activity in the next cycle when solar minimum period. So, knowing the pole magnetic field of the current minimum period is useful to predict the next solar cycle.
In this study, determine the parameters from solar magnetic field observation by the solar observation satellite SDO/HMI. The parameters (such as differential rotation, meridional flow and turbulent diffusion coefficient) are important for surface flux transport model calculations. We have developed a module that calculates the parameters of the sun from observed data by two differential ways (Local Correlation Tracking (LCT), Magnetic Element Tracking (MET)), using the actual data analysis. Compare the results to be estimated by LCT and MET, discussing about the differences and characteristics obtained two ways. Further, by analyzing the data up to now from launched (about 6 years), we report the results of consideration for long-term variation of the three physical parameters in the sun.

Keywords: Sun, Magnetic field observation, Rotation rate, Meridional flow

The role of η-quenching in MHD flux transport dynamo

*Chiaki Ichimura[1], Takaaki Yokoyama[1]

1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo

“Flux-transport dynamo” (FTD), which is one model of the solar dynamos, succeeded to reproduce the basic solar cycle features. However, most of FTD studies have addressed the time-development of the magnetic field in a purely kinematic regime. In a kinematic regime, the fluid velocity is given from observation or other theories, so only magnetic induction equation is solved. On the other hand, in a non-kinematic (or MHD) regime, both of magnetic field and fluid velocity field are computed by solving magnetic induction equation and Navier-Stokes equation. So this regime allows for the feedback of the Lorentz force on fluid velocity field. Rempel (2006) conducted FTD simulation in a non-kinematic regime and showed FTD model worked successfully even if strong feedback on fluid velocity existed.

Here we address FTD simulation based on the model of Rempel (2006) and includes “η-quenching”, which is not considered in Rempel (2006). It is known that the turbulent magnetic diffusivity used in the solar dynamos is quenched by the existence of strong magnetic fields. This phenomenon is called as η-quenching. And η-quenching can be a powerful mechanism for amplifying magnetic fields (Gilman & Rempel, 2005). The following presents the reasons why we include the effect of η-quenching. One reason is that the maximum magnetic field strength is around 15 kG in Rempel (2006), though rising flux tube simulation (Weber et al., 2011) concluded that magnetic flux tubes forming sunspots should have field strengths around 40-50 kG. The other reason is that no study has investigated the role of η-quenching in a non-kinematic FTD model. Stronger magnetic fields amplified by η-quenching result in stronger feedback to fluid velocity. To investigate this effect, we need to conduct a non-kinematic dynamo simulation in which both of velocity fields and magnetic fields are computed.

We find that η-quenching can amplify magnetic fields even in a non-kinematic regime and the maximum magnetic field strength can be up to around 2 times larger than the case without the effect of η-quenching. However, this amplification leads to the significant feedback to fluid velocity. This feedback makes the amplitude of temporal variations of the solar rotation rate, which is known as torsional oscillations, too large to be consistent with observation.

Reconstruction of high energy particle environment in geostationary orbit based on several satellite observations

*Tsutomu Nagatsuma[1], Kaori Sakaguchi[1], Yuki Kubo[1], Hideki Koshiishi[2]

1.National Institute of Information and Communications Technology, 2.Japan Aerospace Exploration Agency

Currently there are several geostationary satellites which monitor high energy particle environment, although more than four hundreds of satellite exist in this orbit. New Japanese geostationary meteorological satellite, Himawari-8, has operated space environment data acquisition monitor since Nov. 2014. Because the magnetic dipole axis is not aligned with the rotational axis of the Earth, L-value of each GEO satellite is not the same and it changes depending on space weather conditions. To monitor the current condition of high energy particle environment for each satellite in GEO, which is a risk of spacecraft charging, we need to reconstruct high energy particle environment in GEO using several high energy particle observations. Before combining individual data from high energy particle sensors, cross calibration of each sensor is essential. However, the cross calibration needs some technique, because the specification of individual sensor is not the same. So we need to develop method of cross calibration of the sensor, and of combining individual particle data for reconstruction. In this presentation, we will introduce cross calibration method of high energy particle sensor and how to reconstruct high energy particle environment in geostationary orbits using data from the sensor onboard Himawari-8, GOES-13, 15, and Kodama. We also introduce our online database for archiving and providing Himawari-8 high energy particle data.

Keywords: Space Weather Forecast, Geostationary Orbit, High Energy Particle Observation

The status of the SEDA-AP/Heavy Ion Telescope

*Haruka Ueno[1], Haruhisa Matsumoto[1], Kiyokazu Koga[1]

1.Japan Aerospace Exploration Agency

Space radiation such as solar energetic particles (SEP), galactic cosmic rays (GCR) and trapped particles cause to our space activities. Heavy ions, in particular, have high linear energy transfer (LET), which exacerbates the risks of radiation exposure for astronauts and errors of electric circuits for satellites. The Japan Aerospace Exploration Agency (JAXA) has operated the Space Environment Data Acquisition Equipment-Attached Payload (SEDA-AP), installed at the International Space Station (ISS) Japanese Experiment Module (Kibo) - Exposed Facility, since 2009. On July 10 2015, JEM-EF was configured with the relocation of the SEDA-AP from no. 9 to no. 11. The Heavy-Ion Telescope (HIT) is the one of the SEDA-AP instruments, which comprises two position-sensitive silicon detectors and 16 silicon detectors. Based on the dE×TE particle-identification method, HIT measures fluxes and energies of energetic ions from Li to Fe and. The results of HIT are consistent with the general GCR model and other experiment inside the ISS in terms of abundances of elements and LET distributions. In addition, HIT has observed heavy ions from a X5.4 solar flare. We will report the new results of analysis for data from July 2015, and the changes of the temperature environment and the count rates in order to evaluate the effects of relocation.

Keywords: ISS, SEDA-AP, heavy ions

The solar modulation of galactic cosmic rays and radiation dose of aircrews during the solar cycle 24/25

Shoko Miyake[1], *Ryuho Kataoka[2], Tatsuhiko Sato[3]

1.National Institute of Technology, Ibaraki College, 2.National Institute of Polar Research, 3.Japan Atomic Energy Agency

The variation of galactic cosmic rays (GCRs) in the heliosphere is caused by the solar-terrestrial environmental changes. Owing to this variation known as the solar modulation of GCRs, the counting rate of the ground-based neutron monitors and a radiation dose of aircrews at the top of the troposphere also change with the solar-terrestrial environmental changes.
We have developed the time-dependent and three-dimensional model of the solar modulation of GCRs, based on the stochastic numerical method. Our model can reproduce and predict the intensity of GCRs in the heliosphere by assuming the variation of the solar wind velocity, the strength of the interplanetary magnetic field, and its tilt angle. Moreover, we can calculate the neutron monitor counting rate and the radiation dose of aircrews at an aircraft altitude by using our model coupled with the results of air-shower simulation performed by PHITS (Particle and Heavy Ion Transport code System).
In this presentation, we report the results of the solar modulation of GCRs, neutron monitor counting rate, and the radiation dose at flight altitude from the solar cycle 22/23 until the cycle 24/25. We also discuss about the possibility of increase of the radiation dose of aircraft at the cycle 24/25.

Keywords: galactic cosmic rays, heliosphere, radiation dose, neutron monitor

The verification experiment for aerosol nucleation focused on a kind of secondary cosmic rays

*Asami Suzuki[1], Kimiaki Masuda[1], Yoshitaka Itow[1], Takashi Sako[1], Yutaka Matsumi[1], Tomoki Nakayama[1], Sayako Ueda, Kazuhiko Miura[2], Kanya Kusano[1]

1.Institute for Space-Earth Environment Research, Nagoya University, 2.Faculty of Science ,Tokyo University of Science

It is considered that the solar activity may affect the global climate, but the correlation mechanism is still not understood. One of the possible mechanisms for the correlation is the cloud formation by the galactic cosmic rays, which are modulated by the variation of solar magnetic activity. This relation was clearly indicated by the good correlation observed for the galactic cosmic-ray intensity and the global low-cloud amount. This hypothesis includes the ion-induced nucleation model, in which new particles in the atmosphere are created efficiently through atmospheric ions produced by cosmic rays, and finally these particles grow up to the size of cloud condensation nuclei. In this study, a laboratory experiment for verification of the hypothesis has been conducted with a reaction chamber. A flow of clean air with water vapor, ozone and sulfuric dioxide was introduced to a metallic chamber, where we irradiated UV light for solar irradiance and accelerator beam for cosmic rays. The beam of the heavy ion accelerator HIMAC at National Institute of Radiological Sciences was used in the present experiment.
In this presentation, I will report the results of the proton and nitrogen ion irradiation experiments. These high-energy ions have different ionization loss. The ionization loss is an index representing the ability to ionize the air molecules, that is, a parameter that contributes to the atmospheric ion generation. Furthermore, the simulation shows that the proton and the neutron contained in the secondary cosmic rays, keep the variation of solar activity even on the ground surface. Neutrons in secondary cosmic rays may generate energetic heavy ions (nucleus) through nuclear collisions with atmospheric atoms. Then, these energetic ions produce ionization ions through electronic energy loss process. Since it is considered that the aerosol particle generation would be increased according to the amount of ions produced in the energy loss, the experiment was carried out by using these heavy ions.
We will present the experimental result and discuss the difference of aerosol nucleation efficiency between different kinds of secondary cosmic rays.

Relationship between solar wind dynamic pressure and amplitude of geomagnetic sudden commencement (SC)

*Tohru Araki[1], Atsuki Shinbori[2]

1.Formerly Kyoto Univ., 2.RISH, Kyoto Univ.

Although the primary cause of the geomagnetic sudden commencement (SC) is the enhanced magnetopause current, induced field aligned currents, ionospheric currents and earth currents produce a complex global distribution of the amplitude and waveform of SC. As the result the SC amplitude shows a clear latitudinal and local time variation. These variations have not been taken into account in the Siscoe's linear relationship (dH = C* d(Pd**0.5)) which connects the SC amplitude (dH) with the corresponding dynamic pressure (Pd) variation of the solar wind.
By considering the physical background of SC we studied which local time is best to extract the information of the solar wind dynamic pressure and concluded that the SC amplitude at 4-5h local time of middle- and low-latitude stations most directly reflects the dynamic pressure effect.
This result is used to re-check the order of magnitude of the largest 3 SCs (dH > 200 nT at Kakioka) observed since 1868 (Araki, 2015). The SC occurred on March 24, 1940 still keeps the first rank even if
the LT variation is taken into account.

Keywords: geomagnetic sudden commencement(SC), solar wind dynamic pressure , , ionospheric current, field aligned current, LT variation, Siscoe's relationship

On measurement plan of geomagnetic induced current of power transformers in Japan

*Shinichi Watari[1], Yusuke Ebihara[2], Shigeru Fujita[3], Tada-nori Goto[4]

1.National Institute of Information and Communications Technology, 2.Research Institute for Sustainable Humanosphere, Kyoto University, 3.Meteorological College, Japan Meteorological Agency, 4.Graduate School of Enginieering, Kyoto University

It has been considered that the effect on power system by geomagnetically induced current (GIC) is not significant in Japan because of its geomagnetic latitude. However, the damage of the power transformers was reported in Republic of South Africa located in the same geomagnetic latitude as the northern part of Japan when a series of geomagnetic storms occurred between in the end of October and in the beginning of November 2003. It is known that amplitude of GIC depends on underground conductivity structure. We need to consider the complex underground structure in Japan when we make a GIC model. We report the measurement plan of GIC for the modeling.

Keywords: geomagnetically induced current, geomagnetic storm, power system

Three components analysis of ground magnetometer network data toward understanding GIC excited by space weather disturbances

*Shuji Abe[1], Hiroki Matsushita[2], Yukari Nawata[3], Akimasa Yoshikawa[4]

1.International Center for Space Weather Science and Education, Japan, 2.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 3.Department of Earth and Planetary Sciences, School of Science, Kyushu University, 4.Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University

The aim of this study is to make hazard maps of induced electric field from geomagnetic disturbances for estimating possible GIC (Geomagnetically Induced Current) effects from space weather events in mid- and low- latitude region, including Japan. As a first step, we performed frequency analyses to three components of 10 ground magnetometers data all over Japan. 5 magnetometers belongs to MAGDAS project managed by International Center for Space Weather Science and Education, Kyushu University, 3 magnetometers belongs to Japan Meteorological Agency, and 2 magnetometers belongs to Geospatial Information Authority of Japan. The analysis period is one month (July, 2012). In this study, we put a focus to not only H- and D-components, reflecting global space weather disturbances, but also Z-component, reflecting local electromagnetic structure around an observation point. The analysis methods are as follows: 1) Comparison of similarities between H- and D-component (global effect) and Z-component (local effect) at each station, 2) Frequency analysis using above data set, 3) Pre-estimation of GIC effect using time derivative data. As a result, we found that the Z-component shows very complex changes because of the difference of underground structure at each station. In this presentation, we will introduce detailed results of our analyses and future plans.

Keywords: GIC, magnetometer network

Studies of the thermosphere and ionosphere with the EISCAT radar and whole atmosphere/ionosphere model: GAIA

*Hitoshi Fujiwara[1], Yasunobu Miyoshi[2], Hidekatsu Jin[3], Hiroyuki Shinagawa[3], Satonori Nozawa[4], Yasunobu Ogawa[5], Ryuho Kataoka[5], Huixin Liu[2]

1.Faculty of Science and Technology, Seikei University, 2.Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, 3.National Institute of Information and Communications Technology, 4.Institute for Space-Earth Environment Research, Nagoya University, 5.National Institute of Polar Research

The thermosphere/ionosphere is the region that shows both the features of the atmosphere and space. For example, the behaviors of the neutral and ionized gases characterize the region through some collision and radiative processes. In addition, interactions between neutral and ionized gases cause various phenomena in the thermosphere/ionosphere. The thermosphere/ionosphere is also important for radio wave propagation and operation of artificial satellites due to the atmospheric drag force. The accuracy of navigation systems and life time of the satellites depend strongly on the thermospheric/ionospheric conditions. In order to investigate the thermosphere/ionosphere, we have developed a numerical model which includes all the atmospheric regions and ionosphere named GAIA. GAIA has reproduced some thermospheric/ionospheric phenomena and revealed physical mechanisms in association with the phenomena. In this study, we present a brief description of GAIA and show some recent results. The collaboration with radar observations enables the GAIA simulations to be more productive. We will show some European incoherent scatter (EISCAT) radar observations in cooperation with GAIA simulations. The future plans of the EISCAT observations and GAIA simulations will be also shown here.

Keywords: thermosphere, ionosphere, GAIA, EISCAT

Occurrence probability of plasma bubbles deduced from GAIA simulation data

*Hiroyuki Shinagawa[1], Hidekatsu Jin[1], Yasunobu Miyoshi[2], Hitoshi Fujiwara[3], Tatsuhiro Yokoyama[1], Yuichi Otsuka[4]

1.National Institute of Information and Communications Technology, 2.Kyushu University, 3.Seikei University, 4.Nagoya University

In the forecast of ionospheric disturbances, it is important to predict mesoscale ionospheric phenomena such as plasma bubbles, sporadic E layers (Es), and Storm Enhanced Density (SED), which have significant influences on radio communication and broadcast systems as well as global positioning systems. Prediction of those phenomena requires real-time observation and a high-resolution numerical model of the ionosphere and atmosphere. We have been developing a whole atmosphere-ionosphere coupled model, GAIA (Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy), which self-consistently solves the entire region from the lower atmosphere to the ionosphere. Although present version of GAIA does not have enough spatial resolution to reproduce individual plasma bubbles, it is possible to deduce the occurrence probabilities by estimating the linear growth rate of the ionospheric Rayleigh-Taylor instability in the GAIA simulation data. We have performed a long-term simulation using GAIA covering a period from 1996 to the present. Using the database we calculated the linear growth rate, and compared the result with plasma bubble observations. We found that a period in which large linear growth rates appeared in the simulation data tends to correspond to a period of plasma bubbles occurrence, suggesting a possibility of prediction of plasma bubble occurrence using GAIA simulation.

Keywords: plasma bubble, GAIA, linear growth rate, Rayleigh-Taylor instability, ionospheric disturbance

The Mid-Latitude Trough and the Plasmapause Detected by DEMETER

*ChaoYen Chen[1], Jann-Yenq Liu[1], I-Tee Lee[2]

1. National Central University, Taiwan, 2.Central Weather Bureau, Taiwan, R.O.C

This paper finds the mid-latitude trough and the plasmapause by the daytime/nighttime (about 10:00/22:00 LT, local time, respectively) electron density, electron temperature, and whistler of DEMETER during 2006-2009. The electron density and the electron temperature are useful to allocate the trough, while the whistler can be used to find the plasmapause. It is found that the trough is very unclear and complex in the daytime, and however the plasmapause can be detected in both daytime and nighttime. Therefore, we focus on the relationship of nighttime trough and plasmapause in various seasons and geomagnetic actives. Results show that the mid-latitude trough tends to appear in the polarward side of the plasmapause, and the trough moves equatorrward during a higher geomagnetic activity, while the plasmapause is insensitive to the activity.

Keywords: ionosphere, mid-latitude trough, plasmapause

Latitudinal and Longitudinal Variations of Ionospheric Storms by the Global Ionosphere Map of Total Electron Content

*TsungYu Wu[1], Jann-Yenq Liu[1]

1.National Central University, Taiwan

In this study, we examine latitudinal and longitudinal variations of the total electron content (TEC) during the 2003 Halloween storm. The global ionosphere map (GIM) of TEC retrieved from Center for Orbit Determination in Europe is used to investigate the positive and negative storm signatures at various universal times (UT) and global fixed local times (GFLT). The positive and negative storm signatures are prominent at low and middle latitudes, respectively. The UT results show clear longitudinal phase shifts in both positive and negative storm signature. The positive (negative) storm signature reveals the period of 26 (24) hrs and the phase velocity of 14 (15) deg/hr in the longitudinal direction. On the other hand, the GFLT results show that the positive (negative) storm signature tend to appear at equatorial-equatorial iononization anomaly (low-middle) latitudes in daytime. Finally, a statistical analysis of the ionoospheric storm signature is carried out and cross compared with that of the 2003 Halloween storm.

Ionospheric Data Assimilation Model by Using Radio Occultation and Ground-based GPS Observations

*CHIYEN LIN[1], Tomoko Matsuo[2,3], Jann-Yenq Liu[1], Charles Lin[4], Ho-Fang Tsai[4]

1.Graduate Institute of Space Science, National Central University, TAIWAN, 2.Cooperative Institute for Research in Environmental Sciences, University of Colorado, USA, 3.Space Weather Prediction Center, National Oceanic and Atmospheric Administration, USA, 4.Department of Earth Sciences, National Cheng Kung University, TAIWAN

Ionospheric data assimilation is a powerful approach to reconstruct the three-dimensional distribution of ionospheric electron density from various types of observations. The ionospheric data assimilation model based on the Gauss-Markov Kalman filter with the International Reference Ionosphere as the background model is used to assimilate two different types of total electron content (TEC) observations from ground-based GPS and space-based FORMOSAT-3/COSMIC (F3/C) radio occultation (RO). The new satellite mission FORMOSAT-7/COSMIC-2 (F7/C2) will place 12 micro satellites in orbits with two launches in 2016 and 2018, the satellite mission is expected to yield more than 8,000 RO observation per day. The Observing System Simulation Experiments (OSSEs) of assimilating FORMOSAT-7/COSMIC-2 (F7/C2) RO and ground-based GPS data in the data assimilation model are implemented in the study, the OSSEs results demonstrate that the F7/C2 RO data can increase model accuracy more than assimilating F3/C RO data. The new ionospheric data assimilation model that employs the location-dependent background model error covariance, Kalman filter forecast step, and Kalman filter measurement update step could reconstruct the three-dimensional ionospheric electron density distribution satisfactorily from both ground- and space-based GPS observations.

Keywords: Ionosphere, Data Assimilation, FORMOSAT-3/COSMIC

Monitoring global ionospheric structures using a near real-time Global Ionospheric Map

*Yang-Yi Sun[1], Jann-Yenq Liu[1], Ho-Fang Tsai[2]

1.Graduate Institute of Space Science, National Central University, 2.Department of Earth Science, National Cheng Kung University

To efficiently monitor the fast changing ionospheric weather events, such as magnetic storms, solar flares, solar eclipses, earthquake precursors, etc., a near real-time (4-hour delay) Taiwan Global Ionospheric Map (TGIM) is constructed from global vertical total electron content (TEC) observations using a spherical harmonics expansion. The TEC is measured by about 120 ground-based GPS stations and FORMOSAT-3/COSMIC. The high correlation (correlation coefficients > 0.95) of the TGIM and the CODE and JPL GIMs suggests that the TGIM show global scale ionospheric structures as well as the other two GIMs. The high temporal resolution of the TGIM (5 to 15 minutes) reveals that it is capable of showing the variation in ionospheric density structures in more detail. Here we also examine a severe geomagnetic storm, which is the largest during the weak solar cycle 24, occurred on 17 March 2015 at 0445 UT, using the GIMs. The results show the positive storm is pronounced at mid- and low-latitudes in the first day after the storm onset. The negative storm remains present in the equatorial ionization anomaly crest regions more than one week. The sudden change in TEC at middle and low latitudes during the main phase period maybe associated with the equatorward disturbance wind and the prompt penetration electric field.

Keywords: Ionospheric weather, Global ionospheric map, FORMOSAT-3/COSMIC, GPS TEC

Operational forecast of foF2 above Tokyo using solar wind input to a neural network

*Herbert Akihito Uchida[1,4], Wataru Miyake[2], Maho Nakamura[3], Ryuho Kataoka[4,1]

1.SOKENDAI (The Graduate University for Advanced Studies), 2.Tokai University, 3.Tokyo Gakugei University, 4.National Institute of Polar Research

A new empirical prediction model of foF2 above Tokyo, Japan (Uchida et al., 2016, submitted), has started its forecast operation at National Institute of Polar Research. Solar wind parameters are used for the first time to the input of a neural network (NN) to predict foF2 in that study. The model showed better forecast results compared to an existing operational NN model (Nakamura et al., 2009) which forecasts foF2 using K-index to the input. The results support our expectation that the NN can represent the physics between the ionospheric variations and the solar wind better. The forecast is operated every day at 0 UT for next 24 hours. The model uses day of year, sunspot number, F10.7 solar proxies, solar wind proton velocity, IMF By and Bz to the input. Prior 24 hour values to the forecast are lined to the input at once. To represent the time dependences, 24 of individual NNs are constructed for each hour and concatenated at forecast. We introduce the operational model and report the summary of current operation, and discuss several possibilities to improve the forecast.

Keywords: Forecast, foF2, Neural network, Solar wind

Preliminary development of radio propagation simulator for HF

*Kornyanat Watthanasangmechai[1], Mamoru Ishii[1], Takashi Maruyama[1], Tatsuhiro Yokoyama[1], Susumu Saito[2]

1.National Institute of Information and Communications Technology, 2.Electronic Navigation Research Institute

To investigate an ionospheric effect on the HF radio propagation, we are developing the radio propagation simulator. Because radio waves in the high frequency (HF) band can be reflected back to Earth by the ionosphere layer, they are widely used for long-distance communication. HF is not only popular among amateur radio users, but it is also valuable remote communication during a disaster e.g. Tsunami and big earthquake. Being involved in the ionosphere, an integrity of HF wave, however, unavoidably relies on sunlight/ darkness of the transmission and reception sites, season, sunspot number, solar activity, aurora activity, and magnetic activity. While the maximum usable frequency (MUF) has a direct variation with the electron density, the lower usable frequency depends on the absorption in the D-layer of the ionosphere. This paper presents a preliminary effort for an integration of the radio propagation knowledge and the ionospheric knowledge. The current status of the simulator development will be reported.

Keywords: Radio propagation, HF, Ionosphere

Nonlinear reflection process of linearly-polarized, broadband Alfven waves in the fast solar wind

*Munehito Shoda[1], Takaaki Yokoyama[1]

1.Graduate School of Science, University of Tokyo

Alfvén waves are frequently observed both in the solar atmosphere (DePontieu et al. 2007 Science, Okamoto et al. 2007 Science) and the solar wind (Belcher & Davis 1971 JGR), and widely believed to play a significant role in the coronal heating and the solar wind acceleration. Since the reflection of Alfvén waves triggers Alfvénic turbulence in the solar atmosphere and the solar wind (Matthaeus et al. 1999 ApJL, Dmitruk et al. 2002 ApJ), turbulent heating rate of the corona is sensitive to the reflection rate. Comparison of recent studies (Suzuki & Inutuska 2005 ApJL, Cranmer & van Ballegooijen 2005 ApJS) strongly suggest that the compressibility of plasma, in other words the nonlinearity of Alfvén waves, enhance the reflection rate up to 100-1000 times, whose mechanism is still unclear.
Using one-dimensional numerical simulations, we study the elementary process of Alfvén wave reflection in a uniform medium, including nonlinear effects. In the linear regime, Alfvén wave reflection is triggered only by the inhomogeneity of the medium, whereas in the nonlinear regime, it can occur via nonlinear wave-wave interactions. Such nonlinear reflection (backscattering) is typified by decay instability. In most studies of decay instabilities, the initial condition has been a circularly polarized Alfvén wave. In this study we consider a linearly polarized Alfvén wave, which drives density fluctuations by its magnetic pressure force. For generality, we also assume a broadband wave with a red-noise spectrum. In the data analysis, we decompose the fluctuations into characteristic variables using local eigenvectors, thus revealing the behaviors of the individual modes.
Different from circular-polarization case, we find that the wave steepening produces a new energy channel from the parent Alfvén wave to the backscattered one. Such nonlinear reflection explains the observed increasing energy ratio of the sunward to the anti-sunward Alfvénic fluctuations in the solar wind with distance (Bavassano et al. 2000 JGR) against the dynamical alignment effect (Dobrowolny et al. 1980 Phys.Rev.Lett.).

Keywords: solar wind, Alfvén wave

Solar energy transport with significantly suppressed velocity

*Shota Arai[1], Hideyuki Hotta[1]

1.Astorophysics Laboratory , Department of Physics , Faculty of Science , Chiba University

We carry out a series of 2D convection calculations with highly suppressed velocity. Thermal convection in the solar interior is thought to maintain differential rotation and meridional circulation. Although the solar equator is rotating faster than polar region, recent high-resolution calculations with solar parameters accelerate the pole. This problem can be attributed to over-excited thermal convection in numerical calculations. Local helioseismology also supports this finding. Recent MHD simulations suggest that the small-scale Lorentz force is able to suppress the convection velocity, but the suppression is not enough and has not been numerical converged, i.e., higher resolution shows stronger suppression.
In this study, we assume that the Lorentz feedback in extremely high resolution, i.e., the sun, becomes stronger enough to explain equator acceleration and the result of the local helioseismology. In order to investigate this extreme condition, we carry out series of 2D hydrodynamics simulations with high viscosity mimicking the strong Lorentz force. The purpose of our research is to investigate energy flux transported by the thermal convection. Even if the velocity is reduced, convection needs to transport imposed energy flux at the bottom boundary. Generally it is expected that upflow and down flow become hotter and cooler, respectively than those without viscosity. We also find that the correlation becomes better with high viscosity with suppressing the small-scale chaotic motion.

Keywords: Sun, Thermal convection, Magnetic field

A study for the improvement of SUSANOO-solar wind model

*Toshihiro Ishida[1], Kanya Kusano[1], Daikou Shiota[1]

1.Institute for Space-Earth Environmental Research, Nagoya University

The Earth is exposed to solar wind that emanates constantly from the Sun and influences the structure and dynamics of the magnetosphere of the Earth. Hence, the prediction of solar wind is crucial for the space weather forecast.
In recent years, our group have developed a space weather prediction model: SUSANOO (Space-weather-forecast-Usable System Anchored by Numerical Operations and Observations), which can predict the solar wind profile at the Earth's orbit and high-energy electrons flux of the radiation belt on the basis of three-dimensional MHD simulation of solar wind (SUSANOO-SW) [Shiota et al., 2014]. Although SUSANOO-SW may reproduce the large-scale three-dimensional structures of solar wind on the basis of observation of the photospheric magnetic field, the model is not yet able to well reproduce the observation of the short term variation of solar wind and the amplitude of fast solar wind velocity.
In this research, we study the cause of deviation between the model and observations focusing on the solar wind speed model which is used to specify the solar wind distribution on the inner boundary condition of SUSANOO-SW. We found that peculiar high speed structures around pseudostreamers, which must be formed by the Wang-Sheeley model [Arge and Pizzo, 2000], might be a cause of degradation of reproducibility.
In order to improve it, we take into account not only of the expansion factor but also of the magnetic intensity based on a theoretical work by Suzuki [2006]. I will quantitatively evaluate the performance of the new model, and discuss about what is needed to improve the predictability of solar wind model based on the comparison with the in-situ observation.

Keywords: solar wind

Three-Dimensional MHD Simulation of the Interaction between CME and Ambient Plasma in Solar Corona

*Masaki Shirota[1], Kanya Kusano[1], Daikou Shiota[1]

1.Institute for Space-Earth Environmental Research, Nagoya University

Coronal mass ejections (CMEs) are one of main drivers of various disturbances in space weather. In particular, the timing of arrival, the strength, and the amount of southward magnetic flux brought by CMEs are important for the magnitude of the space weather disturbances, and those are depend on the following factors: whether the CMEs hit the earth or not, speeds of the CMEs, and the magnetic field structures within the CMEs. Because the factors are determined as a results of the dynamics in their propagation as well as in formation in the solar corona, the understanding of the influence of ambient corona on the dynamics of CMEs is necessary for an improvement of space weather forecast. However, what determines the structure and intensity of magnetic field of CME is not yet well understood.
In this study, we performed magnetohydrodynamic simulations of a formation process of CMEs in the solar corona, focusing on the interaction between an ejecting flux rope and its ambient field by extending the work by Shiota et al. (2010). We examined the dynamics of magnetic flux rope in three different ambient plasma conditions: the uniform atmosphere, the hydrostatic atmosphere, and the steady state of the solar wind.
In the uniform atmosphere case, the flux rope are decelerated very much with continues rotation around the propagation direction as same as the previous study (Shiota et al. 2010). In contrast, we found that in the other two cases the flux rope speed is much faster than in the uniform atmosphere case because of a much weaker drug force in the stratified or steadily flowing plasma. Since the magnetic interaction between the flux rope and the ambient field seems to be weaker in those cases, the rotation of CME becomes weaker. We will discuss how the ambient plasma influences the dynamics of the CMEs.

Keywords: magnetohydrodynamic, coronal mass ejections (CMEs), corona

Mode Conversion of Alfven Waves Propagating in the Solar Chromosphere and Contribution to the Heating

*Shunya Kono[1], Takaaki Yokoyama[1]

1.The University of Tokyo

Alfven waves, which are generated in the solar photosphere and propagate along magnetic flux tubes, have been suggested to carry sufficient energy to the upper solar atmosphere and heat the atmosphere through wave dissipation. The chromosphere is an intermediate layer connecting the photosphere to the corona. Propagation and dissipation of waves in the chromosphere regulate the energy flux penetrating the corona. The chromospheric heating by waves is important for understanding the mechanism of solar atmospheric heating and solar wind acceleration. In this presentation, we report on our numerical works of Alfven wave propagation along open flux tubes from the solar convection zone to the corona. In 1.5-dimensional magnetohydrodynamic (MHD) numerical simulations, it is shown that 60-90% of the upward-propagating Alfvenic pulse with frequencies of 3-100 mHz are reflected at the transition region, which is the top boundary of the chromosphere. Meanwhile, most of the waves reflected at the transition region penetrate the convection zone without being reflected at the bottom of the photosphere. These results suggest that Alfven waves are unlikely to be trapped in the chromosphere. During the wave propagation in the chromosphere, Alfven waves exhibit nonlinear effects with longitudinal wave generation. The mode conversion rate is calculated with different plasma beta in the chromosphere. In the case with low plasma beta (~ 0.1-1), 0.01-1% of input Alfven wave energy is converted to the longitudinal wave energy. This energy is almost comparable to the required energy for the chromospheric heating. As plasma beta becomes larger and background Alfven speed becomes smaller in the chromosphere, more longitudinal wave appears due to increase of nonlinearity of the Alfven wave. In the case with high plasma beta (~ 1-10), the mode conversion rate becomes 1-10%. The generated longitudinal waves carry sufficient energy to heat the chromosphere.

Keywords: chromosphere, wave, nonlinear, heating

Influence of solar wind and ozone on the temperatures of the troposphere and stratosphere

*Kazuyoshi Yamashita[1], Kiminori Itoh[2]

1.Yokohama National University, 2.Inst.Env.Sci.&Technol.,Yokohama National Univ.

The correlation between global atmosphere and solar magnetic activity is evident though the cause is not clear. In this presentation, we analyze the influence that solar wind and ozone give to the global atmosphere to examine the cause on the basis of the previous observations [1].
The AE index data were used to detect the influence of the solar wind on the total ozone and the air temperature change of the troposphere and stratosphere.
In the analysis, the following factors were taken into account: 1)EPP-NOx effects on ozone at low latitudes may be comparable to the effects of solar UV radiation [Callis et al., 2000, 2001; Langematz et al., 2005; Rozanov et al., 2005]. 2) Since the ozone generated at low latitude is conveyed to the pole aria of the winter hemisphere, EPP-NOx has affected the ozone reduction of the pole area.
As the analysis result, showalter stability index which is calculated from the temperature of 500hPa and 850hPa in polar regions correlates with the AE index, Especially when the Arctic Oscillation is changed from the positive phase to the negative phase, the tendency is strong.
This increase in high-energy particles with the solar wind, to reduce the stratospheric ozone polar, it is possible to increase the amount of solar radiation reaching the troposphere, there is a possibility that influence the stability of the atmosphere.
Thus, changes in the stratospheric ozone due to the influence of the solar wind appears to affect the climate of the troposphere.

Reference
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Keywords: atmospheric stability, AE index, AO index, ozone

Space Weather and Terrestrial Weather during the Transition Period of the Solar Activity in 13th and 14th Century: an Examination on Disaster Records in Yuan Dynasty.

*Hisashi Hayakawa[2], Hiroko Miyahara[5], Harufumi Tamazawa[1], Hiroaki Isobe[3,4], Ryuho Kataoka[6,7]

1.Kwasan and Hida Observatories, Graduate School of Science, Kyoto University, 2.Graduate School of Letters, Kyoto University, 3.Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, 4.Kyoto University Unit of Synergetic Studies for Space, 5.Musashino Art University, 6.National Institute of Polar Research, 7.SOKENDAI

Space Weather and Terrestrial Weather during the Transition Period of the Solar Activity in 13th and 14th century: an examination on disaster records in Yuan Dynasty. In the 13th century, the rapid fall down of the solar activity ended the Medieval Maximum (1100-1250) and started the Wolf Minimum (1280-1340). This change of the solar activity also caused a considerable climate change on the earth and brought an end of the Medieval Warm Period (10c-13c) and the Little Ice Age (14c-19c). In the 13th century, Eurasia witnessed an unexampled worldwide empire by the Mongolian Empire and the trade routes across the Eurasia had gotten connected between the West and the East under the "Pax Mongolica". Even this worldwide Empire could not conquer the contemporary climate change and had disintegrated in the early Little Ice Age. It is frequently pointed out that hunger or social unrests caused by extreme weathers are one of its biggest reasons. However, as for such extreme terrestrial weathers, they have only gotten pointed out vaguely and they have left unexamined till now. So, in this presentation, we treat the records of disasters in the China under Mongolian rule (1235-1368) and show the detail of the extreme terrestrial weather caused in the period during the transition of the solar activity, shown by the records of carbon-14 in tree rings. Historical records provides important information on the regional differences of solar influence on climate. It also gives some clues on the ocean-atmospheric circulation during the time.

Keywords: Wolf Minimum, Medieval Warm Period, solar activity, Extreme Terrestrial Weathers

Aurora Candidates from the Chronicles of *Qing* Dynasties for Decoding Past Solar Activities

*Akito Davis Kawamura[1], Hisashi Hayakawa[2], Haruhumi Tamazawa[1], Hiroaki Isobe[3,4]

1.Kwasan Observatory, Kyoto University, 2.Graduate School of Letters, Kyoto University, 3.The Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, 4.Unit of Synergetic Studies for Space, Kyoto University, Japan

We present the survey result of observational records of auroras in chronicles of *Qing* dynasties, *Qingshigao*, the draft chronicle of *Qing* dynasty (1644-1912 CE). In total we found 111 records of aurora candidates associated with the keywords such as vapor (*qi*), cloud (*yun*), and light (*guang*). Among the 111 records we found, 14 records are considered as very likely to be low latitude auroras with corresponding records of simultaneous observation in the western world, and 6 records are newly found low latitude aurora candidates after moon phase analysis in order to eliminate a possibility of atmospheric optics involving. Some of our presenting candidates of low latitude aurora are dated during the Maunder minimum, and therefore we would suggest our presenting data potentially helpful for further discussion on past solar activities.

Keywords: Aurora, Space Weather, Historical Resources

Development of user-oriented space environment prediction model for individual satellite

*Tsutomu Nagatsuma[1], haruhisa matsumoto[2], Kiyokazu Koga[2], Masao Nakamura[3], Mamoru Ishii[1]

1.National Institute of Information and Communications Technology, 2.Japan Aerospace Exploration Agency, 3.Osaka Prefecture University

Geospace environment is dynamically changing depending on the solar wind conditions. As a result, space environment disturbances, such as substorms and relativistic electron enhancements are occurred. These are the key subjects of space weather research. On the contraly, there are numbers of commercial satellites operated in geospace. These satellites sometimes faced on the hazardous conditions because of geospace disturbances. Changing the particle environment surrounding individual satellite causes spacecraft charging problem. Less than 100 keV energy of charged particles, and more than 500 keV energy of charged particles cause surface and internal charging to satellites, respectively. Spacecraft charging is one of the major reasons of spacecraft anomaly. To mitigate the risk of satellite anomaly, prediction of middle to high energy particle environment in geospace is important.

However, the risk of spacecraft anomaly is also depend on the specification of the satellite (e.g. surface materials, radiation tolerance, etc.). Therefore, the prediction of space environment is still not enough for satellite operators. These information should be interpreted to the risk of individual satellite.

To estimate a risk of spacecraft charging for individual satellite, we try to combine forecasting model of space environment and engineering model for individual satellite. Based on the combination of these models, we will provide specific information of charging risk for individual satellite. In this presentation, we will introduce our approach of developing user-oriented space environment prediction model for individual satellite, and our initial results.

Keywords: Space Weather Forecast, Spacecraft Charging, User-Oriented

Space weather effects on aeronautical communication, navigation and surveillance systems

*Susumu Saito[1], Mamoru Ishii[2]

1.Navigation Systems Department, Electronic Navigation Research Institute, 2.National Institute of Information and Communications Technology

Space weather can be defined as the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems.
It becomes more important especially when the reliability are of relevance. Aeronautical applications are one of those which requires high level of reliability and safety. In fact, International Civil Aviation Organization (ICAO) is working on standardizing the space weather information for aeronautical operations.
The main objective of this paper is to present necessary space weather studies to which the science community are expected to contribute to enhance the performance, reliability and efficiency of aeronautical communications, navigation and surveillance (CNS) systems. Space weather phenomena which can influence the aeronautical CNS systems are presented from the operation point of view. Possible impacts of space weather phenomena on aeronautical CNS systems and necessary space weather studies to evaluate the operational impact and devise effective mitigation methodology are discussed.

Keywords: aeronautical applications, ionosphere, communications, navigation, and surveillance systems

