St Patrick's Stormの原因となったフィラメント噴出のトリガに関する研究

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Triggering Scenario of Geo-effective Solar Eruption on 15 March 2015

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The largest magnetic storm so far, called St Patrick's Day event, in the solar cycle 24 occurred on 17 March 2015. It was caused by fast coronal mass ejection (CME) on 15 March 2015 from solar active region (AR) NOAA 12297. Surprisingly, the CME is suggested to be related to a C9.1 flare while the large CME is usually corresponding to a large flare. The propose of this study is to understand the onset mechanism of the huge solar eruption which caused big impact on a magnetic environment of the geospace. The magnetic field structure in the AR was complicated: There were several filaments including the one which erupted and caused the CME. We hence carefully investigated the photospheric magnetic field, brightenings observed in the region from the chromosphere to the corona, and the three-dimensional coronal magnetic field calculated through our nonlinear force-free field (NLFFF) model using photospheric vector magnetic field data from the Hinode/Solar Optical Telescope and the Solar Dynamics Observatory. We focused on the C2.4 flare occurred prior to the C9.1 flare and filament eruption. Through our provisional analysis covering long time span, we noticed the C2.4 flare prior to the C9.1 flare is important to understanding the dynamics of this AR system and the CME event. (1) There was a compact but noticeably highly twisted magnetic field structure. During the C2.4 flare, flux cancellation was seen on the photospheric magnetic field data. (2) The erupting filament is sustained by the coronal magnetic field prior to the flare, and C2.4 flaring site locates in the vicinity of one footpoint of them. (3) The top of the coronal loops sustaining the filament touch to a region where the torus instability would be expected.Therefore, we consider that the magnetic reconnection at the C2.4 flaring site changed the magnetic environment of the filament, destabilized the highly twisted magnetic field structure, and finally allowed the twisted magnetic field to erupt.

各地方時における SFE の発生特性について

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The characteristics of SFE and SFE∗in each local time.

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It is well known that solar flare effect (SFE) is a temporary magnetic disturbance caused by intensifying ionospheric current due to strong solar flare, which emits intense X-ray or EUV radiations. In general, SFE shows similar variation as the Sq or equatorial electrojet (EEJ) in terms of the direction and magnitude. On the other hands, some previous studies have analyzed the unusual SFEs in the dip equator and near noon, which related to the occurrence of the partial equatorial counter electrojet. (Yamazaki et al., 2009; Rastogi et al., 2013)

In this study, besides the dip equator, the SFE in the low-mid latitudes also was analyzed. Consequently, some SFEs which did not correspond to Sq variation ($SFE_{Sq}*$) existed. We focused on the local time when SFE or SFE∗occurred in order to clarify its occurrence characteristics globally. We used the geomagnetic field data of the stations on the longitude of Japan, and evaluated the equivalent currents of SFE or SFE∗and pre-flare Sq. The results suggested that the SFE∗event was due to the enhancement of local current different from Sq current. More details will be explained at the time of presentation.

Solar Flare Effect（SFE）は太陽フレアにより放出される X 線や EUV が電離層の電気伝導度を高め、電離層電流を増長させることで発生する地上磁場の一時的な擾乱現象である。一般的な SFE は EEJ や Sq 電流の向きや大きさに対応した変動を示す。Yamazaki et al., [2009] では磁気赤道の正午付近で counter-Sq 方向への変動を示す SFE を SFE∗と定義し、２つの SFE∗イベントを報告している。これらのイベントは Rastogi et al., [2013] で、正午付近で発達していた partial CEJ と関連していると結論づけられた。

本研究で SFE の解析を磁気赤道域だけではなく中低緯度域にまで広げたところ、中低緯度域においても幾つかの特異的な変動を示す SFE が存在することがわかった。中低緯度域で Sq と対応していない変動を示す SFE を $SFE_{Sq}*$イベントとして成分ごとに $SFE_{Sq-H}*$、 $SFE_{Sq-D}*$、$SFE_{Sq-H,D}*$と分類している。主に日本の経度帯の観測点を使用し、等価電流法を用いて SFE 発生時の等価電流系を評価し、LT ごとに SFE の発生特性がどのように異なるのかについて解析を進めている。より詳細な内容については発表時に紹介する予定である。

太陽表面磁場を用いた次期太陽周期活動度予測

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Predicting the Next Solar Cycle from the Photospheric Magnetic Field

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Prediction of the solar cycle amplitude is an important task to know the future space weather environment in the time-scale over several years. One successful prediction method is precursor method where the photospheric magnetic field in the polar region at the solar cycle minimum is used as a precursor of the amplitude of the next solar cycle maximum. The high correlation between the precursor and the strength of the next cycle is found at least in the past 100-years. The precursor method allows us to predict the solar cycle amplitude 5–6 years before the solar maximum.

Our next step for the solar cycle prediction is to predict the polar field strength at the solar minimum several years before the minimum. The Surface Flux Transport model (SFT) is a model to describe the evolution of the solar surface magnetic field. Recently, the prediction of the polar field by the SFT is reported in several studies. However, this model has a large uncertainty on the modeling of the new emergence of the sunspots. We investigate the contribution of the new emergence of the sunspots on the polar field prediction based on the observed magnetogram in the last four solar cycles. We find that the contribution of the new sunspots becomes very small in the period of several years before the each solar cycle minimum. The result indicates that the current polar field strength in 2017 can be used as a precursor of the next solar cycle. Based on the findings, we suggest that the next solar cycle will be similar or slightly weaker than the current cycle.

歴史文献におけるオーロラ図像史料と宇宙天気研究における可能性

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Auroral Drawings in Historical Documents and their Possibility for Space Weather Science

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In this presentation, we examine a couple of auroral drawings in historical documents in comparison with their relevant text descriptions to see the detail of some contemporary mid to low latitude auroras caused by severe magnetic storms. While historical documents allow us to trace space weather activities back for more than 2.5 millennia, we have only limited number of drawings within this coverage. However, auroral drawings can provide us the information that may be difficult to reconstruct from the text records. Therefore, especially, we examine auroral drawings in 8th century within the Syriac autograph manuscript and those in 18th century in East Asian manuscripts. Thus, we show how we can make use of these auroral drawings to improve our understandings on the activity of auroras and space weather events in historical time in connection with text descriptions. These drawings are of great importance to show that auroras have been seen quite vividly by naked eye in low latitude areas and hence we should revisit the brightness and color of historical auroras in low latitude areas.

本報告では，歴史文献における二三のオーロラ図層をその関連記述と比較の上議論し，強い磁気嵐によって引き起こされた同時代の中緯度・低緯度オーロラを検討する。歴史文献では宇宙天気活動を 2500 年近く遡上できるが，それに対する図像史料となるとその数は限られる。その一方，このような図像史料はしばしば文字記録だけからは斎下験しがたい情報を補うことがある。そこで特に本報告では 8 世紀のシリア語自筆写本や 18 世紀の東アジアの写本に見える二三のオーロラの図像史料を検討する。そのため，本報告では歴史時代におけるオーロラや宇宙天気現象を文字記録と比較することにどのように寄与し得るかを明かす。これらの図層は低緯度地域においてオーロラが肉眼で鮮やかに実見された事例である点で非常に重要で，それ故低緯度地域のオーロラ記録の輝度や色と言った事項についても再検討を迫るものである。

宇宙天気と放射線被ばく

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Space Weather and Radiation Exposure

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Radiation effects on astronaut and aircrew due to cosmic-ray exposure are of great public concern. Galactic cosmic-ray (GCR) is the dominant contributor to their cosmic-ray doses, but solar energetic particle (SEP) can also play an important role in their dose evaluation when a large solar flare occurs. Thus, the investigation on the acceleration mechanism of SEP and the forecast of the SEP doses is one of the most important issue in the space weather research related to social needs. In this presentation, the current status of research on cosmic-ray exposure is briefly reviewed, including the recent improvements of WASAVIES (WArning System for AVIation Exposure to SEP) developed under framework of PSTEP.

宇宙飛行士や航空機乗務員の宇宙線による放射線被ばくが，近年，社会の大きな関心を集めている。その主な被ばく源は銀河宇宙線（GCR）であるが，巨大な太陽フレアに伴って発生する太陽高エネルギー粒子（SEP）も大きな被ばく源となる可能性がある。したがって，SEP 発生メカニズムの解明とその被ばく線量予測は，社会的ニーズに対応した宇宙天気研究の一環として，重要な研究課題の 1 つとなっている。本発表では，宇宙線被ばくの概要について解説するとともに，科研費新学術領域 PSTEP の一環として実施している航空機被ばく警報システム WASAVIES の開発について紹介する。

Modeling geomagnetically induced currents (GIC) in the 500 kV power grid in Japan

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A realistic model of GIC in the Japanese 500 kV power system is developed for the first time to estimate the influence of the geomagnetically induced currents (GIC) on the Japanese electrical distribution grid. Previously, it is believed that there is no threat in Japanese power grid because of the Japanese location at mid-latitude far from auroral- or equatorial- electrojet. Then, scarce research has been done to assess detailly the GIC influence in Japan.

We develop the 500 kV power grid model in Japan and calculate GIC assuming uniform electric fields on Earth's surface and more realistic electric fields. Geomagnetically induced electric field (GIE) is obtained by Finite-difference time-domain (FDTD) method, given a uniform sheet current changing with a period of 100 s at the upper air as a source. A three-dimensional electrical conductivity is derived from a global relief model (NOAA) and a global map of sediment Thickness (Gabi Laske and Guy Masters). The Japanese GIE exhibit strong coastal effects and some anomaly spots resulting from underground structures of the conductivity. Due to the shape of a thin bow, Japanese lands can play a role like a capacitor according to the direction of the source current. Basically, a largest magnitude of GIC is obtained at Kashiwazaki with a North-South electric field. Using our model, we can compare factors of resistance parameters of the power grid, the positional relationship, the direction of source currents, underground structures in GIC distributions in the Japanese high-voltage power grid.

地磁気から再現する誘導電流の周期依存性

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Period dependence of reproducibility of the geomagnetically induced currents

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The GIC has been evaluated from the magnetic field using the Faraday's law, i.e., dB/dt [Viljanen GRL1997; Carter et al., JGR2016]. On the other hand, Watari et al. [SW2009], analyzing the GIC and magnetometer data in Hokkaido, showed that the GIC is not correlated with the dBx,y,z/dt, but well correlated with By. The results indicate that the Ampere's law relating the electric current and magnetic field should be included to reproduce the GIC. In this paper, we first made correlation analyses between the GIC and By with short (<1h) and long (>several hours) periods, to examine if the GIC-By correlation is valid for any space weather disturbances. We found that the correlation is good for short period (cc >0.8) but poor for long periods (cc <0.3). To reproduce the long period GIC from the By, we calculated the electric field induced by By in the conducting Earth. Assuming the Earth be a uniform conductor, we obtained the induced electric field with better correlations (cc >0.9 for T >several hours). Our technique is based on the convolution of the step response of the uniform conductor and dBy/dt. The period dependence of the GIC may be due to inhomogeneous structures of the electric conductivity of the Earth, which remains one of important issues for prediction of the GIC.

Recent activity of HF-START

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HF-START (HF Simulator Targeting for All-users' Regional Telecommunications) is a user-friendly simulator developed to meet the needs of space weather users. Prediction of communications failure due to space weather disturbances is of high priority. HF-START is originally developed for radio propagation in HF band (3-30 MHz). It is the first approach to utilize regional ionospheric data, especially in Japan and southeast Asia, as a propagation medium. The evaluation campaign of HF-START for Japan region is planed to be launched by the end of fiscal year 2017. If the evaluation campaign successes, it will be expanded to southeast Asia region hopefully in the next fiscal year. Even though the HF-START is developed for the HF band, we plan to expand the frequency coverage up to L band under the collaboration with Centre National D' Etudes Spatiales (CNES), France. GAIA will be the priority model employed as a global ionospheric input. The final goal of the project is to provide the near-realtime necessary radio parameters as well as the warning message of radio communications failure to the radio and space weather users.

HF Doppler多点観測による磁気嵐の夜側過遮蔽電場

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Night-side overshielding electric fields during the geomagnetic storm as observed with HF Doppler sounders

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Prompt penetration electric field on the night-side was investigated using HF Doppler sounders (HFDs) at multipoint during the intense geomagnetic storm on 22-23 June, 2015. The storm was initiated by a storm sudden commencement at 1833 UT and immediately after that, storm main phase developed and reached a minimum SYM-H of -207 nT. The global magnetometer networks, NICT chain, INTERMAGNET showed that the DP2 currents and equatorial electrojets (EEJs) developed on both the day- and night-sides during the storm main phase. The global ionospheric current suddenly decreased during the time period of 1950 UT to 2010 UT because of the sudden northward turning of the interplanetary magnetic field. We found anomalously strong overshielding electric fields on the nightside at the beginning of the recovery phase based on the HFD observations in Iidate, Japan (0500 MLT) and Prague, Czech (2130 MLT). The overshielding electric field was eastward with the intensity of 9.9 mV/m at Iidate and 14.8 mV/m at Prague and the duration was about 17 minutes. On the other hand, the midlatitude SuperDARN radar in the American sector (Blackstone) observed anti-sunward plasma flows at latitudes lower than 47 degrees GM after 2010 UT, equatorward of the expanded dusk convection cell, indicating that the overshielding occurred due to the northward excursion of the IMF. It is remarkable that the overshielding caused westward counterelectrojet (CEJ) at the dayside equator and eastward equatorial electrojet (EEJ) on the nightside. Based on the HF radio and magnetometer observations, we suggest that the intense overshielding electric field penetrated near-instantaneously to the mid- and low-latitudes and caused the EEJ/CEJ on both the day- and night-sides during the geomagnetic storm.

宇宙環境変動を考慮した衛星帯電シミュレーション研究の現状と展望

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Recent Advancement of Spacecraft Charging Predictions via Computer Simulations

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As strong demand arises regarding the assessment of space weather effects on human infrastructures, we need to develop a better understanding of space environmental perturbation effects on spacecraft charging processes. Owing to advancement in computer technology, numerical simulations have progressed as a powerful method for spacecraft charging model predictions. There are a number of software packages (e.g., MUSCAT) for spacecraft charging analysis based on a particle description of space plasma. To reduce the computational cost resulting from the particle model, however, a number of approximate treatments are normally introduced in the models. We believe the necessity of self-consistent considerations of transient processes of plasma interactions with solid spacecraft surfaces to understand a close linkage between spacecraft charging and dynamically-changing space environment. We present some examples of such situations and discuss the outlook for future spacecraft charging study via computer simulations.

多様な宇宙天気現象によりダイナミックに変動する地球磁気圏プラズマ環境と、衛星障害の原因となりうる帯電現象の間の物理的関連を明らかにすることは、宇宙天気が人類の社会インフラに及ぼす影響を定量的に評価する上で非常に重要である。衛星帯電解析に関して、近年特にその有効性が認識されているのが、数値シミュレーションによる帯電評価である。現在、世界各国で粒子モデルに基づく衛星帯電解析ソフトウェアが開発され、実用化されている。粒子モデル解析はその計算コストが膨大であるため、上記ソフトウェアでは、衛星表面付近でのプラズマ素過程の一部を解析解もしくは経験モデルにより近似することで、計算の高速化を図っている。一方、最新の研究成果では、衛星表面近傍の空間電荷効果やプラズマ波動現象に伴う変動電磁場等が、衛星帯電に影響を及ぼすことも指摘されており、衛星周辺の非一様プラズマ構造や過渡応答を考慮した第一原理計算に基づく解析の必要性が提起されている。本講演では、そのような詳細解析が有効な事例を紹介した上で、衛星帯電の数値シミュレーション研究の今後の方向性について議論を行う。

Dst 指数の上下限値と IMF の太陽風プラズマ依存性

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Upper and lower limit of Dst index and IMF dependence upon solar wind plasma.

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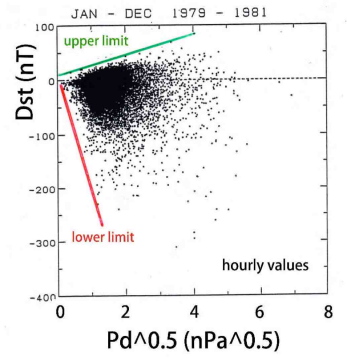
The scatter plot of the Dst index versus the square root of the solar wind dynamic pressure (sqrt(Pd)) shows a upper limit which slowly increases with sqrt(Pd) and a rapidly decreasing lower limit (Araki et al.,1993).

The increasing upper limit expresses the magnetic effect of the magnetopause current which increases with Pd. The IMF-Bz is positive at the upper limit and from there the Dst increases negatively with increasing negative Bz. It means development of the ring current and therefore, the ring current intensity becomes minimum at the upper limit.

The decreasing lower limit of the Dst plot means that development of the ring current is suppressed when Pd becomes smaller. We checked solar wind properties and found that the IMF-Bz converges to zero with decreasing Pd while IMF-Bx and By converge to the spiral field values (+- 3-5 nT). Contrary to our general expectation, IMF depends upon solar wind plasma parameters (dynamic pressure or density in this case) when the dynamic pressure is small.

太陽風動圧 (Pd) の平方根に対する Dst 指数のスキャタープロットは，緩やかに増加する（右上がりの）上限値と急速に減少する（右下がりの）下限値を示す (Araki et al., 1993)．右上がりの上限値は，Pd と共に増加する磁気圏界面電流の磁場効果を表わしている．ここでは IMF-Bz は正であり，IMF-Bz が負方向に動くにつれて，Dst は負方向に増加する．これは，環電流の増加によるものであり，上限値では環電流強度が最小になっている筈である．

右下がりの下限値は，Pd が小さくなると環電流が発達し難くなる事を示しているが，磁気圏がそのような性質を持っているのであろうか？ 解析の結果，下限値は，磁気圏ではなく太陽風の構造によって作られていることが判った．即ち，Pd が小さくなるにつれ，IMF の Bx, By はスパイラル磁場に対応する値（正負 3-5nT）に，また，Bz は零に収斂する．つまり，Pd が小さい時，IMF-Bz は，正にも負にも大きな値を取れないのである．一般に，IMF は太陽風プラズマとは独立に振る舞うと思われていたが，そうではなかったことになる．



Comparison of magnetic field variations at quasi-zenith orbit based on Michibiki observation and REPPU global MHD simulation

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We are developing a numerical simulator for future space weather forecast using magnetosphere-ionosphere coupling global MHD simulation called REPPU (REProduce Plasma Universe) code. We investigate the validity of the MHD simulation result as compared with observation. In this study we simulate some events including both quiet and disturbed geomagnetic conditions using OMNIWeb solar wind data. The simulation results are compared with magnetic field observations from Michibiki satellite, which is on the quasi-zenith orbit (QZO). In quiet geomagnetic condition, magnetic field variations at QZO obtained from simulation results have good consistency as compared correspondence with those from Michibiki observation. In disturbed geomagnetic condition in which the Dst <-20 nT, however, V component of magnetic field variations from simulation results tend to deviate from observations especially at the night side. We consider that this deviation during disturbed geomagnetic condition might be due to tail and/or ring current enhancement which is already suggested by many other MHD simulation studies as compared with the magnetic field observation at geosynchronous orbit. In this presentation, we will discuss the cause of this discrepancy in more detail with studying the relationship between the magnetic field deviation and some parameters such as Dst and solar wind.

日本における電離圏脅威モデル最適化のための電離圏勾配解析

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Ionospheric gradient analyses for the optimization of the GBAS ionospheric threat model in Japan

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Ground-Based Augmentation System (GBAS) using Global navigation satellite systems (GNSS) is planned to be implemented in Japan in the near future. It is important to understand the statistical characteristic of ionospheric gradient over Japan to mitigate the effect of the ionospheric threat for GNSS. This paper presents the result of ionospheric gradient analyses for the optimization of the ionospheric threat model in Japan which targets the plasma bubbles. This research aims to optimize the ionospheric threat model developed for International Civil Aviation Organization (ICAO) Asia-Pacific region by Electronic Navigation Research Institute (ENRI). The single-frequency-carrier-phase based and code-aided technique and GEONET data are used.

衛星航法 (GNSS) は、次世代の航空航法として導入が進んでおり、日本においても静止衛星型衛星航法補強システム (SBAS) が MSAS として運用されているほか、地上型衛星航法補強システム (GBAS) の導入が進められている。本報告では, 日本における，GBAS 性能に影響を及ぼすプラズマバブル等に伴う局所的電離圏脅威モデルの構築のための電離圏勾配解析について報告を行う。航空航法では GPS L1 帯信号（1.5742GHz）の 1 周波のみが使用可能であるため, プラズマバブル等の電離圏脅威の影響を統計的に把握しておく必要がある。これまでに電子航法研究所（ENRI）では, 国際民間航空機関（ICAO）においてアジア太平洋地域 GBAS 共通電離圏脅威モデルの提案を行ってきた [Saito et al., submitted to GPS Solutions]。本研究はこのアジア太平洋地域 GBAS 共通電離圏脅威モデルを基礎とし、日本におけるデータのさらなる解析により、脅威空間の最適化を目的としている。解析手法としては、L1 信号のみを用い２受信機間の電離圏遅延量差を精密に導出する Single-Frequency Carrier-Based and Code-Aided 法 [Fujita et al., JAAA, 2011; Saito et al., ION GNSS 2012] を用いる。データは、GEONET により観測されたものを用い、プラズマバブルが到達する範囲及び空間スケールや速度等を中心とした統計的解析を行う。講演では、比較的磁気緯度の高い本州付近及び磁気緯度の低い沖縄付近における解析の中間結果について報告する。

GAIAを用いたプラズマバブル発生予測について

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On the prediction of plasma bubble occurrence using GAIA

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Recently, prediction of plasma bubble occurrence has become one of the most important issues in space weather forecast. Prediction of ionospheric disturbances requires a high-resolution numerical model of the ionosphere and atmosphere coupling system as well as real-time ionospheric observations. We have been developing a whole atmosphere-ionosphere coupled model GAIA (Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy). However, the present version of GAIA does not have enough spatial resolution to reproduce plasma bubbles directly. Under the present conditions, there are two methods of predicting plasma bubble occurrence: (1) estimating the linear growth rate of the ionospheric Rayleigh-Taylor instability (RT-GRT) in the GAIA simulation data and using the value for index of plasma bubble occurrence, and (2) reproducing plasma bubbles by coupling a local high-resolution ionospheric model (plasma bubble model) and GAIA to predict the occurrence and propagation of plasma bubbles. We first studied the method (1). We obtained the maximum of RT-GRT for each day, and compared the values with observations of plasma bubble occurrences. The result suggests that large values in RT-GRT tend to correspond to the plasma bubbles occurrence. For the method (2), we are examining the coupling scheme and developing the coupled model. For both methods, predictive simulation of one day to a few days is necessary for practical use in space weather forecast. For the prediction of the atmospheric model part, we are examining two methods: (1) employing the meteorological forecast data instead of the meteorological reanalysis data, and (2) running the GAIA model freely without any input for the lower atmosphere. As for the polar ionospheric disturbances, which have significant effects on the occurrence of plasma bubbles, long-term prediction is rather difficult. We will report the current status of the prediction of plasma bubble occurrence using GAIA, and discuss outstanding problems.

電離圏プラズマバブルの発生予測は宇宙天気予報における最重要課題の一つであるが、そのためにはリアルタイムの電離圏観測とともに、高精度の大気圏・電離圏結合モデルが必要である。我々のグループでは、全大気圏-電離圏結合モデル（GAIA）を開発してきたが、現在のGAIAは分解能がまだ十分ではなく、プラズマバブルなどの電離圏メソスケール現象を直接再現することはできない。現時点で可能な予測方法としては、(1) GAIAのデータからレイリー・テイラー不安定の線形成長率を見積もり、それを用いてプラズマバブルの発生確率を予測する方法、(2) GAIAと高精度局所電離圏モデル（プラズマバブルモデル）を結合してプラズマバブルを直接再現してその発生・伝搬を調べる方法、の２つが考えられる。我々はまず(1)の方法を検討し、GAIAのシミュレーションデータから、各日について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、線形成長率が大きくなる日はプラズマバブルの発生日と概ね一致する傾向があり、確率予測を行える可能性があることがわかった。(2)の方法については現在、結合スキームの検討と試験を進めているところである。プラズマバブル発生予測においては、実用的には1日から数日の予測が必要であるが、予測計算の方法としては、(1) GAIAの下層大気に入力している気象再解析データの代わりに気象予報データを入力とする方法、(2) 下層大気の入力なしでGAIAを実行して予測する方法、の２つがある。また、プラズマバブルの発生には、地磁気じょう乱の影響もあると考えられているが、極域での磁気圏からの影響については長時間の予測が難しいという問題がある。本講演では、GAIAを用いたプラズマバブルの発生予測方法についての現状を報告し、問題点を議論する。

GAIA結果を用いた電離圏嵐指数評価

垰 千尋 [1]; 品川 裕之 [1]; 西岡 未知 [1]; 陣 英克 [1]; 三好 勉信 [2]; 藤原 均 [3]; 津川 卓也 [1]; 石井 守 [1]
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Estimation of ionospheric storm scale using GAIA

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Total electron content (TEC) derived from the Global Navigation Satellite Systems (GNSS) observation network is one of important parameters to monitor the ionosphere. Ionospheric daily- and disturbed-variations change with season, location, and local time. Ionospheric storm scale, I-scale, is proposed to measure the ionospheric disturbance above the daily-variation compared with the statistical standard deviations binning into the seasonal, latitudinal, and local time dependence [Nishioka et al., 2017]. The occurrence ratio of large I-scale values at Japan increases with geomagnetic activities through ionospheric positive and negative storms. In addition, the disturbed I-scale is often occurred during the geomagnetic quiet condition (Kakioka K-index <4), which contributes more than half of the total number of the ionospheric disturbance. This would be mainly caused by the TEC variation due to extensions of the geomagnetic equatorial anomaly (EA) up to the middle latitude. Energy input from the low altitude atmosphere affect the position change of the EA via dynamo effect.

GAIA (Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy) is a physical model which solves dynamics and chemical reactions of the whole atmosphere region from the troposphere to the exosphere under interactions with the ionosphere. In order to apply GAIA to the space weather forecast, this study derives the TEC I-scale based on a long-term (1996-2016) dataset derived by GAIA. In this presentation, we will present comparisons of statistical variations between GAIA and observation results, those among locations, and I-scale variation due to solar flux and atmospheric dynamics.

電離圏全電子数 (TEC) は、GNSS 観測網を活かして、準リアルタイムにモニターできる電離圏観測量である。場所・時間・季節によって、電離圏の定常的な周期的変化も擾乱による変化の大きさも異なる。これらの依存性に依らない、電離圏電子密度の擾乱の規模を評価する指標の一つが、電離圏嵐指標 I-scale である。I-scale は、参照電離圏変動を直前の 27 日平均の日変動で定義し、この参照電離圏変動からのずれ具合を、緯度・時間・季節を分類した長期観測データの統計的分散量を基準に測ることで、擾乱の大きさを定める [Nishioka et al., 2017]。地磁気活動度が高いほど、電離圏正相嵐・負相嵐の発生によって、日本上空での電離圏擾乱の発生確率が高くなる。しかし、柿岡の地磁気 K 指数が 3 以下の地磁気静穏時でも、電離圏擾乱の半数ほどを占める擾乱現象がみられる。これは、磁気赤道異常の電子密度増大構造が中低緯度まで張り出してくることも TEC 変動に影響するためである。磁気赤道異常の形成位置の変化に、大気運動の変化によるダイナモ電場も影響する。

GAIA（Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy）は、地上から超高層領域までを境界なくつなぎ、大気圏と電離圏の相互作用をはじめ主要な物理過程を含む物理モデルである。モデルは、下層大気からの伝搬波動の影響を含む大気運動やダイナモ電場のもとで、電離圏電子密度の変動を見積もる。本研究は、GAIA のモデル評価と宇宙天気予測への応用を目的に、1996 年から 2006 年にかけての GAIA 計算結果を用いて、I-scale 導出とその変動の調査を行った。本発表では、I-scale の導出時に評価する統計分布の観測との比較や、地域別の違い、太陽紫外線および大気擾乱による I-scale 変動への影響について議論する。

SMILES-2衛星計画における惑星大気・天文観測応用

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Applications of SMILES-2 Satellite Mission to Observations of Planetary Atmospheres and Astronomy

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For better understanding of global warming, space weather predictions, recovery of Ozone layer, physics and dynamics such as planetary and gravity waves, and chemical reaction networks of the Earth middle atmosphere, the Superconducting Submillimeter-Wave Limb-Emission Sounder 2 (SMILES-2) mission is currently being studied. The targets of this mission are wind profiles, global temperature, and three dimensional minor constituents such as HO, HO_2, NO, NO_2, H_2O, N_2O, O, O_2, CO, H_2CO, HCl, ClO, HOCl, CH_3Cl, and their isotopes. The SMILES-2 will employ 4 K-cooled superconductor/insulator/superconductor mixer detectors for 487 to 653 GHz range and superconducting hot-electron bolometer (HEB) mixer detectors for 1.8 to 2.0 THz range, respectively.

In this mission, the atmospheres of the planets in the solar system and interstellar matters will be observed. Mars and Venus are the important targets to research how the physical and chemical conditions of planetary atmospheres balance under the activities of host stars. To investigate the origin of the chemical stability of CO_2-dominated atmospheres and the destruction processes of CH_4 on Mars, it is crucial to reveal the fundamental oxidization networks on the Martian and Venusian atmospheres. The observation of the oxidants like OH, O_3, O_2, OI, and so on which are difficult to access with ground-based telescopes is the key to address these issues. In this conference, we will present the current status of the developments of 2.0 THz band horn/waveguide-type HEBM detector receivers for superconducting NbTiN nano-brigde and the feasibility studies of the spectral lines of these minor constituents achieved by SMILES-2.

現在、国際宇宙ステーション JEM/SMILES の後継となる SMILES-2(Superconducting Submillimeter-Wave Limb-Emission Sounder 2) のワーキンググループが立ち上がり、サブミリ・テラヘルツ (THz) 波帯での地球中間圏・下部熱圏の衛星観測が提案されている。このミッションでは、地球における O_3 層回復や地球温暖化などの予測精度向上や成層圏・中間圏の風速場、重力波/Planetary 波の影響などの総括的理解を目指しており、H_2O, N_2O, NO_2, NO, CH_3Cl, BrO, CO, H_2CO, OH, O_2, O_3 and O-atom などの分子種を観測ターゲットとし、487 GHz から 2.0 THz 帯までをカバーする複数バンドの観測を見据えている (Suzuki et al. Proc. of SPIE, 2015)。受信機には閉サイクルの 4 K 機械式冷凍機を搭載し、SIS 接合や HEB 細線などを集積した超伝導ヘテロダイン検出素子を実装する計画である。

このなかで THz 帯は検出器において未開拓な波長領域であるが、我々は現在、SMILES-2 のリムサウンディングに対応可能な、超伝導 NbTiN 細線を集積した 1.8-2.0 THz 帯ホーン/導波路集光型ホットエレクトロンボロメータ (HEB) ミクサの開発を進めている。これにより、地球大気だけでなく、太陽系惑星の観測も可能になると期待される。中心星の活動環境下における惑星の中層大気の化学的・物理的バランスを理解する上でも、火星や金星は重要な観測・研究サンプルである。特に太陽系地球型惑星では CO_2 の安定問題の議論が古くからあり、また最近では火星において生物起源の可能性が示唆される CH_4 などが観測されており、惑星環境における基本的な酸化反応のネットワークの解明は急務の課題となっている。これには地上から観測が困難な H_2O や O_2 だけでなく、THz 帯に輝線をもつ OH や O 原子など酸化を司る微量分子の同時観測が鍵を握る。これらの分子は、系外惑星のバイオマーカーの振る舞いの理解にも重要な役割を担う。また、天文観測への応用として、星間分子雲の物理・化学進化に重要な役割を果たす C+や O 原子の詳細分布や、星間雲においてイオン・原子から成長する有機分子の多様性の解明が期待される。本研究では SMILES-2 を用いた、火星や金星の中層大気の放射輸送モデル計算や、超伝導 NbTiN 細線を用いた HEB 検出器の開発状況について報告する。

衛星帯電予報のための衛星表面電位のリアルタイム推定手法の開発

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Development of a real-time risk estimate method of spacecraft surface charging

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Spacecraft anomalies are often induced due to surface charging and resultant discharging arcs. We are developing a real-time estimate method of surface charging potential for the Space Environment Customized Risk Estimation for Spacecraft (SECURES) of the space weather forecast Project for Solar-Terrestrial Environment Prediction (PSTEP). We will show current status of our system.

地球磁気圏のプラズマ環境が原因で、人工衛星が表面帯電・放電し、結果的に異常を引き起こすことがある。設計段階で、表面帯電由来の衛星の異常を防ぐために、衛星の表面帯電をシミュレーションするソフトが各国で開発されてきた。これらのソフトは、与えられたプラズマ環境に対して衛星表面電位を求めることができるが、一般に計算には時間がかかり瞬時に電位を返すものではない。そこで、宇宙天気予報の一環として衛星帯電予報をリアルタイムで行うために、帯電予報の対象となる衛星を想定して、プラズマ環境を与えると瞬時に衛星表面電位を推定する手法の開発を行なっている。現在開発中の手法では、対象とする衛星に対して，まず衛星表面帯電解析ソフトの Spacecraft Plasma Interaction Software (SPIS) を用いて衛星モデルを作り、衛星軌道環境パラメータとして、日照・日陰でのプラズマの密度と温度の代表的な組み合わせでシミュレーションを事前に行い、衛星表面電位の計算結果をテーブルとして用意しておく。そして、衛星軌道上のプラズマの密度と温度の入力に対して、このテーブルデータの値を用いて補間することで、衛星表面電位をリアルタイムで推定する。この推定手法のプロトタイプとして、Van Allen Probes 衛星モデルを用いて、事前計算しておく環境パラメータの組み合わせ等を、観測値との比較・検証により調べる。その後、静止軌道衛星を模したモデルも対象にする計画である。本発表では、その現状を報告する。

衛星太陽電池劣化から探る放射線帯プロトンの空間分布

三宅 亙 [1]; 戸田 穂乃香 [1]; 三好 由純 [2]; 豊田 裕之 [3]; 宮澤 優 [3]; 篠原 育 [4]; 松岡 彩子 [5]
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Spatial distribution of trapped protons deduced from solar cell degradation on satellites

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Output of solar cells on any satellite decreases due to damage of the space radiations. We made analysis on the degradation of solar cells on the Akebono satellite orbiting in the inner magnetosphere over 20 years, and we successfully deduced spatial distribution of trapped protons. The Arase satellite has recently been launched and we are trying the similar analysis on the degradation of solar cells. The energy range of protons affecting the solar cells are higher than that of particle instruments on board the Arase satellite, so that we expect our unique method to deduce any additional information of the proton radiation belt. We will summarize the analysis results from the Akebono satellite and report recent progress for the Arase satellite.

Comparison Between Surface Charging Event from Michibiki (QZS) Satellite and Space Environment Data from Global MHD Simulation

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Space environment around geospace varies depending on the solar wind and high energy particle conditions originated from the solar activity. It is well known that the satellite anomaly sometimes happened because of the dynamical variations of the space environment. To understand the current and future conditions of space environment, which we call 'Space Weather Forecast', is one of the quite important activities for safety and security of the satellite operation.

On the other hand, the detailed information of satellite anomaly, possibly related to space disturbances, cannot be available in usual. The risk of the individual satellite depends not only on the space environment, but also on the materials of the satellite body and electrical components, which controls the satellite charging condition. Therefore, it is hard for the satellite operator to judge the risk of the satellite based on the space environment information only.

To solve this type of problem. we will try to develop specialized information for the nowcasting and forecasting space environment for each satellite, and also estimate the risk of satellite anomaly by combining information of space environment and that of satellite materials with a charging model. To seek this approach, we estimate the risk of satellite charging based on the prediction of space environment using the case study of MICHIBIKI satellite, which is on the quasi-zenith orbit. As a first step, we are comparing the space environment data and surface charging data obtained from MICHIBIKI satellite and space environment data obtained from Global magnetospheric MHD simulation. Although the global MHD simulation only produce MHD temperature and density, we need to make an empirical relationship between simulation and observation to obtain the estimated electron and ion temperature and density. In this presentation, we will introduce the results of our data analysis.

Impact evaluation of long term space weather activities on space debris environment evolutionary model

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Space debris is the collection of defunct objects in space made by human activities (payload, rocket body, mission related debris, and so on). It is very important to reduce amount of space debris around the Earth, because they put serious crimps in space developments. Kyushu University and JAXA developed the space debris environment evolutionary model, named NEODEEM (Near-Earth Orbital Debris Environment Evolutionary Model) for evaluating current and future conditions of space debris on geospace and validities of space debris reduction measures. Atmospheric drag force is one of the main causes of space debris orbit change. Atmospheric density change is affected from space weather, for example, solar and geomagnetic activities. It is essential for development of space debris evolutionary model to consider the impact of space weather. We improved atmospheric density model in our space debris evolutionary model to incorporate many kind of space weather related parameters and calculate more precise density. We performed some simulations under different solar and geomagnetic parameters to evaluate long term effects of these activities. In the result, we found that space debris environment would also become significantly worse because of collision cascading even with no launches in the case of low solar activity, like as solar cycle 24. Space debris environment would become worse under low geomagnetic activity caused by low joule heating and atmospheric drag. These effects are different between Kp and Dst indexes. In this presentation, we will introduce improved atmospheric density model and its responses to space weather activities in term of space debris environment evaluation.

IUGONET Type-A: Data service for data-driven-science in solar-terrestrial physics

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IUGONET is a community to promote comprehensive research in solar-terrestrial physics, which is composed of many Japanese universities and institutes, such as NIPR, Nagoya Univ., Kyoto Univ., Tohoku Univ., Kyusyu Univ., NICT, NAOJ, JMA and Kanazawa Univ.. Our team has mainly developed and provided two products, i.e., IUGONET Type-A and UDAS (IUGONET Data Analysis Software). IUGONET Type-A is a data service to provide data information, and UDAS is an analysis software based on SPEDAS (Space Physics Environment Data Analysis Software) and IDL (Interactive Data Language).

IUGONET Type-A provides not only data information (e.g., description, acknowledgement [data policy], start and stop date, contact person, data publisher URL, observatory, and instrument) but also quick-look images (QLs) of the data and how to create these QLs. In particular, thumbnail viewer for QLs is very useful to compare and/or calculate the correlation among various data. In addition, UDAS web enables to plot data easily on web browser (PC, smartphone, tablet device and more) using the SPEDAS/UDAS and IDL engine without any installation/setup of dedicated software and license. Therefore, IUGONET Type-A is a one-stop data service that enables to search, understand, visualize and examine data, and thus can quickly promote and support new interdisciplinary studies regarding the solar-terrestrial physics.

Furthermore, our team has developed abstraction framework named IUWAF (IUGONET Universal Web Application Framework). This framework can also work as the base of other system and handle multiple data format. It is expected to become a basic technology to lead to the discovery of new knowledge such as AI (Artificial Intelligence), and in fact, we have started the challenge to realize the data-driven-science in cooperation with other projects aiming for the same purpose (e.g., project to research the way of correlation, historical data such as historical literature, and so on.)

超高層大気長期変動の全球地上ネットワーク観測・研究 (通称: IUGONET) は，情報・システム研究機構，極地研究所，東北大学，名古屋大学，京都大学，九州大学，気象庁柿岡地磁気観測所，情報通信研究機構，国立天文台，金沢大学が連携し，各機関が所有する太陽地球系科学分野の観測データを融合して総合的な研究を推進するコミュニティである．IUGONET は，観測データに関する情報を提供するためのデータサービス IUGONET Type-A と，実際の観測データを解析するためのソフトウェア SPEDAS (Space Physics Environment Data Analysis Software) のプラグインである UDAS (IUGONET Data Analysis Software) を開発・公開している．

IUGONET Type-A は，観測データに関する説明，利用ポリシー，観測日時，データ保有者，コンタクト先，実際のデータの所在，観測機器，観測所などのカタログ型の情報に加え，観測データのプロット画像 (Quick-Look)，解析方法を，ウェブ上で一元的に提供している．特に，検索により得られたプロット画像を並べて表示する機能は，データの比較，相関の把握を迅速なものにする．また，SPEDAS/UDAS と連動しウェブ上でプロット画像を作成することができる UDAS web は，専用ソフトウェアのインストールを必要とせず，パソコンのみならずスマートフォンやタブレット端末でも，データ自由に組み合わせてプロット画像を手軽に作成することができる．つまり，IUGONET Type-A は，データを発見する，解析したいデータを抽出する，解析する，比較することにより，新たな知見を迅速に得るための研究活動をワンストップで支援する．

また，IUGONET は，IUGONET Type-A の開発と並行して，設計部を抽象化したフレームワーク IUWAF (IUGONET Universal Web Application Framework) の開発を開始した．抽象化されたフレームワークは，異種データサービスへの適用，複数のデータの取り扱いも可能であり，例えば AI (Artificial Intelligence) と呼ばれるような，全く異種のデータを組み合わせて新しい知見の獲得に向かうための根幹としても期待される．事実，人間の生活を示す社会データと太陽地球系分野の観測データなど異種データ間の相関手法を研究するプロジェクト，歴史文学等の史料データを扱うプロジェクトなどと連携し，第4の科学に象徴されるデータ駆動型科学の実現に向けた動きが始まっている．

IDLを用いた電離圏電気伝導度モデルの更新

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Update of the ionospheric conductivity model by using IDL

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http://researchmap.jp/7000010467/

The ionospheric conductivity model was implemented and opened to the public by Koyama et al. in 2014. This model uses the equations by K. Maeda and P.M. Banks, and is substituted each data by IRI2012, MSIS, and IGRF11. In this year, we updated the model to use the latest IGRF12.

In this presentation, we show the result by the latest ionospheric conductivity model. Then we compare the results from the latest model with the results from the older model.

2014年に小山らによって,「電離圏電気伝導度モデル」が開発および公開された．このモデルは，K. Maedaや P.M. Banksらによって導かれた数式に，IRI2012, MSIS, IGRF11のそれぞれのモデルから得られたデータを代入する．本発表では，最新のIGRF12を用いた電離圏電気伝導度モデルの計算結果を示し，過去のモデルとの比較を行う．

デジタル地球儀Dgik Earthのための半球面マルチタッチパネルの開発

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Development of the Hemispherical Multi Touch Panel for Digital Globe "Dagik Earth"

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http://researchmap.jp/7000010467/

For the digital globe Dagik Earth, development of an intuitively operable multi-touch panel is desired. Then we started to develop the hemisherical multi-touch panel. First, 1. irradiate the infrared light into the acrylic spherical surface, 2. the total reflection collapses at the touched location, 3. it is detected by using infrared camera, 4. our software to convert touch location and movement vector to mouse operation. For the software development, we used Community Core Vision, and A Protocol for Table-Top Tangible User interfaces.

Currently, we are trying to calibrate to make mouse operation intended for touch operation. In this presentation, we show the current status of our development.

デジタル地球儀 Dagik Earth には，直観的に操作可能なマルチタッチパネルの開発が望まれている．そこで我々は，半球面マルチタッチパネルの開発を開始した．まず，1. アクリル球面内に赤外線を照射し, 2. タッチした箇所で全反射が崩れ， 3. それを赤外線カメラで検出し，4. タッチ箇所や移動ベクトルをマウス操作にソフトウェア的に変換する，という過程によってマルチタッチパネルを実現する．ソフトウェア処理には，Community Core Vision，A Protocol for Table-Top Tangible User interfaces を用いた．予稿作成現在においては，タッチ動作を意図したマウス操作にするためのキャリブレーションを繰り返している段階である．本発表では，本研究の進捗を説明する．

超高層物理学におけるモデルとシミュレーションによるデータのメタデータ表現の考察

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Study of the Metadata Expression for Model and Simulation Data in Upper Atmospheric Physics

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http://researchmap.jp/7000010467/

The IUGONET provides the IUGONET common metadata format which is customized to accommodate metadata for the various kinds of ground-based observational data based on the SPASE data model/metadata format. The IUGONET has mainly dealt with ground-based observational data. However, for research on upper atmospheric physics, not only observational data but also model and simulation data are necessary. In the SPASE group, the metadata schema for simulation has already been provided. In this presentation, we focus on the model and simulation data, we discussed the metadata representation.

IUGONET は SPASE データモデル／メタデータフォーマットを基に，地上観測データに対応するように拡張を施し，IUGONET 共通メタデータフォーマットを提供している．IUGONET はこれまで地上観測データを中心に扱っていたが，多種多様な観測やデータ処理を必要とする研究には，モデルやシミュレーションを用いた補完的な研究が必須である．SPASE グループにおいては，既にシミュレーションのためのメタデータスキーマが提供されている． そこで，本研究においては，現在の IUGONET メタデータフォーマットが主な対象としていないモデルデータやシミュレーションデータに着眼し，そのメタデータ表現について考察を行った．

低緯度コロナホール起源の太陽風変動に対する地球磁気圏応答

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Response of the Earth's magnetosphere to solar wind variations originating from the low-latitude coronal holes

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Corotating interaction regions (CIRs) are produced by interaction between low- and high-speed solar winds. The high-speed solar wind originates from coronal holes and causes a major disturbance of the Earth's magnetosphere. Coronal holes are frequently observed in a declining phase of the solar cycle and have open magnetic fields expanding to the interplanetary space. Tsurutani et al. [2006] proposed that analyses of the temporal area of polar coronal holes over the solar cycle [Harvey et al., 2000; Harvey and Recely, 2002] provide a good idea of the geoeffectiveness of high speed solar wind over the solar cycle. However, an effect of isolated equatorial coronal holes has yet to be evaluated. In this study, in order to clarify the effect of the Earth's magnetosphere and ionosphere associated with the high-speed solar wind originating from the equatorial coronal hole, we conducted a superposed epoch analysis of the variations of coronal hole area, solar wind, interplanetary magnetic field (IMF), and geomagnetic indices (AL, AU, and SYM-H). The geomagnetic indices are provided by World Data Center for Geomagnetism, Kyoto University. We further divide the temporal variation of IMF into 4 types (IMF Bx : positive, IMF By : negative and IMF Bz : positive or negative, IMF Bx : negative, IMF By : positive and IMF Bz : positive or negative), and then investigate the variation of solar wind, IMF, and geomagnetic indices before and after CIRs reach the Earth's magnetosphere for each case. In the present analysis, we used the Sun whole two-dimension images taken by the Extreme ultraviolet Imaging Telescope (EIT) onboard the Solar and Heliospheric Observatory (SOHO). For analysis of solar wind and IMF, we referred to the advanced composition explorer (ACE), Wind. Their data availability period is from May 1996 to December 2009. For the coronal hole areas, we defined a threshold of the solar brightness in an extreme ultraviolet (EUV) range as a half of the median value of the intensity in a whole area and divided the solar surface in four regions: (-60 - -30, -30 - 30), (-30 - 0, -30 - 30), (0 - 30, -30 - 30), and (30 - 60, -30 - 30) (degrees) in the solar latitude and longitude, respectively. Finally, we determined the coronal holes area as a ratio of pixel numbers less than the threshold to each region. As a result, we observe a north-south asymmetry in the coronal hole areas, which shows that the coronal hole area is much larger in the southern hemisphere than in the northern hemisphere from 2000 to 2003. The temporal variation of the coronal hole area is the largest in the low-latitude to equatorial regions (-30 - 0) degrees during the data period. The sign of each IMF component tends to be reversed after CIRs pass though the Earth's magnetosphere in all events. The variation of AL and AU is maximum in a case of IMF Bx : positive, IMF By : negative and IMF Bz : negative. On the other hand, the variation of the SYM-H index is maximum in a case of IMF Bx : negative, IMF By : positive and IMF Bz : negative. From the above results, it can be inferred that the Earth's ring current flowing in the inner magnetosphere is efficiently developed in a case of IMF Bx : negative, IMF By : positive and IMF Bz : negative while the high-latitude ionospheric currents are significantly intensified in a case of IMF Bx : positive, IMF By : negative and IMF Bz : negative.

共回転相互作用領域 (Corotating interaction regions : CIRs) は低速 - 高速太陽風間の相互作用によって形成される。高速太陽風はコロナホールを起源としており、地球磁気圏の大きな擾乱の要因となる。コロナホールは太陽活動周期衰退期によく出現し、惑星間空間に開いた磁場構造をしている。Tsurutani et al. [2006] によれば、極域コロナホールの時間変動に着目した解析によって、太陽活動周期にわたる高速太陽風の地球磁気圏への影響が明らかになっているが (たとえば Harvey et al., 2000; Harvey and Recely, 2002) 、独立した赤道域コロナホールについての評価はまだ十分にされていない。そこで、本研究では赤道域コロナホールを起源とする高速太陽風の地球磁気圏・電離圏に与える影響を明らかにすることを目的とし、1996 年 3 月から 2009 年 12 月のコロナホール面積・太陽風・惑星間空間磁場 (IMF) ・地磁気指数 (AL、AU、SYM-H) について superposed epoch analysis をおこなった。また IMF の空間変動を 4 つのパターンに分け (IMF Bx :正, IMF By:負かつ IMF Bz:正または負、IMF Bx:負, IMF By:正かつ IMF Bz:正または負) 、各パターンにおいて CIRs が地球磁気圏に到達する前後での太陽風・IMF・地磁気指数の変動を調査した。今回の解析では、SOHO 衛星の極紫外線望遠鏡 (EIT) の 2 次元太陽全面画像を使用した。太陽風・IMF は ACE 衛星と Wind 衛星の観測データを用いた。地磁気指数は京都大学地磁気世界資料解析センター (WDC, Kyoto) のデータを用いた。また、太陽全面を極紫外線で観測したときの輝度の中央値の半分を閾値とし、太陽全面を緯度 (-60 - -30)、(-30 - 0)、(0 - 30)、(30 - 60) (度)、経度 (-30 - 30) (度) の 4 領域に分け、各領域内のピクセル数と閾値より輝度の低いピクセル数の比から面積を推定した。結果として、コロナホール面積の空間変動は南北で非対称であることがわかった。具体的には 2000 年から 2003 年の間に南半球の方が北半球よりコロナホール面積が大きかった。また、解析期間全体での面積変動は南半球の低緯度 (-30 - 0) (度) がもっとも多かった。さらに、CIRs が地球磁気圏を通過した後に IMF 各成分の符号の反転が全イベントで見られた。地磁気指数は IMF Bx:正、 IMF By:負、 IMF Bz:負のとき AL、AU 指数の変動が最大だった。一方で、IMF Bx:負, IMF By:正かつ IMF Bz:負のとき SYM-H 指数の変動が最大だった。このことから、IMF Bx:負、IMF By:正かつ IMF Bz:負の場合は内部磁気圏を流れる環電流が発達し、IMF Bx:正、 IMF By:負かつ IMF Bz:負の場合は高緯度電離圏電流が発達すると考えられる。

Ionospheric TEC forecasting model based on linear time-series and ARMA methods over a Low latitude GNSS Station

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Forecasting of ionospheric time delays has become a significant importance in satellite based navigation and communication system applications. Several researchers have been developed and implemented univariate Total Electron Content (TEC) forecasting models successfully over low, mid and high latitude regions. Therefore, identifying an effective multivariate forecasting technique is very essential to protect the GNSS users under various geophysical conditions. In this paper, a new ionospheric TEC forecasting model based on linear time-series and Autoregressive and Moving Average (ARMA) is proposed and implemented using Bangalore International GNSS Service (IGS) station data (geographic 13.02^{o}N, 77.57^{o}E; geomagnetic latitude 4.4^{o}N) during an extended period (2009-2016) in the 24th solar cycle. ARMA model can provide high accuracy in forecasting the localised ionospheric TEC variations from its estimated coefficients in the proposed forecast model. The major factors, namely, solar Extreme Ultraviolet (EUV) irradiance (F10.7p), geomagnetic activity (Ap), periodic oscillations (annual, semiannual and terannual oscillations) and secular trend are considered in the model as input parameters along with real time TEC observations. The proposed model is twofold: first, the impact of different solar, geomagnetic, trend and periodic factors on TEC has been investigated from linear model. Second, ARMA method is applied for forecasting the each factor. The forecasted individual factors are combined to obtain forecasted TEC values. The correlation coefficient of the estimated TEC from the proposed model TEC and the observed Global Positioning System (GPS) -TEC is around 98%. The magnitudes of semiannual variation have been reflected to be high during the High Solar Activity (HSA) period. It is also found that the geomagnetic effect on TEC is relatively low. The proposed ionospheric TEC forecasting model would be useful for characterizing the low-latitude ionospheric variations.

全球TECデータに見られる磁気嵐時の電離圏・プラズマ圏の時空間変動

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Temporal and spatial variations of the ionosphere and plasmasphere during geomagnetic storms as seen in global TEC data

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The global structure of the ionosphere and plasmasphere is drastically changed during geomagnetic disturbances such as storms and substorms, and the response of the ionosphere and plasmasphere to geomagnetic disturbances is very complicated.. Previous studies showed (1) a large enhancement of Total Electron Content (TEC) in the equatorial and middle-latitude regions within a few hours during a severe geomagnetic storm [e.g., Mannucci et al., 2005], (2) formation of storm-enhanced electron density (SED) extending from middle to high latitudes [e.g., Foster, 2013], and (3) physical process of SED formation and variation of the equatorial ionosphere on the basis of global SAMI3-Rice Convection Model (RCM) simulation [Huba and Sazykin, 2014]. However, these studies did not investigate detailed temporal and spatial variations of the ionosphere and plasmasphere with high time resolution during the main and recovery phases of geomagnetic storms on the basis of global TEC data analysis. In this study, we analyzed the temporal and spatial variations of ionospheric trough associated with development and decay of geomagnetic storms with the global TEC data in order to clarify the variation of the plasmapause location. In this analysis, we used the geomagnetic Kp and SYM-H induces and global TEC data, and the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) data analysis tool [Tanaka et al., 2013]. These data are provided by World Data Center for Geomagnetism, Kyoto University, and Dense Regional And Worldwide INternational GNSS-TEC observation (DRAWING-TEC) project, NICT [Tsugawa et al., 2007], respectively. We first produced a global distribution of the 10-day quiet-time average TEC in a month of investigated storm events. As a next step, we created a global map of difference of TEC (d-TEC) in between the storm-time and quiet-time periods, and investigated the global variation of the d-TEC during the main and recovery phases of geomagnetic storms. During the pre-storm and initial phase of geomagnetic storms, d-TEC showed a small variation with the amplitude of less than 3 TECU except for the equatorial and low-latitude (less than 30 degrees, GMLAT: geomagnetic latitude). After the sudden commencement identified as a step-like increase of the SYM-H index, d-TEC began to increase in the middle-low latitudes (30-55 degrees) of the morning sector (9-10 h, LT: local time). As geomagnetic storms grow, the enhanced d-TEC region expanded to the afternoon sector (15 h, LT) within 4-5 hours. 4 hours after the start of the main phase, the decreased d-TEC region with a line structure in a longitudinal direction, which is identified as an ionospheric trough, appeared in the afternoon sector (14-17 h, LT). The location moved equatorward with a wavy structure with a scale of 500-1000 km in a longitudinal direction associated with the development of geomagnetic storms. This implies that the plasmapause move earthward with a spatially inhomogeneous structure in association with an intensified convection electric field with a small-scale structure. On the other hand, in the high-latitude region (more than 60 degrees, GMLAT) of the morning sector (10-11 h, LT), a plume-like structure of d-TEC appeared, which corresponds to the SED phenomenon. The ionospheric trough and SED disappeared within 1 hour after the start of the recovery phase of the geomagnetic storm. The disappearance of these phenomena suggests that the SAPS/SAID activity and convection electric field decrease associated with the recovery phase of the geomagnetic storm.

Seasonal dependence of semidiurnal equatorial magnetic variations

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The fundamental structure and features of EEJ are well known from the many studies involving the ground-based magnetometer, rocket observations, radars and simulation. These results are based on the data during the geomagnetic quiet time. We believe that the continuous observation of EEJ is most important on the study of space weather and space climates. In 2008, International Center for Space Weather Science and Education, Kyushu University (ICSWSE) proposed the EE-index (Uozumi et al., 2008; Fujimoto et al., 2016), which is an index to monitor quantitatively various equatorial geomagnetic phenomena in real time. EE-index separates the magnetic disturbances in the equatorial region into the global (EDst) and local (EUEL) magnetic variations. Especially, the detail analysis of EUEL index provides the quantitative and visible information in order to reveal the electromagnetic phenomena affecting the fundamental structure of Equatorial Electrojet (EEJ).

We have already demonstrated some examples applying EE-index to the equatorial magnetic variation by using EUEL data: solar cycle variation of EEJ peak, semiannual EEJ variation. In this presentation, we will show the result from the time series analysis of the semidiurnal EUEL variation by using the data from Huancayo in Peru and Davao in Philippine during 2005-2009. We found the 5-year average of semidiurnal EUEL variation is strongly related to the lunar phase. The strong semidiurnal EUEL variation appears around full and new moons. The monthly average of 5-year semidiurnal EUEL variations show the remarkable seasonal dependence. The semidiurnal variation is stronger around January solstice and weaker around July solstice. This feature is confirmed on the data from Huancayo and Davao. The seasonal dependence of semidiurnal variation agrees with the seasonal profile of atmospheric neutral wind (2.2) mode. The quiet EEJ is well known to be associated with lunar tides. The unquiet EEJ, however, has not well examined the relationship with the lunar tides. In this paper, we will present comprehensively that the quiet and unquiet semidiurnal EUEL variations result from the lunar tide effect.

磁気擾乱時における中低緯度領域電磁誘導応答の研究

中原 美音 [1]; 吉川 顕正 [2]; 魚住 禎司 [3]; 藤本 晶子 [4]; 松下 拓輝 [5]
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Research for electromagnetic induction response in the low-and-mid-latitudinal region at geomagnetic disturbances

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Geomagnetically Induced Current (GIC) is known as one of the phenomena caused by geomagnetic disturbance phenomenon. In the estimation of GIC, it is said that the horizontal component of the ground electric field is useful [Pulkkinen et al., 2007], and estimation of electric field by using realistic magnetic field fluctuation is discussed for the electric field induced to the ground surface. Although many of GIC are in the high latitude region, the study of GIC has been started even in Japan with low-mid geomagnetic latitudes [Watari et al., 2015]. The purpose of this project is to understand the process up to the observation and prediction in Japan located in the middle and low latitudes. In this study, examine the influence of geomagnetic field variation on the electric field. Focusing on the horizontal component of the induction electric field of the ground surface which can be the main electromotive force of GIC. And visually examined the magnetic field and the electric field components of 3 observation points for 1 year in 2015, consider the characteristics of the fluctuation of magnetic field and electric field on the ground. From the verification, it was found that the space weather phenomenon is involved in the change of the ground electric field, and in particular, it shows the characteristic variation in the magnetic storm, the substorm, and the SFE (Solar Flare Effect). In this issue, we focus on ground magnetic field and electric field fluctuation by substorm and we will consider the consideration.

地上の磁場は様々な宇宙天気現象と連動して, 日々変動している. そのような地磁気擾乱現象が引き起こす現象の一つとして GIC(Geomagnetically Induced Current) が知られている. GIC の推定には地表の電場の水平成分が有用 [Pulkkinen et al., 2007] と言われており, 地表に誘導される電場については現実的な磁場変動を用いることによる推定が議論されている. GIC による被害報告は高緯度領域に多いが, 地磁気的な緯度が低い日本でも GIC の検討が開始されている [Watari et al., 2015]. 本研究では中低緯度領域に位置する日本で, 磁気擾乱現象から GIC の観測, 予測に到るまでの過程理解を目的とし, 地磁場変動が地電場に及ぼす影響を検証する. GIC の主要な起電力となりうる地表の誘導電場の水平成分に着目, 2015 年の 1 年間, 3 観測点の磁場, 電場成分を目視で検証, 磁場と電場の変動の特徴を考えた. データの検証から, 地上電場の変動に宇宙天気現象が関わっていることがわかり, 特に磁気嵐、サブストーム、SFE(Solar Flare Effect) で特徴的な変動を示すことがわかった. 今回はその中で夜側, 昼側それぞれでのサブストームによる地上電場変動を検証した. その結果, 地上電場の変動は Local な地上磁場変動に対応していることが改めて確認された. また日変動のような時間スケールの長い磁場変動に対して電場の反応は鈍いが, 反対にサブストームなどの数時間程度の比較的短い時間スケールでの変動に対しては反応が良く出ることがわかった.

電離圏電流によって駆動される地磁気誘導電場のシミュレーション

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Simulation of Geomagnetically Induced Electric Field Originating from Ionospheric Current

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During geomagnetically disturbed conditions, geomagnetic induced currents can cause severe damages on our life. It has become thought that such strong GIC flows at high latitudes. The direct cause of the GIC is the geomagnetically induced electric field on the ground. In order to evaluate the GIE, we need to solve the propagation of electromagnetic fields from the current source that is presumably located in the ionosphere and the magnetosphere. Previously, estimation of GIE has often been made with 1D conductivity models and plane waves because small inhomogeneities of the ground conductivities are thought not to play a significant role. However, the GIE depends largely on the structure of the ground conductivities, known as the coast effect. Japan has complicated structures of the ground conductivities due to volcanos and plate boundaries. The purpose of this study is to understand the effect of the 3D treatment of the ground conductivity on GIE. We simulated the propagation of the electromagnetic fields by using the FDTD method.

Simplified structures of the ground conductivities were tested for qualitative understanding of GIE. For the sake of simplicity, we also assume simplified ionospheric currents as a source current. First, we changed only ionospheric current. When we introduced a pair of two vertical line currents, charge is accumulated in ionosphere, resulting in localized, small GIE on the ground below the line currents. Second, we introduced different ground structures. A uniform sheet current is assumed to flow in the ionosphere. For an island with a bay and an island with a peninsula, GIE was enhanced near the edge of a bay, or peninsula by a factor of two. For an island with a mountain, the current penetrates vertically into the interior of the ridge of the mountain, and GIE has local maxima at foots of the ridge. These maxima are as great as GIE at the coast. For a land with a large conductivity region, such as magma, embedded in the ground, the phase of the electric field is different from ambient. We will discuss the GIE on the ground having complicated structures in terms of current lines and charge distribution.

太陽風による磁気擾乱現象の一つである地磁気誘導電流 (GIC) は停電など、時に私たちの生活に大きな経済的被害を及ぼす。GIC は極域付近で起こる現象だと考えられていたが、近年の観測より GIC は中低緯度でも起こる現象であることが明らかとなっている。GIC は地磁気誘導電界 (GIE) が送電網等の下に発生することにより発生する。従来の GIE の解析としては電流源として平面波を与えた一次元のモデルの利用が中心だった。しかし日本のように複雑な海岸線構造やマグマやプレートなどの地下構造を持っている地域では一次元モデルで GIE を解析することは難しい。このような地域においては三次元モデルで GIE を解析することが求められる。私たちの研究目標としては三次元空間での GIE の解析を行い、GIE の振舞いを理解することにある。私たちは今回三次元 FDTD(Finite-difference time-domain) 法を用いて GIE のシミュレーションを行った。

シミュレーションのモデルとしては電離圏と大気、地面が存在するモデルを設定した。まず地面が一様な導電率を持つと仮定し、電離圏電流を様々な形状に与えた。電離圏電流として垂直かつ逆方向に二本の電流を与えた場合は、二本の電流間の直下の部分で小さな GIE が発生することが分かった。続いて電流源を電離圏の薄い層で水平方向に一様に流れるようなシート電流を仮定し、地構造を様々なモデルに変えて GIE のシミュレーションを行った。まず湾構造を持つ海に囲まれた島を仮定した場合は、湾の角に電荷が溜まり、他の陸の二倍程の大きさの GIE が集中することが明らかになった。これは半島構造を持つ島を仮定した場合にも同じ現象が起きた。海に囲まれた陸に山が存在するモデルでは、海岸の GIE と同程度の GIE が山の麓部分に発生することが明らかとなった。地中にマグマが存在するモデルでは、マグマの上の領域で他の領域と比べ GIE の位相がずれることが明らかとなった。発表では、電流線と電荷分布の観点で非一様地下構造上の GIE について議論する。

CEJ発生日のプラズマバブルイベント

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Plasma bubble event on CEJ occurrence day

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Plasma bubble is one of the ionospheric disturbance that occurs after sunset in magnetic equator. It causes amplitude and phase fluctuation (scintillation) of the received radio wave and affects communication system such as GPS satellites. Recently, it has been suggested that there is a relationship between plasma bubble and equatorial electrojet (EEJ) [e.g. Dabas et al., 2003; Uemoto et al., 2010]. The plasma bubble occurs due to Rayleigh-Taylor instability, so generation of eastward electric field is expected as necessary condition for development of plasma bubble. Therefore, occurrence of plasma bubble (PB) is supposed to be suppressed when counter electrojet (CEJ) accompanied by westward electric field occur [e.g., Uemoto et al., 2010].

The EE-index is one of the ICSWSE space weather indices for monitoring local and global components of geomagnetic disturbances at low and equatorial region, which was originally developed by Uozumi et al., (2008) and later updated by Fujimoto et al., (2016). Since then, ICSWSE has continued to monitor the EEJ activity by using this EE-index. The EE-index is composed of EDst (global component) and EUEL (local component), which correspond to magnetic field changes at dip equator caused by magnetospheric current such as ring current and, caused by ionospheric current such as EEJ and Sq, respectively.

In this study, we found that there were some days when PB occurred even though the CEJ also occurred by the EUEL at equatorial station (Langkawi (LKW), Malaysia (GG Lon. =99.78, Dip lat. =-1.07)) and S4-index (equivalent to amplitude scintillation of GPS signal) by ISEE, Nagoya University, in Kototabang (KTB), Indonesia (GG Lon. =100.32, Dip Lat. =-10.1). To investigate relation between occurrence of CEJs and PBs, we compare EE-index and differences of H-component at LKW and at KTB, which is often used to measure EEJ enhancement component, for events that CEJ and PB occur in same day.

As the result, when PB occurs in CEJ day, the electric field tended to change from westward to eastward between the peak of CEJ and around sunset. We may conclude that plasma bubble can be generated even if CEJ occurs, if the electric field turn to eastward at sunset region, like prereversal enhancement is occurs.

Dependence of Schumann resonance parameters on solar activity

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The Schumann resonance (SR) is the global resonance of electromagnetic waves generated by global lightning activity. The resonance is formed by the Earth-ionosphere cavity and the specific resonance frequencies, which are about 8, 14, 21, and 26 Hz, appears in ground magnetic field variation. The diurnal variations of SR parameters reflect the properties of both global lightning activity and the state of the Earth-ionosphere cavity.

Recently the SR is further expected as an indicator of earth's climate. In order to use the SR parameters for studying such earth's climate, we need a better understanding of the long-term variations of the SR in terms of correlation between solar activities. In this study, we examined the fundamental mode of SR at Kuju, Japan (KUJ, M.Lat. = 23.4 degree, M. Lon. = 201.0 degree) by comparing solar activities.

The ground magnetic field variation in the extremely low frequency (ELF) range has been measured by an induction magnetometer at KUJ since 2003. The observation is a part of activities by International Center for Space Weather Science and Education Kyushu University. The components of ground magnetic field used in this study are horizontal northward component (H) and horizontal eastward component (D). To compare the magnetic field data with solar activity, we also used daily F10.7 and daily EUV flux data in 0.1-50 nm wavelength bands. The EUV data is obtained by the Solar EUV Monitor (SEM) aboard the Solar Heliosphere Observatory (SOHO) satellite at the L1 point.

The fundamental mode of the SR frequency follows solar activity (i.e., F10.7 and EUV flux). The SR frequency tends to increase with increasing solar activity. Such tendency is especially prominent in the H component. Also the correlation coefficient between the SR frequency in the H component and EUV flux is high (C.C. = 0.71). We conclude that the SR frequency depends on the density in the ionospheric D region which varies with solar activity.

Ionization of protoplanetary disks by galactic cosmic rays, solar protons, and supernova remnants

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Galactic cosmic rays and solar protons ionize the present terrestrial atmosphere, and the air showers are simulated by well-tested Monte-Carlo simulations, such as PHITS code. We use the latest version of PHITS to evaluate the possible ionization of protoplanetary disks by galactic cosmic rays (GCRs), solar protons, and by supernova remnants. The attenuation length of GCR ionization is updated as 118 g cm2, which is approximately 20% larger than the popular value. Hard and soft possible spectra of solar protons give comparable and 20% smaller attenuation lengths compared with those from standard GCR spectra, respectively, while the attenuation length is approximately 10% larger for supernova remnants. Further, all of the attenuation lengths become 10% larger in the compound gas of cosmic abundance, e.g. 128 g cm2 for GCRs, which can affect the minimum estimate of the size of dead zones in protoplanetary disks when the incident flux is unusually high. In this presentation we further discuss our recent progress.

Cosmic ray modulation and radiation dose of aircrews during the solar cycle 24/25

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Weak solar activity and high cosmic-ray flux during the coming solar cycle are qualitatively anticipated by the recent observations that show the decline in the solar activity levels. We predict the cosmic-ray modulation and resultant radiation exposure at flight altitude by using the time-dependent and three dimensional model of the cosmic-ray modulation. Our galactic cosmic ray (GCR) model is based on the variations of the solar wind speed, the strength of the heliospheric magnetic field (HMF), and the tilt angle of the heliospheric current sheet. We reproduce the 22-year variation of the cosmic-ray modulation from 1980 to 2015 taking into account the gradient-curvature drift motion of GCRs. The energy spectra of GCR protons obtained by our model show good agreement with the observations by BESS and PAMELA except for a discrepancy at the solar maximum. Five year annual radiation dose around the solar minimum at the solar cycle 24/25 will be approximately 19% higher than that in the last cycle. This is caused by the charge sign dependence of the cosmic-ray modulation, such as the flat-top profiles in a positive polarity. In this presentation we further discuss our recent progress.

27-day solar rotational cycle in lightning activity in Kyoto from the 17th to 18th century

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A solar rotational period of approximately 27 days has been detected in cloud and lightning activities, although the mechanism of the sun-climate connection remains unclear. In this paper, we analyze the time series of lightning activity in the late 17th century to the mid 18th century, extracted from old diaries in Kyoto, Japan, and search for the signal of solar rotational cycles. The 27-day cycles were detected in the lightning data, but they disappear during the Maunder Minimum. This finding provides insight into the connection between solar activity and the Earth’s climate.

Reconstruction of the flux of galactic cosmic rays using travertine deposits: A pilot study

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Cosmogenic nuclides in the annual layers of natural materials record temporal variation of galactic cosmic ray flux in the past. Carbon-14 in tree rings or beryllium-10 in ice cores from polar region are often used to retrieve accurate history of GCRs. However, the variation of carbon-14 produced in the atmosphere is strongly attenuated in the carbon cycle. In the case of beryllium-10 in ice cores, it remains relatively large amplitude, but the records are accompanied with dating uncertainties. We therefore seek for a possibility to retrieve the information of GCR flux from the beryllium-10 content in annual layers of endogenic travertine deposits. In this paper, we report on our preliminary results of the measurements of beryllium-10 in travertine samples obtained from China.