

## 太陽風磁気ロープ発生頻度と太陽活動サイクルに関する検討

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

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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.

キーワード: solar wind、interplanetary magnetic flux rope

Keywords: coronal mass ejection, solar-cycle variation

## 太陽磁気フラックスロープを生む4重極活動領域の形成

## Formation of a Quadrupolar Active Region Producing a Magnetic Flux Rope

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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.

キーワード：太陽、フレア、黒点

Keywords: Sun, Flares, Sunspots

フォースフリー磁場モデリングを用いた四重極磁場構造におけるホモロガスフレアの研究  
Studies on homologous flares at quadrupole magnetic field using force-free field modeling

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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 converging 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.

キーワード：太陽フレア、磁気リコネクション

Keywords: Solar flare, Magnetic reconnection

## 太陽コロナにおけるダブルアーク不安定性 Double Arc Instability in the solar corona

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太陽コロナにおけるフラックスロープの安定性は、太陽フレアやコロナ質量放出（CME）といった宇宙天気擾乱の主たる原因となる現象の発生に関連している。近年、太陽面爆発現象の原因としてトーラス不安定性がKliem & Toeroek (2006)によって提案された。しかしながら、いかにして不安定性が駆動されるのかについてはよくわかっていない。その一方で、不安定なフラックスロープを生じさせる過程のシナリオとして有名なものの一つに、Moore et al. (2001)で提案されたテザーカッティングリコネクションがある。このシナリオは強くシアした磁力線間の磁気リコネクションがダブルアーク型ループを形成し、やがて爆発現象が生じることを提案している。しかしながら、この初期段階の際に見られるダブルアーク型ループの安定性は未だに解析されていない。

本研究の目的は、ダブルアーク型電流ループの安定性を理論的に解析することである。そのため、ダブルアーク型電流ループをお互いに結合した二つの円形トーラスでモデル化し、その安定性を数値的に計算した。その結果TIとは対照的に、ダブルアーク型電流ループは一様な外部磁場の元でも不安定化しうることを見出した。この結果はダブルアーク型電流ループに対する不安定性、すなわちダブルアーク不安定性（DAI）はTIとは異なるものであることを示している。またTIの臨界の基準として用いられるdecay indexはDAIには適用できず、さらにDAIの必要条件は磁力線の半回転以上のねじれであることが分かった。DAI後の成長はフラックスロープの爆発の観測結果ともよく一致している。これらの結果は、テザーカッティングリコネクションに基づくDAIは実際に爆発現象のもとで機能し、どのように爆発現象が駆動されるのかよく説明しうる、ということを示している。

キーワード：太陽、太陽フレア、不安定性

Keywords: Sun, solar flare, instability

## 国際コンソーシアムによる野辺山電波ヘリオグラフの科学運用

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

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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 Radioheliograph (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](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.

キーワード：太陽、電波

Keywords: Sun, radio

## 太陽磁場観測による自転速度算出とその長期変動について

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

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太陽から放出されるプラズマ（太陽風）により地球周辺の宇宙環境は影響を受け続けている。太陽から放出されるプラズマはフレアやCMEなどの現象により、爆発的に放出され、地球及び人工衛星に甚大な被害を及ぼす。これを太陽嵐と呼ぶ。また、太陽風の変動全体を宇宙天気と呼び、それを正しく予測するための研究が様々な角度から行われている。太陽地球環境予測研究のひとつに太陽の活動メカニズムの研究が挙げられる。太陽は約11年周期で活動の大きさが変動することが知られており、活動が強い時、弱い時をそれぞれ極大期、極小期と呼ぶ。それに伴って太陽風の強さも変動し、極大期には太陽嵐も多く起こる。さらに、周期毎に活動の強さが異なることが過去の長期に渡る観測によって報告されている。太陽活動極小期において、極磁場（太陽の北極及び南極の磁場）の強さと次サイクルの太陽活動度には強い相関があることが知られており、現在の太陽活動極小期の極磁場を知る事は次期太陽サイクルを予測するのに有用である。

そこで本研究では差動回転、子午面循環流、乱流拡散係数などの表面磁束輸送モデル計算によって極磁場を見積もるのに重要なパラメーターを太陽観測衛星SDO/HMIによる太陽磁場観測から求める。2つの異なる方法（Local Correlation Tracking (LCT)、Magnetic Element Tracking (MET)）で観測データから太陽のパラメーターを算出するモジュールを開発し、実際のデータ解析に用いた。LCTとMETから見積もられる結果を比較し、両者の方法での違い・特徴について議論を行う。また、打ち上げ(2010年)から現在までのデータ（およそ6年分）を解析することにより、太陽における3つの物理パラメーターの長期変動について考察を行った結果を報告する。

キーワード：太陽、磁場観測、自転速度、子午面循環流

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

MHD磁束輸送ダイナモにおける $\eta$ 抑制の役割The role of  $\eta$ -quenching in MHD flux transport dynamo\*市村 千晃<sup>1</sup>、横山 央明<sup>1</sup>\*Chiaki Ichimura<sup>1</sup>, Takaaki Yokoyama<sup>1</sup>

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"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 " $\eta$ -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  $\eta$ -quenching. And  $\eta$ -quenching can be a powerful mechanism for amplifying magnetic fields (Gilman & Rempel, 2005). The following presents the reasons why we include the effect of  $\eta$ -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  $\eta$ -quenching in a non-kinematic FTD model. Stronger magnetic fields amplified by  $\eta$ -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  $\eta$ -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  $\eta$ -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.



複数衛星粒子観測データを用いた静止軌道高エネルギー粒子環境の再構成

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

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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.

キーワード：宇宙天気予報、静止軌道、高エネルギー粒子観測

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

## ISS/JEM-EF搭載SEDA-AP重イオン観測装置のデータ取得状況

## The status of the SEDA-AP/Heavy Ion Telescope

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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 dExTE 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.

キーワード：国際宇宙ステーション、SEDA-AP、重イオン

Keywords: ISS, SEDA-AP, heavy ions

## 太陽サイクル24/25における銀河宇宙線の太陽変調と航空機搭乗員の被ばく線量

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

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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.

キーワード：銀河宇宙線、太陽圏、被ばく線量、中性子モニター

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

## 二次宇宙線の種類に着目したエアロゾル核生成の検証実験

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

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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.

## 地磁気急始変化 (SC) 振幅と太陽風動圧変化の関係

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

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太陽風衝撃波・不連続面の動圧 (Pd) 急増によって生じる地磁気急始変化 (SC) は、地上観測からPd変化を知るプローブとして有効に使える。これは、飛翔体観測開始前時代には特に重要である。Siscoe et al.(1968)は、SC振幅(dH)が、Pd\*\*0.5の衝撃波・不連続面前後の変化量、d(Pd\*\*0.5)に比例する ( dH =C・d(Pd\*\*0.5) ) と仮定して、観測から比例係数Cを定めた。その後、Cを決める幾つかの解析がなされている。

SC振幅 (dH) は、緯度とLTに依存して大きく変わる。これは、磁気圏急圧縮時には、磁気圏界面電流 (MC) と共に、沿磁力線電流 (FAC) ・電離層電流 (IC) ・地電流 (EC) も急変化し、それらの磁場が複雑な緯度・LT依存性を示すからである。しかし、Cを決める際に、この緯度・LT依存性は、考慮されてこなかった。

ここでは、FAC・ICが作る磁場日変化の計算と、赤道から中緯度までの4観測所のデータから求めたCの日変化の解析から、4-5hLTに観測されるSCは、FAC・ICの影響を最も受けにくく、MC変化(従って、Pd変化)を直接的に表しているとの結論を得た。

これに従って、1868年以降に観測された3大SC(柿岡でdH>200nT)の振幅のLT依存性を考察し、最大とされていた1940.3.24SCが、やはり最大であることを確かめた。

キーワード：地磁気急始変化(SC)、太陽風動圧、電離層電流、磁気圏電流、日変化、Siscoe関係式

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

## 日本での電力トランスの地磁気誘導電流の測定計画について

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

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日本は、地理緯度に比べて地磁気緯度が低いこともあり、地磁気誘導電流（GIC, Geomagnetically Induced Current）による電力システムへの影響はそれほど大きくないと考えられている。しかし、2003年10月末から11月の始めにかけて発生した大きな地磁気嵐の際には、日本の北部とほぼ同じ磁気緯度に位置する南アフリカ共和国で、電力トランスの障害事例が報告されている。また、GICの大きさは、地下導電率構造に依存することが知られており、GICのモデリングにおいて日本の複雑な地下構造の影響を考慮する必要がある。GICのモデリングのために計画しているGICの測定について報告する。

キーワード：地磁気誘導電流、地磁気嵐、電力システム

Keywords: geomagnetically induced current, geomagnetic storm, power system

## 磁気擾乱により励起されるGICの理解に向けた地上磁場変動の全成分解析

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

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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.

キーワード：地磁気誘導電流、磁力計ネットワーク

Keywords: GIC, magnetometer network

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

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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



## GAIAシミュレーションデータを用いたプラズマバブル発生確率の推定

Occurrence probability of plasma bubbles deduced from GAIA simulation data

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プラズマバブルやスプラディックE層、SED (Storm Enhanced Density)などの電離圏擾乱現象は、通信、放送、測位などに障害を起こすため、宇宙天気予報における最重要課題の一つとなっている。これらの現象は、一般に水平スケールが数100km以下のメソスケール現象であり、その予測には、リアルタイム電離圏観測と高精度の大気圏・電離圏モデルが必要である。我々のグループでは、電離圏擾乱現象の再現と予測を目的とした全大気圏-電離圏結合モデル (GAIA) を開発してきた。現在のGAIAは、これらのメソスケール現象を直接再現するには分解能がまだ十分でないが、プラズマバブルについては背景場から線形成長率を見積もることにより、発生しやすさを推定できる可能性がある。今回我々は、1996年から現在までの長期シミュレーションデータから、各日についてレイリー・テイラー不安定の線形成長率の最大値を求め、プラズマバブル発生の観測データと比較した。その結果、GAIAデータから計算された線形成長率が大きい期間は、実際にプラズマバブルが発生した期間に対応する傾向があることがわかった。この結果は、GAIAのシミュレーションデータを用いてプラズマバブルの発生確率を推定できる可能性を示すものと言える。

キーワード：プラズマバブル、GAIA、線形成長率、レイリー・テイラー不安定、電離圏じょう乱

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

## The Mid-Latitude Trough and the Plasmapause Detected by DEMETER

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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 equatorward 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

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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 ionization anomaly (low-middle) latitudes in daytime. Finally, a statistical analysis of the ionospheric 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

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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

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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

ニューラルネットワークを用いた太陽風入力によるfoF2の予報

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

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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.

キーワード：予報、foF2、ニューラルネットワーク、太陽風

Keywords: Forecast, foF2, Neural network, Solar wind

## Preliminary development of radio propagation simulator for HF

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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

## 高速太陽風における直線偏波・広帯域アルフベン波の非線形反射過程

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

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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 & Inutsuka 2005 ApJL, Cranmer & van Ballegoijen 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.).

キーワード：太陽風、アルフベン波

Keywords: solar wind, Alfvén wave



強く速度場が抑えられたときの太陽のエネルギー輸送について

Solar energy transport with significantly suppressed velocity

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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.

キーワード：太陽、熱対流、磁場

Keywords: Sun, Thermal convection, Magnetic field

## 太陽風モデルSUSAN00の改善に向けた研究

A study for the improvement of SUSAN00-solar wind model

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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: SUSAN00 (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 (SUSAN00-SW) [Shiota et al., 2014]. Although SUSAN00-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 SUSAN00-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.

キーワード：太陽風

Keywords: solar wind

3次元MHDシミュレーションにおける太陽コロナ中での背景場プラズマとCMEの相互作用  
Three-Dimensional MHD Simulation of the Interaction between CME and Ambient Plasma in  
Solar Corona

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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 drag 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.

キーワード：磁気流体力学、コロナ質量放出、コロナ

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

## 太陽彩層伝播アルフベン波のモード変換と加熱への寄与

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

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Alfvén 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 Alfvén 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 Alfvénic 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 Alfvén waves are unlikely to be trapped in the chromosphere. During the wave propagation in the chromosphere, Alfvén 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 ( $\sim 0.1$ – $1$ ), 0.01–1% of input Alfvén 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 Alfvén speed becomes smaller in the chromosphere, more longitudinal wave appears due to increase of nonlinearity of the Alfvén wave. In the case with high plasma beta ( $\sim 1$ – $10$ ), the mode conversion rate becomes 1–10%. The generated longitudinal waves carry sufficient energy to heat the chromosphere.

キーワード：彩層、波、非線形、加熱

Keywords: chromosphere, wave, nonlinear, heating

## 対流圏及び成層圏の気温に対するオゾンと太陽風の影響

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

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太陽磁気活動と地球大気の温度変化は相関関係にあることは間違いないが、その原因は明らかではない。この問題に対して今までの研究成果[1]に基づき、太陽風とオゾンが地球大気に与える影響について分析検討する。

今回、太陽風の影響を確認するためA E 指数データを使用し、オゾン全量と対流圏及び成層圏の気温の変化を解析した。

なお、解析を進めるにあたって次に点に注意した。低緯度でのオゾンに対するE P P - N O x の影響がUV 紫外線に匹敵する可能性がある[Callis et al.,2000,2001;Langematz et al.,2005;Rozanov et al.,2005]。低緯度で生成されたオゾンは冬極域に輸送されるため、E P P - N O x が極域のオゾン減少に影響を与えている。

解析結果として、極域における500 h P a 面の気温と850 h P a 面の気温から計算したショワルター安定指数 ( S S I ) は、A E 指数と相関関係にあり、特に北極振動が正の位相から負の位相へ変化するときその傾向が強い。このことは太陽風に伴う高エネルギー粒子の増加が、極域における成層圏オゾンを減少させ、対流圏に到達する日射量を増加させることで、大気の安定度に影響を与えている可能性がある。

以上のことから太陽風の影響による成層圏オゾンの変化は、対流圏の気候に影響を与えていることを示唆している。

[1]伊藤公紀、地球惑星科学連合大会2008-2015

キーワード：大気安定度、AE指数、北極振動、オゾン

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

13-14世紀の太陽活動移行期における宇宙気候と地球気候：元王朝の災異記録の検討を通して  
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.

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13世紀、太陽活動は急速に低調になり、中世極大期（1100-1250）を終えて、所謂ウォルフ極小期（1280-1340）  
に突入した。このような太陽活動の変化は地球にも大きな気候変動をもたらし、いわゆる中世温暖期  
（10c-13c）が終わり、小氷期（14c-19c）が始まった。当初、ユーラシア大陸はモンゴル帝国による空前の世界  
帝国を経験し、東西の交易路が「モンゴルの平和」の下に統合される稀有な時代にあったが、かような世界帝  
国も折からの気候変動には勝てず、小氷期の始まりと時期を同じくして解体し、その背景に異常気象による飢  
餓や社会不安があったことは夙に語られるところである。しかし、そのような異常気象については漠然とその  
存在が語られるのみで従来踏み込んだ検討がなされてこなかった。そこで本報告では、モンゴル治下中国（元  
王朝：1235-1368）の災異記録を検討し、C14などの科学データとの比較を通して、太陽活動の移行期に地球上に  
もたらされた異常気象の具体像に迫る。

キーワード：ウォルフ極小期、中世温暖期、太陽活動、異常気象

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

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

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We present the survey result of observational records of auroras in chronicles of *Qīng* dynasties, *Qīngshǐgǎo* (清史稿), the draft chronicle of *Qīng* dynasty (1644-1912 CE). In total we found 111 records of aurora candidates associated with the keywords such as vapor (氣, *qì*), cloud (雲, *yún*), and light (光, *guāng*). 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.

キーワード：オーロラ、宇宙天気、歴史資料

Keywords: Aurora, Space Weather, Historical Resources

## 個別の衛星のためのテーラーメイド型宇宙環境予測モデルの開発

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

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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 contrary, 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.

キーワード：宇宙天気予報、衛星帯電、テーラーメイド型

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



航空用通信・航法・監視システムに対する宇宙天気現象の影響について

Space weather effects on aeronautical communication, navigation and surveillance systems

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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.

キーワード：航空利用、電離圏、通信・航法・監視システム

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