太陽地球圏環境予測プロジェクト（PSTEP）の挑戦
Challenge of PSTEP (Project for Solar-Terrestrial Environment Prediction)

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我々が生きる太陽地球圏の環境は太陽活動に起因して大きく変動しますが、そのメカニズムは未だに十分解明されていません。このため、幅広い宇宙利用と高度な情報化が進んだ現代社会は太陽地球圏の環境変動に対して潜在的なリスクを抱えています。太陽地球圏環境予測プロジェクト(PSTEP)は、こうした問題の解決を目指して文部科学省科学研究費補助金新学術領域によって組織された全国的な研究プロジェクトです。PSTEPには９０名以上の研究者が参加し、４つの計画研究と公募研究の有機的な連携を通して太陽地球圏環境変動についての科学研究と予測研究を相乗的に発展させることを目指しています。これによって、太陽フレア発生機構、地球放射線帯の生成機構、太陽活動の気候影響機構といった重要な科学課題を解決すると同時に、激甚宇宙天気災害に備える社会基盤の形成を推進しています。本講演ではPSTEPの主要なねらいとその研究戦略を紹介します。

キーワード：宇宙天気、宇宙気候、予測
Keywords: space weather, space climate, prediction

宇宙天気情報利用におけるニーズ・シーズマッチングの検討
Analysis of Needs-Seeds Matching for Using Space Weather Information

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情報通信研究機構では、2005年よりほぼ毎年「宇宙天気ユーザーズフォーラム」を開催してきたことに加え、2013・14年の2年にわたり宇宙天気情報の利用者に対して姉k-戸やヒアリングを通しそのニーズの調査を行ってきた。
2015年に新学術領域「太陽地球圏環境予測」（PSTEP)が採択された。この中の主要な目標の一つとして「宇宙天気情報の双方向システムの構築」が挙げられている。この実現のために、新たに「宇宙天気ユーザー協議会」を立ち上げるとともに、研究者側から提供できる情報と、利用者が必要としている情報の調査を行い、ギャップ解析およびマッチングに向けた分析を行っている。
現在、宇宙天気情報の実利用検討で最も進んでいる分野として、航空運用が挙げられる。2014年には、国際民間航空機関（ICAO)で航空気象を規定する第三付属書の改訂が検討され、使用される宇宙天気情報の仕様が示された。しかしながら航空関係者にとってはこの利用について未だ十分な理解を得られているとは言えない状況である。このような事例を挙げつつ、ニーズ・シーズマッチングに向けた議論を行う。

キーワード：宇宙天気、市場調査、航空運用
Keywords: space weather, user investigation, aviation

ベクトル磁場と彩層発光を用いた機械学習による太陽フレア予測
Solar Flare Prediction with Vector Magnetogram and Chromospheric Brightening using Machine-learning

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Solar flares have been empirically predicted based on the solar surface observations. Before large class of flares, photospheric magnetic field in the active region becomes complex and sharp magnetic neutral lines are formed. It is also known that chromospheric brightening recurrently occurs at around the neutral lines. In NICT, solar flares occurring in the next 24 hours have been predicted by scientists in the daily forecast operations, but the flare mechanism has not been well revealed and we still have a difficulty in predicting flares with high accuracy and good confidence. Currently, we can access huge amount of observation data, so we developed a system to automatically predict flares using the near real-time observation data by satellites and the machine-learning technique.
We used observation data sets taken by SDO and GOES satellites during 2010-2015: (1) line-of-sight direction magnetogram and vector magnetogram data by HMI/SDO, (2) lower chromospheric brightening data by AIA 1600 Angstrom filter/SDO, and (3) soft X-ray emission by GOES. Firstly, we automatically detect active regions using full-disk images of magnetogram every 1 hour, to predict a flare class occurring in the region in the next 24 hours. Secondly, we extract solar features for each region, i.e., the maximum magnetic field strength, the maximum gradient of magnetic field in the line-of-sight direction, the number of magnetic neutral lines, the maximum length of neutral lines, the magnetic free energy, the shear angle, the time variations of magnetic field configurations, the history of X/M-class flares, the background GOES X-ray emission, and the activity of chromospheric brightening. Thirdly, we apply the machine-learning technique to the dataset of solar features to predict flares. We divided the total data set into two for training and test. We adopted three machine-learning techniques for comparison: the support vector machine (SVM), the k-nearest neighbor (k-NN) and the extra random trees (ERT). As a result, we succeeded in achieving good prediction of X-class flares, as verified by the True Skill Score (TSS) larger than 0.7, which is better than human forecast operations (TSS~0.5). In this presentation, we would like to introduce our flare predictions model and to discuss flare triggering mechanism.

キーワード：宇宙天気予報、太陽フレア、統計解析、機械学習、光球ベクトル磁場、彩層
Keywords: Space Weather Forecast, Solar Flare, Statistical Analysis, Machine-Learning, Photospheric vector Magnetic field, Chromosphere

汎用時系列予報機UFCORINを用いた太陽フレア予測の進展について
Solar Flare Prediction Studies Using Universal Time Series Predictor UFCORIN

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我々は、自動化された宇宙天気予報を提供するためのソフトウェアプラットフォームUFCORIN(Universal Forecast Constructor by Optimized
Regression of INputs)を開発し、それを用いて宇宙天気予報を研究している。
これまでの実験では、2011-2012年の二年間の期間において、GOES衛星の観測による太陽X線フラックスの時系列データを予測対象とし、GOESデータの過去データおよびSDO/HMIによる太陽面視線垂直磁場画像データをもとに、6160通りの予報戦略を試し、その性能比較を行った(Muranushi et al. 2015)。
太陽フレア予測の研究では、
Bloomfield et. al(2012)の提案以来、予報性能の指標としてTSS(True Skill Statistics)が広く使われている。ところが我々は、数多くの予報戦略を比較する
場合、TSSの値は、予報戦略どうしの平均値の差にくらべ、交差検定データを変
えたときのゆらぎが大きすぎて、適切な性能比較ができないことを発見した。
そこで、交差検定データごとに、各予報戦略のTSSの偏差値(z-value)を算出したところ、交差検定データを変えても一貫して高い偏差値を示す予報戦略の存在が観察された。我々はこの偏差値を用いる手法を、数多くの予報戦略を比較する手段として提案する。
本研究の中で、X,M,Cクラスフレアに対する最善の予報戦略のTSSはそれぞれ0.75 ± 0.07, 0.48 ± 0.02, および 0.56 ± 0.04であった。
また、我々は(Muranushi et al. 2015)を元に、２０１５年８月よりリアルタイムフレア予報を提供している。この予報はサーバ障害等によるダウンタイムがあるものの、１２分おきに自動的に提供されている。本発表ではこのリアルタイム予報実験の進捗についても報告する。

キーワード：宇宙天気予報、フレア予測
Keywords: Space Weather Forecast, Flare Forecast

Realtime Solar X-ray Flux Forecast using Deep Learning

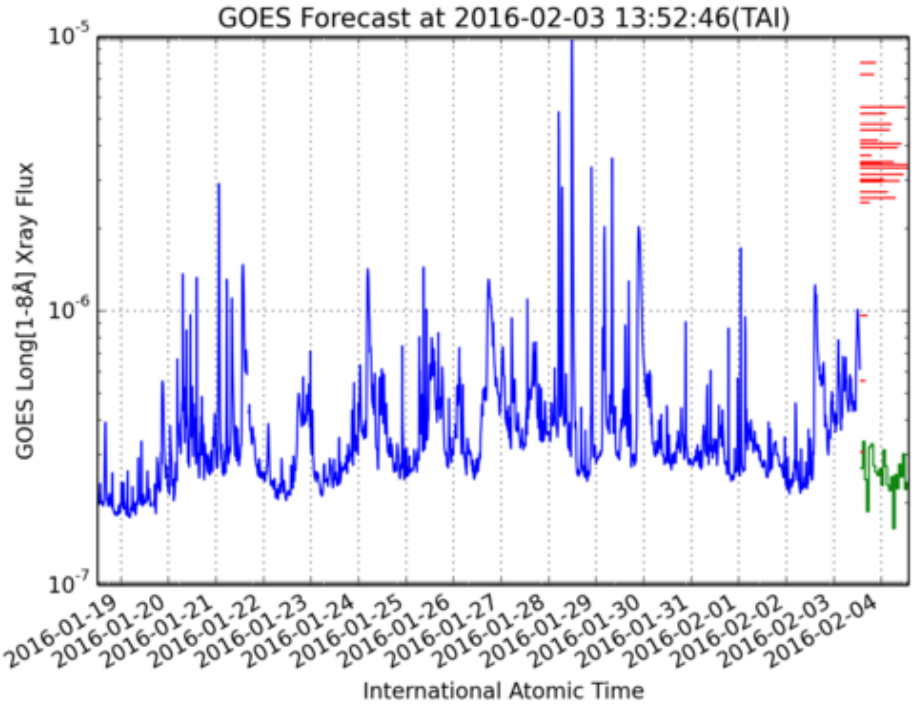
We present the 24-hour forecast of GOES X-ray flux, based on realtime GOES data and HMI-720s Near-Real-Time data.

The forecast is produced by regression of the time series using Long-Short Temporal Memory (LSTM) neural network.

The feature vector is produced from (1) GOES X-ray flux and (2) wavelet analyses of HMI images, as described in Muranushi et al (2015): http://arxiv.org/abs/1507.08011 .

The source code is available under MIT license at https://github.com/nushio3/UFCORIN/tree/master/script .

Largest flare in next 24 hours: 3.3e-06 W/m²
Flare category forecast: C Class



宇宙及び航空機高度における放射線防護：WASAVIES開発の現状と今後の展望
Radiation Protection of Humans in Space and Aviation: Current States and Future Needs on the Warning System for Aviation Exposure to SEP (WASAVIES)

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Forecast of radiation doses for astronauts as well as aircrews due to the exposure to solar energetic particles (SEP) is one of the greatest challenges in space weather research. In last 5 years, we have developed a WArning System for AVIation Exposure to Solar energetic particles: WASAVIES. In this system, the SEP fluxes incident to the atmosphere are calculated by physics-based models, and they are converted to radiation doses using a database developed on the basis of air-shower simulation. However, it takes approximately 2.5 hours to determine the parameters used in the physics-based models after the detection of GLEs, and thus, the current WASAVIES cannot predict doses during the peak of GLEs. Therefore, we are trying to reduce the time for evaluating the parameters, as well as to develop a nowcast system for the radiation dose due to SEP exposure, under the framework of Project for Solar-Terrestrial Environment Prediction (PSTEP, http://www.pstep.jp/) in Japan. A brief outline of WASAVIES together with our future strategy will be presented at the meeting.

キーワード：太陽高エネルギー粒子、放射線被ばく、宇宙天気
Keywords: SEP, Radiation Exposure, Space Weather

Recent Progress in Space Weather Modeling and Forecasting at NOAA's Space Weather Prediction Center

Recent Progress in Space Weather Modeling and Forecasting at NOAA's Space Weather Prediction Center

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We discuss the current state of the art of space weather modeling and forecasting at the NOAA Space Weather Prediction Center (SWPC) in Boulder, Colorado. Recent progress in modeling the solar wind using a data assimilative flux transport model (ADAPT) from the Air Force Research Laboratory (AFRL) has shown that incorporating current and modeled solar magnetic field data results in a better correlation with measurements of the solar wind at the ACE spacecraft in L1 orbit. SWPC is also transitioning the University of Michigan's "Geospace" model to operations, enabling 15-30 minute forecasts of geomagnetic storming and regional K-value predictions. In addition SWPC and the University of Colorado Cooperative Institute for Research in the Environmental Sciences (CIRES) are developing the Whole Atmosphere Model (WAM) and the Ionosphere Plasmasphere Electrodynamics (IPE) coupled system to enable three-day forecasts of ionospheric conditions as well as neutral atmosphere density for satellite drag calculations. In accordance with the new National Space Weather Strategy released by the White House in October 2014, these and other models and products will be integrated into the Space Weather Forecast Office to enable SWPC forecasters to deliver impact-based decision support services to satellite operators, commercial airlines, GNSS users, and electrical grid operators to protect critical infrastructure from the threat of extreme space weather events.

NASA Heliophysics and the Science of Space Weather

NASA Heliophysics and the Science of Space Weather

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NASA formulates and implements a national research program for understanding the Sun and its interactions with the Earth and the solar system and how these phenomena impact life and society. This research provides theory, data, and modeling development services to national and international space weather efforts utilizing a coordinated and complementary fleet of spacecraft, called the Heliophysics System Observatory (HSO), to understand the Sun and its interactions with Earth and the solar system, including space weather. NASA’s space-based observational data and modeling efforts have provided significant contributions to the science of space weather. Current and future space weather research will provide key information to improve the ability of the United States and its international partners to prepare, avoid, mitigate, respond to, and recover from the potentially devastating impacts of space-weather events.

Scientific research in support of space weather goals

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Unlike terrestrial weather, space weather is immature from a scientific point of view. While the last decades have seen tremendous scientific progress, which, among others, manifested itself in form of advanced space weather models, many key scientific processes underpinning space weather remain poorly understood or not understood at all. These processes span the gamut of Heliophysics domains; starting from magnetic filed generation processes in the solar interior and reaching to Earth's upper atmosphere, where we still lack kowledge of the processes responsible for ionospheric scintillations. In addition, we are in many, rather fundamental from a space weather point of view, cases not able to predict with any confidence the expected amplitudes of space weather phenomena. This presentation will review scientific progress to-date, and attempt to map out a path forward toward the desired quantitative and accurate predictabily.

Keywords: Space weather, Space research, Heliophysics

Geomagnetically induced currents: the latest science, engineering and policy actions in the US

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Geomagnetically induced currents (GIC) flowing in long manmade conductor systems have become one of the main space weather concerns. The potential for widespread problems in operating high-voltage power transmission systems during major geomagnetic storms has prompted increasing federal regulatory, science, industry and public interest in the problem. The impact caused by extreme storm events has been of special interest and consequently much of the recent GIC research has been focused on defining extreme GIC event scenarios and quantifying the corresponding transmission system response. In addition, there is an elevated need for developing next generation GIC prediction products for the power industry. In this presentation, I will discuss the latest science, engineering and policy actions around the topic especially in the US. Perhaps the most significant policy action are the standards work pushed by the US Federal Energy Regulatory Commission. GIC are centerpiece also in the newly released National Space Weather Strategy reflecting the strong interest in the topic at the highest levels of the US government. Much of the recent progress in understanding GIC and its impact on power grids has resulted from improved scientific community-power industry interactions. The common language and information exchange interfaces established between the two communities have led to significant progress in transitioning scientific knowledge into detailed impacts analyses. We also face a number of future challenges in specifying GIC, for example, in terms of more realistic modeling of the three-dimensional geomagnetic induction process. I will discuss briefly some of these future challenges.

Keywords: Space weather, Geomagnetically induced currents

地磁気データから変電所GICの推定
Empirical estimation of GICs from the geomagnetic data in Japan

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Pulkkinen et al (2007) proposed the new method of estimating geomagnetically induced currents (GICs) at a transformer station by employing the linear relation between the GICs and the corresponding geomagnetic variations as

$$GIC(\omega)=A(\omega)B_y(\omega)+B(\omega)B_x(\omega) \quad (1)$$

By using the two transfer functions in the frequency domain ($A(\omega)$ and $B(\omega)$ in Eq. (1)), we obtain

$$GIC(t)=\int A(\tau)B_y(t-\tau)d\tau + \int B(\tau)B_x(t-\tau)d\tau \quad (2)$$

This method (the transfer function method) successfully reproduced the GICs from the geomagnetic variations in Finland [Pulkkinen et al., 2007] and in Hokkaido [Pulkkinen et al., 2010]. However, as the electrical conductivity distributions in both areas are rather uniform, it is important to evaluate how this method is applied to GICs observed at a station in other area of Japan with heterogeneous conductivity distribution. This is the motivation of this research. We employ one-minute values of the GICs observed at a transformer station and those of the geomagnetic data at Kakioka Magnetic Observatory during the Halloween event.

To confirm how this method is effective, we need to investigate how the GICs during one event are reproduced from the geomagnetic data in this event with the transfer function obtained from the other event. Fortunately, the Halloween event has two activities on Oct/30 (the event #1) and on Oct/31 (the event #2), we can calculate separately two transfer functions for the two events. First, we confirm that the transfer functions obtained from the events are essentially identical. This fact indicates that the transfer function method by Pulkkinen et al. (2007) is applicable to the GIC data in Japanese transformer station. Next, the GICs in the event #1/#2 are estimated from the geomagnetic data in the event #2/#1 and the transfer function of the event #2/#1. When calculating GICs in time domain in Eq. (2), we noticed that the integral from t=0 to 50min reproduces sufficiently accurate GICs. This fact is a little bit different from Pulkkinen et al. (2007) who estimated the GICs through the integral only at t=0 and 1min. At last, we confirm that the reproduced GICs are essentially similar to the observed ones.

In the last, we estimate the GICs at the transformer station in the magnetic storm in 1989 which caused the large-scale blackout in Canada and US.

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キーワード：地磁気誘導電流、変電所、伝達関数

Keywords: geomagnetically induced current, transformer station, transfer function

グローバルMHDシミュレーションを用いたバスティーユイベント時の極冠電位差飽和の研究
Polar cap potential saturation during the Bastille day storm using global MHD simulation

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We are developing a real-time numerical simulator for the solar wind-magnetosphere-ionosphere coupling system using next generation magnetosphere-ionosphere coupling global MHD simulation called REPPU (REProduce Plasma Universe) code. The feature of simulation has an advanced robustness to strong solar wind case because a triangular grid is used, which is able to calculate in the uniform accuracy over the whole region. Therefore we can simulate extreme event such as the Bastille day storm. The resolution is 7682 grids in the horizontal direction and 240 grids in the radial direction. The inner boundary of the simulation box is set at 2.6 Re. We investigate the reproduction of the magnetosphere-ionosphere coupling simulation in strong solar wind case. Therefore we compared the simulation results with the observation of the Bastille day storm event (2000/7/15), in which the solar wind velocity is above 1000 km/s and the value of Bz reached -60 nT. Especially, we focus the CPCP saturation and time variation because the CPCP represents the value of magnetospheric - ionospheric convection strength via region 1 current. The CPCP depends on solar wind electric field, dynamic pressure and ionospheric conductivity [Siscoe et al., 2002; Kivelson et al., 2008]. The model of Kivelson et al. [2008] shows a good reproduction to the CPCP variation. However their study assumes that the ionospheric conductivity is constant. The conductivity in our simulation of the Bastille day event is varied by the auroral activity. In this lecture, we discuss the effect of both the auroral conductance and solar EUV-driven conductance to CPCP saturation.

キーワード：グローバル磁気圏シミュレーション、極冠電位差、極端現象
Keywords: global MHD simulation, polar cap potential, extreme event

Space weather forecast of energetic particles and extreme space weather of magnetic storms

Space weather forecast of energetic particles and extreme space weather of magnetic storms

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I review our recent research activities on the space weather forecast of energetic particles, including galactic cosmic rays, solar protons, ring current, and radiation belt electrons. Theoretical approaches on the extreme space weather of geomagnetically induced currents and on extreme space climate during grand minima are also discussed. A new citizen science approach to investigate world-wide aurora sightings during extreme magnetic storms is also introduced.

What is the Largest Flare that can Occur on the Sun?

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The question of whether so-called superflares (energies from 10^{33}-10^{35} ergs) could occur on the Sun is of great interest scientifically. There are also obvious practical (space weather) implications. Shibata et al. (2013) suggested that flares on the order of 10^{34} ergs could occur every 800 years on the Sun, while Schrijver et al. (2012) argued that the magnetic energy for such a flare would require a sunspot 20 times greater then ever observed, and that 10^{33} ergs was a practical upper limit for flares.
Major solar eruptions such as X-class flares and very fast coronal mass ejections originate in active regions on the Sun. The energy that powers these events is believed to be stored as free magnetic energy (energy above the potential field state) prior to eruption. Therefore, the maximum free energy that can be stored in an active region bounds the largest possible eruption that can emanate from it. Using line-of-sight or vector magnetograms, the maximum energy that can be stored in a region can be estimated with the aid of the Aly-Sturrock theorem. We have investigated the active regions where the largest flares in the last 30 years have originated. We have found six cases where the maximum free energy is on the order of or greater than 10^{34} ergs. Our results suggest that 10^{34} erg solar flares cannot be ruled out based on magnetic energy storage.

Solar Origin of a Sequence of SEP-Producing CMEs via the "Lid Removal" Mechanism

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Both coronal mass ejections (CMEs) and solar energetic particle (SEP) events are of concern for space weather. Here we report on the solar source of a pair of CMEs that produced a strong SEP event. The CMEs resulted from back-to-back ejective eruptions from a single active region on 2012 January 23. We examine the onset of these eruptions using magnetograms and EUV images from the HMI and AIA instruments on the Solar Dynamics Observatory (SDO) spacecraft, and EUV images from the STEREO spacecraft. Cheng et al. (2013) showed that the first eruption's (``Eruption 1'') flux rope was apparent only in ``hotter'' AIA channels, and that it removed overlying field that allowed the second eruption (``Eruption 2'') to begin via ideal MHD instability; here we say Eruption 2 began via a ``lid removal'' mechanism. We show that during Eruption-1's onset, its flux rope underwent ``tether weakening'' (TW) reconnection with the field of an adjacent active region. Standard flare loops from Eruption 1 developed over Eruption-2's flux rope and enclosed filament, but these overarching new loops were unable to confine that flux rope/filament. Eruption-1's flare loops, from both TW reconnection and standard-flare-model internal reconnection, were much cooler than Eruption-2's flare loops (GOES thermal temperatures of ~9 MK compared to ~14 MK). This eruption sequence produced a strong solar energetic particle (SEP) event (10 MeV protons, >10^3 pfu for 43 hrs), apparently starting when Eruption-2's CME blasted through Eruption-1's CME at 5---10 R_s. This occurred because the two CMEs originated in close proximity and in close time sequence: Eruption-1's fast rise started soon after the TW reconnection; the lid removal by Eruption-1's ejection triggered the slow onset of Eruption 2; and Eruption-2's CME, which started ~1 hr later, was three times faster than Eruption-1's CME.

Keywords: Coronal Mass Ejection (CME) Onset, Solar Energetic Particles (SEPs), Solar Filament Eruptions, Solar Flares

Solar Corona and Space Weather

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It is now well established that the activity in the solar corona plays a major role in the processes at the origin of space weather effects in the heliosphere. The almost uninterrupted observations by the LASCO coronagraph onboard SOHO since January 1996 have allowed an unprecedented view of the coronal activity over almost two solar cycles 23 and 24 which reflects to a larger extent the magnetic activity of the Sun. I will report on the evolution of the corona and its large scale structure through various parameters, such as its radiometry and its three-dimensional electron density. The temporal variations will be compared with standard solar indices and various proxies of solar activity in order to identify the driving mechanisms that control the activity of the corona. Coronal mass ejections (CMEs) are strongly controlling space weather and the ARTEMIS-II catalog based on their automatic detection on high-quality calibrated synoptic maps of the corona allows performing an unbiased statistical analysis of their properties and investigate how they evolve with solar activity. I will present the results for occurrence and mass rates, waiting times, position angle, angular width, kinetic energy, and mass flux first globally and then separately for the two solar cycles 23 and 24 emphasizing the differences. I will further compare the statistical properties of CMEs with those of the standard indices of solar activity as well as those of their potential progenitors, flares and eruptive prominences.

Keywords: Sun, Coronal activity, Space weather

世界最大の太陽ダイナモ計算で明らかになった大規模磁場生成のメカニズム
Generation mechanism of large-scale magnetic field revealed with high-resolution solar dynamo calculation

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We carry out series of high-resolution solar dynamo calculations in spherical geometry to investigate generation mechanism of large-scale magnetic field. Solar observations indicate large-scale magnetic field in the solar interior in spite of the chaotic and turbulent fluid motion. Recent high-resolution calculations show that higher-resolution calculations generate weaker large-scale magnetic field, since small-scale turbulence tends to destruct the coherent large-scale magnetic field. In order to address this issue, we carry out a series of higher-resolution calculations. In our "middle"-resolution calculation, we find the same result as previous studies, i.e., when we increase the resolution, the large-scale magnetic field loses its energy. In our unprecedentedly high-resolution calculation, however, large-scale magnetic energy is recovered. In the calculation, we find an efficient small-scale dynamo which leads to strong Lorentz feedback in the small scale. The small-scale turbulent motion, which tends to destructs the large-scale magnetic field is suppressed. As a consequence, the large-scale magnetic field is maintained even with large Reynolds numbers.

キーワード：太陽、熱対流、ダイナモ
Keywords: Sun, Thermal convection, Dynamo

Modeling the thermosphere ionosphere system and space weather impacts

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The thermosphere-ionosphere-plasmasphere system has several direct impacts on space weather. Uncertainty in thermospheric neutral density affects satellite drag, orbit prediction, and collision avoidance. Variations in total electron content, together with steep gradients in plasma density, disrupts GNSS navigation signals and positioning accuracy, affecting a range of users including civil aviation. Changes in ionospheric layers modifies HF propagation due to absorption in the D-region and changes in reflection from F-region positive and negative storm phases. During a geomagnetic storm these changes can be dramatic. The modeling challenges are significant and diverse. The response of the system to geomagnetic storms has to capture dynamic neutral density changes, huge increases in storm-enhanced plasma densities by a factor of five, followed by extreme negative phases where the ionosphere can be severely depleted. During geomagnetically quieter conditions the day-to-day changes can be more subtle. The impact of waves propagating from instabilities in stratospheric jets or convective storms in the troposphere, produce persistent ionospheric variability perturbing HF propagation. Predicting the day-to-day variability of equatorial ionospheric irregularities, and their impact on satellite communication and navigation, remains a challenge, although there are hints that variability of lower atmosphere waves may be playing a role. Improvement in thermosphere-ionosphere and whole atmosphere models show promise in being able to simulate the response of the system to solar, geomagnetic, and lower atmosphere forcing with a goal of mitigating some of the impacts of space weather on operational system.

Keywords: Thermosphere-Ionosphere Modeling, Space Weather, Satellite drag, Geomagnetic storms

Effects of energetic particle precipitation and solar irradiance on ozone

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The term energetic particle precipitation (EPP) commonly refers to particles of different energy which routinely impact the polar regions. EPP ionizes the atmosphere and triggers catalytic cycles of ozone depletion driven by odd nitrogen (NOx) and odd hydrogen (HOx) species. While the most energetic particles can directly affect ozone in the mesosphere, during winter the (almost) continuous flux of auroral electrons produces high NOx amounts which can be transported downwards inside the polar vortex and influence stratospheric ozone. On the other hand, the wavelength dependence of the solar irradiance variation can induce stratospheric ozone changes in phase with solar activity. Here, we investigated ozone variability in response to EPP and solar activity during the 1979-2014 period by combining satellite ozone observations from Solar Backscatter Ultraviolet Radiometer and Microwave Limb Sounder on Aura. In particular, we analyze the correlation of the polar ozone variability with EPP and with solar irradiance in an attempt to distinguish between the two effects and to quantify the ozone variations caused by EPP on long time scales.

Keywords: Energetic particle precipitation (EPP), ozone, solar radiation

脈動オーロラに伴う高エネルギー電子がもたらす大気微量成分変動の解明に向けた国際共同研究
International joint study of EEP effects on the atmospheric minor components during pulsating aurora

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In recent years, variations of the atmospheric minor component (NOx, HOx, O3, etc) due to energetic electron precipitation (EEP) have been widely studied by many researchers. There are several sources to cause EEP, such as solar proton event, electron precipitation during pulsating aurora, and relativistic electron precipitation. This study focuses on pulsating-auroral (PA-) EEP, which is an almost daily occurrence in the morning sector of the auroral ionosphere. EISCAT measurements and GEMSIS-RBW simulation reveal that energy range of the PA-EEP is higher than 10 keV to a few hundred keV [Saito et al., 2012; Miyoshi et al., 2015]. Such energetic electrons can cause ionization in the mesosphere and upper stratosphere, resulting in forced modifications in the chemical equilibrium of the atmospheric minor components. This process is essentially important for understanding solar-climate relationships.
Japanese and Finnish researchers organize an international joint team, and conduct observation campaigns with the EISCAT radars, optical instruments, KAIRA riometer, and VAPs satellites in order to understand generation mechanism of PA-EEP and its impact on the ionosphere and atmosphere. Additionally we will analyze the archived data sets to understand EEP features. These scientific objectives will be accomplished by collaborations with the GEMSIS-RBW model and Sodankyla Ion Chemistry (SIC) model. In this presentation we will introduce some case studies of measurements and model calculations.
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キーワード：脈動オーロラ、大気微量成分
Keywords: pulsating aurora, atmospheric minor component

Exploring Predictive Performance of Ground dB/dt Models: A Reanalysis of the Geospace Model Transition Challenge

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Geomagnetically Induced Currents (GICs) are electric currents driven by activity in near-Earth outer space as our magnetic field interacts with that of the Sun's. These currents can flow through any conducting path, including pipelines and high voltage electric power lines. When GICs become strong enough, these technological systems can be interrupted or damaged, drastically affecting those who depend on them. Developing systems to accurately monitor and predict GIC events has therefore become a critical task for national security. An initial effort to assess the performance of five operationally-promising GIC models was presented by *Pulkkinen et al.* [2013]. The results of this validation effort showed that the models can provide predictive value, but shortcomings exist. While this work represents a landmark first-step towards numerical space weather forecasting, many questions remain concerning each of the models' capabilities. How do the models perform for different levels of geomagnetic activity? What is the range of activity for which the models have been validated? Based on the assumptions and input data for each model, what is the maximum driving for which the results can be considered valid?
This study presents a reanalysis of the *Pulkkinen et al.* [2013] results to extend our understanding of the models' capabilities and answer the questions posed above. Data-model errors between predicted and observed magnetometer dB/dt values are binned by activity (solar wind electric field or D_{ST}). The bins are arranged to yield error as a function of driving. Input data for empirical relationships, on which the models either rely or of which they comprise entirely, are binned by activity to determine the range of conditions over which each model is valid. A comparison of each model is presented to further illustrate previously published results. Additionally, because GICs are intimately linked to the electrojets which are in turn closely related to field-aligned currents, we also compare Birkeland currents from the different models to observations. For this we use radial current distributions from AMPERE based on the Iridium satellite constellation, providing assessments of the intensities and distributions of the global scale currents every ten minutes. From this new analysis, we place error bars on recent predictions of dB/dt made by the Space Weather Modeling Framework.

Keywords: Geomagnetically Induced Currents, Space Weather Modeling

サブストームのシミュレーション：電流系とオーロラ構造
Substorm simulation: Current system and auroral structure

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Substorm is known to cause strong geomagnetically induced current (GIC) on the ground in the polar region. The GIC is primarily caused by the ionospheric current that is intensified by field-aligned current (FAC) during the substorm. On the basis of the result obtained by a global magnetohydrodynamic (MHD) simulation, we propose a scenario for the evolution of the current system associated with a substorm expansion. (1) Near-Earth neutral line releases magnetic tension in the near-Earth plasma sheet to compress plasma and accelerate it earthward. (2) Earthward, perpendicular flow is converted to parallel flow when flow braking takes place. (3) Plasma moves earthward parallel to a field line. The plasma pressure is additionally enhanced at off-equator. (4) Flow vorticities coexist near the off-equatorial high-pressure region. Resultant FAC is connected to the ionosphere, which may manifest initial brightening of aurora. The ionospheric current starts to increase. (5) Due to continued earthward flow, the high-plasma pressure region continues to expand to the east and west. (6) The ionospheric conductivity continues to increase in the upward FAC region, and the conductivity gradient becomes steeper. (7) The convergence of the Hall current gives rise to divergent electric field near the steep gradient of the conductivity. (8) Due to the divergent electric field, magnetospheric plasma moves counterclockwise at low altitude (as seen in the Northern Hemisphere). (9) The additional flow vorticity generates a localized upward FAC at low altitudes, which may manifest westward traveling surge (WTS) of aurora. As a consequence, the ionospheric current, conductivity, and the magnetospheric current system are redistributed. The evolution of the substorm depends on the solar wind condition as well as the magnetospheric condition. We will discuss the optimal condition that potentially causes the strong substorm.

キーワード：サブストーム、オーロラ、地磁気誘導電流(GIC)
Keywords: Substorm, Aurora, Geomagnetically Induced Current (GIC)

SuperDARNレーダーデータを用いた太陽フレア・粒子降り込みによる電離圏電子密度変動の同定
Identification of ionospheric plasma density changes due to solar flares and energetic particle precipitation using the SuperDARN radar data

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Watanabe and Nishitani (Adv. Polar Sci, 2013) showed that during solar flares the SuperDARN data show positive Doppler velocities in ground / sea scatter echoes, and that this velocity change can be interpreted mainly in terms of the abnormal ionization of the D-region ionosphere due to EUV / X-ray, leading to the shortening of the HF ray paths. They also showed that it is possible to identify the plasma density changes from the Doppler velocity distributions. These result suggests that it might be possible to identify the D-region plasma density changes due to energetic particle precipitation events such as substorms using the same technique.

Ionospheric convection around substorm expansion onset are characterized by reduction of sheared flow and enhancement of equatorward flows (e.g., Bristow et al., J. Geophys. Res., 2007). However, there have been no studies on the effect of D-region HF wave absorption due to particle precipitation, which could lead to positive Doppler shift, which is independent of beam number but could be positively (negatively) correlated with the range (elevation angle) Initial result of the quantitative estimation of Doppler velocities associated with particle precipitation will be presented.

キーワード：SuperDARNレーダー、電離圏電子密度変動、太陽フレア・粒子降り込み
Keywords: SuperDARN radars, ionospheric plasma density change, solar flare / energetic particle precipitation

Total electron content forecast model over Japan using a machine learning technique

Total electron content forecast model over Japan using a machine learning technique

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Forecasting ionospheric condition is important for space weather operation, especially for predicting propagation delay of the radio waves in the ionosphere. National Institute of Information and Communications Technology (NICT), Japan, develops an ionospheric forecasting system of total electron content (TEC) in addition to a TEC monitoring system. Although several empirical and theoretical models have been developed in a decade, no model is available for forecasting TEC over Japan. Our purpose is to accomplish an operational TEC model over Japan using an artificial neural network technique which is developed by Maruyama [2007]. In our model, absolute TEC values for each day over Japan were projected on a two-dimension TEC map, that is, a local-time and latitudinal map. Then the time-latitudinal variation was fitted by using the surface harmonic function. The coefficients of the expansions were modeled by using a neural network technique. For the learning process, we used absolute TEC value from 1997 to 2014. The input parameters are proxies of the season, the solar activity, and the geomagnetic activity. Thus, daily two-dimensional TEC maps can be obtained for any days when the input parameters are available. We used input parameters which are provided in real-time by some institutes and achieved one-day TEC prediction over Japan.

キーワード：machine learning、total electron content、TEC forecast
Keywords: machine learning, total electron content, TEC forecast

GPS phase scintillation during the geomagnetic storm of March 17, 2015: The relation to auroral electrojet currents

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Ionospheric irregularities cause rapid fluctuations of radio wave amplitude and phase that can degrade GPS positional accuracy and affect performance of radio communication and navigation systems. The ionosphere becomes particularly disturbed during geomagnetic storms caused by impacts of coronal mass ejections compounded by high-speed plasma streams from coronal holes. Geomagnetic storm of March 17, 2015 was the largest in the current solar cycle. The high-latitude ionosphere dynamics is studied using arrays of ground-based instruments including Global Navigation Satellite System (GNSS) receivers, HF radars, ionosondes, riometers and magnetometers. GPS phase scintillation index is computed for L1 signal sampled at the rate of up to 100 Hz by specialized GNSS scintillation receivers of the Expanded Canadian High Arctic Ionospheric Network (ECHAIN) and the Norwegian Mapping Authority network supplemented by additional GNSS receivers operated by other institutions. To further extend the geographic coverage, the phase scintillation proxy index is obtained from geodetic-quality GPS data sampled at 1 Hz. In the context of solar wind coupling to the magnetosphere-ionosphere system, it has been demonstrated that GPS phase scintillation is primarily enhanced in the cusp, tongue of ionization (TOI) broken into patches drawn into the polar cap from the dayside storm-enhanced plasma density (SED) and in the auroral oval during energetic particle precipitation events, substorms and pseudo-breakups in particular. In this paper we examine the relation to auroral electrojet currents observed by arrays of ground-based magnetometers and energetic particle precipitation observed by DMSP satellites. Equivalent ionospheric currents (EICs) are obtained from ground magnetometer data using the spherical elementary currents systems (SECS) technique developed by Amm and Viljanen (1999) that has been applied over the entire North American ground magnetometer network by Weygand et al. (2011).
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Keywords: Polar and auroral ionosphere (Ionospheric irregularities, Ionospheric currents, Energetic particles), Radio science (Radio wave propagation, Space and satellite communication), Space weather (Impacts on technological systems)

TIE-GCMモデルと地上GPS-TEC観測による磁気嵐時の電離層データ同化
Ionospheric data assimilation with TIE-GCM and GPS-TEC during geomagnetic storm period

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The main purpose of this study is to investigate the latency time for the ionosphere data assimilation during the geomagnetic storm. An Ensemble Kalman Filter (EnKF) module developed by National Center for Atmospheric Research (NCAR), called as Data Assimilation Research Testbed (DART), is applied to assimilate the ionospheric electron density into a theoretical model (Thermosphere-Ionosphere-Electrodynamics General Circulation Model, TIE-GCM) with ground-based GPS total electron content (TEC) observations during the 26 September 2011 geomagnetic storm period. Effects of various assimilation time intervals, 60-, 30-, and 10-minute, on the ionospheric forecast responses are examined by their global root-mean-square errors (RMSEs) during the entire storm period. Substantial reduction of RMSEs for 10 minutes assimilation cycle suggests the ionospheric data assimilation system greatly improve the capability of model forecast during the geomagnetic storm period. Further examination shows that the neutral state variables in the assimilation model are the important factor to change the trajectory of model forecasting. However, the assimilation model with neutral state variables still needs the shorter assimilation cycle (10-minute in this study) to restrain overfitting of neutrals and lead to higher forecast accuracy during the geomagnetic storm.

キーワード：電離層データ同化、磁気嵐
Keywords: Ionospheric data assimilation, geomagnetic storm

大気圏電離圏結合モデルGAIAの高精度化およびデータ同化に向けた取り組み

Development of a whole atmosphere-ionosphere model GAIA for higher accuracy and its application toward data assimilation modeling

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超高層大気領域は人工衛星や地上 - 衛星間をつなぐ電波の通り道であり、その擾乱や変動は衛星の軌道や姿勢、また電波の伝搬に影響する。超高層大気の擾乱や変動の起源は、太陽フレアなど太陽面の活動が磁気圏を通して入ってくるだけではなく、地表付近の気象の影響も中層大気を通り入ってくることが知られてきた。我々は、電離圏・熱圏の全球分布を将来的に数値的に推測・予測するために、地表から熱圏上部までの中性大気領域と電離圏領域を相互に結合する大気圏電離圏結合モデル（GAIA）を開発してきた。しかし、長期シミュレーションと電離圏・熱圏の観測などとの比較・検証を行ったところ、数値予測への応用や大気研究により有効利用するためには、モデルの高精度化を進める必要があると分った。
本発表では、モデル高精度化の一環として、電離圏のダイナミクスやエネルギーの扱いの改良や、高分解能化などの試みとその結果について紹介する。また、数値予測に向けてデータ同化に対するインターフェースを開発しており、今後のデータ同化への取り組みについて紹介する。

キーワード：電離圏、熱圏、シミュレーション、モデリング、データ同化
Keywords: ionosphere, thermosphere, simulation, modeling, data assimilation

実時間データ同化にもとづくオーロラ活動指数の予測

SUSANOO-Aurora Activity Forecast: Forecast of the aurora index with the real time data assimilation

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The AU/AL indices are a manifest of the global aurora activity, and their forecast is useful to recognize the future evolution of geospace. In order to forecast the aurora activity, we have developed the forecast system of the aurora index based on the prediction model of Goertz et al.(1992). The model calculates the time evolution of the aurora index using the solar wind electric fields. The real time space weather forecast system SUSANOO (Shiota et al., 2014, http://st4a.stelab.nagoya-u.ac.jp/susanoo/) has provided the next 7 days solar wind parameters at 1 AU, and we calculate the time variations of the aurora indices using the electric fields from the SUSANOO-solar wind simulation. The Goertz model includes several empirical parameters, and the forecast skill depends on the accuracy of these parameters. We have implemented the real-time data assimilation to improve these parameters by comparing the model results and the actual aurora index. The developed system consists of the hindcast and forecast stages. In the hindcast stage, prediction, smoothing and filtering in the data assimilation are performed for the previous 7 days using the data from the SUSANOO-solar wind simulation and the observed aurora index, which improves the parameters for the model. Using the estimated parameters from the hindcast stage, we calculate the time evolution of the aurora index for the next 7 days as the forecast stage. In this presentation, we will present the concept of SUSANOO-aurora activity forecast and initial results from test-operations.

キーワード：データ同化、予測、オーロラ活動指数
Keywords: Data assimilation, Forecast, Auroral activity index

NICTの新太陽電波望遠鏡と宇宙天気予報
New solar radio telescope of NICT and its space weather forecasting

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太陽ではフレアに代表される爆発現象が絶えず起きている。この爆発現象に伴い、高エネルギー粒子(SEP)や、コロナ質量放出現象(CME)が発生する。これらの一部は地球にも到来し、人工衛星の運用や電波通信に大きな影響を与えることがある。太陽の爆発現象では突発的な電波が放射される(太陽電波バースト)。電波は粒子よりも早く伝搬するため、太陽電波バーストを定常的に観測することは、宇宙天気の予報にとって極めて有効である。
NICTでは太陽活動を監視することを目的に茨城県平磯にて太陽の電波観測を行ってきた。今回、より高性能な太陽電波の広帯域分光観測を目指し、観測場所をNICTの山川電波観測施設(鹿児島県指宿市)に移転するとともに、新しい太陽電波望遠鏡の開発を行った。本望遠鏡は、口径8メートルのパラボラアンテナからなる。太陽電波バーストはメートル波からマイクロ波にかけて発生する広帯域の連続波放射である。本望遠鏡は焦点に2種類の広帯域アンテナを用いることで、0.07GHzから9.0GHzまでを1台のアンテナでカバーしている。太陽の視直径は約0.5度あり、太陽フレアはどこで発生するか事前の予報が難しいため、望遠鏡は太陽全面の視野を持つ必要がある。そこで高周波側のアンテナ位置をデフォーカスすることで、観測する全帯域で太陽全面の視野を確保した。受信信号は受信機内で分割され、FPGAを用いたデジタル分光計に供給される。本望遠鏡に開発されたデジタル分光計は、帯域幅2GHz・分光点数4096点と、帯域幅1GHz・分光点数32768点の2種類があり、合計10台で9GHzの帯域幅の両円偏波同時観測を実現した。分光計はデッドタイム無く連続的に分光可能で、スペクトルは内部で積算され、8ms毎に積算スペクトルを記録することで、高時間分解観測を可能とした。本装置の広帯域な感度特性は、様々な周波数で発生する電波バーストの観測に有効であり、宇宙天気現象の検出精度向上に大いに活用できること考えられる。また、本装置の高分解なスペクトルデータは、太陽電波バーストに含まれる微細なスペクトル構造を分解可能であり、フレアにおける非熱的粒子の生成過程の解明につながる成果も期待される。

キーワード：太陽、太陽電波バースト、宇宙天気予報、太陽高エネルギー粒子、電波観測
Keywords: Sun, solar rasio burst, space weather forecasting, solar energetic particle, radio observation

Cross-field superslow propagation by phase-mixing of Alfven/slow mode waves in solar corona

Cross-field superslow propagation by phase-mixing of Alfven/slow mode waves in solar corona

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We discuss the apparent cross-field propagation by phase mixing of continuum Alfven waves or continuum slow mode waves in the solar coronal magnetic structures.
Recent observations and numerical simulations for coronal waves have found waves propagating across magnetic field lines at rather slow speed. Although only fast mode waves can propagate across magnetic field lines, the observed propagation speed is much slower than the typical fast mode speed. Hence it has been difficult to understand the nature of this cross-field ‘superslow’ propagation. We show that the phase-mixing of continuum Alfven or slow mode waves can explain this phenomenon. Phase-mixing of continuum Alfven or slow mode waves produces phase velocities perpendicular to magnetic field that decrease with time. Hence phase mixing can produce a cross-field superslow propagation after a sufficient lapse of time. We show that the analytical solutions of apparent wavelength and phase speed of phase-mixing quantitatively explain the superslow waves in the results of numerical simulation. We also show the existence of superslow waves in coronal potential arcades and discuss the applicability of our results to coronal seismology.

キーワード：太陽コロナ、太陽プロミネンス/フィラメント、磁気流体波動
Keywords: Solar corona, Solar prominence/filament, MHD wavess

Magnetohydrodynamic simulation of interplanetary propagation of multiple coronalmass ejections with internalmagnetic flux rope (SUSANOO-CME)

Magnetohydrodynamic simulation of interplanetary propagation of multiple coronalmass ejections with internalmagnetic flux rope (SUSANOO-CME)

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Coronal mass ejections (CMEs) are the most important drivers of various types of space weather disturbance. Here we report a newly developed magnetohydrodynamic (MHD) simulation of the solar wind, including a series of multiple CMEs with internal spheromak-type magnetic fields. First, the polarity of the spheromak magnetic field is set as determined automatically according to the Hale-Nicholson law and the chirality law of Bothmer and Schwenn. The MHD simulation is therefore capable of predicting the time profile of the southward interplanetary magnetic field at the Earth, in relation to the passage of a magnetic cloud within a CME. This profile is the most important parameter for space weather forecasts of magnetic storms. In order to evaluate the current ability of our simulation, we demonstrate a test case: the propagation and interaction process of multiple CMEs associated with the highly complex active region NOAA 10486 in October to November 2003, and present the result of a simulation of the solar wind parameters at the Earth during the 2003 Halloween storms. We succeeded in reproducing the arrival at the Earth's position of a large amount of southward magnetic flux, which is capable of causing an intense magnetic storm. We find that the observed complex time profile of the solar wind parameters at the Earth could be reasonably well understood by the interaction of a few specific CMEs.

キーワード：コロナ質量放出、太陽風、MHD
Keywords: CME, solar wind, MHD

適合格子細分化法を用いた太陽圏の動的モデルの構築

A dynamical model of the heliosphere with the adaptive mesh refinement

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A change in the heliospheric environment plays an important role in the modulation of the galactic cosmic rays; the magnetic field structure and the speed of the solar wind affect the cosmic ray transport in the heliosphere. Since the heliospheric environment is affected by the solar wind activities, we have been developing a framework for simulating the heliosphere by using MHD simulations.
The simulation code is based on SFUMATO code (Matsumoto 2007), which employs the block-structured adaptive mesh refinement (AMR) technique. The solar wind model gives the inner boundary condition of the simulations, and it is based on the model of Kataoka et al. (2009) and Shiota et al. (2014). The solar wind model adopted here is reconstructed by the observation of the solar magnetic fields. At this moment, the refinement criterion of AMR grid is only a function of the distance from the Sun. Our model reproduces the Parker spiral owing to the solar rotation.
We also measured the performance of the simulation code for massively parallel calculations. In the case of 1024/2048 cores calculations, our code exhibits parallel ratios of 99.945-99.982% and parallel efficiencies of 73.4-86.4%, depending on the implementation of a refinement manner. Such a high scalability is demonstrated even by a flat MPI parallelization.

キーワード：太陽圏、太陽風、MHD
Keywords: heliosphere, solar wind, MHD

伊勢スギの酸素同位体比分析から明らかになった小氷期末期の降水量増加
A humid climate of the last stage of the Little Ice Age in central Japan reconstructed using oxygen isotopes from tree-ring

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The Asian monsoon is an important part of the Earth’s climate system that is characterized by variations in the strength and expansion of the summer rain band. Rainfall reconstructions in China have revealed changing patterns of rainfall during the Little Ice Age (LIA), but few hydroclimate reconstructions around Japan have hindered the understanding of physical processes associated with the atmospheric system in the western North Pacific. Here, we report on rainfall variations in the Meiyu/Baiu season from AD 1600–1959 by using tree-ring cellulose oxygen isotopes from central Japan; this is the longest record in the eastern most regions under the monsoon’s influence. Data suggest that the wettest period occurred around AD 1790–1860, the final stage of the LIA. This shift was concurrent with sea surface temperature anomalies around the Philippines and off eastern Japan. Thus, meridional atmospheric circulation was likely weak during the last stage of the LIA.

キーワード：小氷期、モンスーン、樹木年輪、酸素同位体比
Keywords: Little Ice Age, Monsoon, tree-ring, oxygen isotopes

台風の発生と太陽活動の関係
Relationship between typhoon occurrence and solar activity

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It has been pointed out that atmospheric activity has ~27-day periodicity, which implies the connections between solar activity and the earth's climate since the rotation period of the sun near its equator is 27 days. We have showed a close relationship between globally synchronized thunderstorm/cloud activities in the tropical latitudinal range and solar parameter with ~one-month periodicity for a certain half year, using lightning data, a proxy of thunderstorm activity, obtained by the global radio wave network and a proxy of cloud amount, Outgoing Longwave Radiation (OLR). It was reported that the thunderstorm activity in Asia Maritime Continent (AMC) shows a seesaw correlation with the cloud in Western Pacific Warm Pool (WPWP), which show strong correlation with intensity of cosmic ray without time lag. It was revealed that this cloud increases in WPWP correspond to typhoon occurrences. Here we found a strong similarity and synchronization between the variation of lightning activity in AMC and that of the averaged OLR in broad longitudinal range in equatorial region (280E - 110E, 10S - 10N), where very limited numbers of typhoons take place. Moreover, all these parameters apparently show a clear correlation with solar parameters, such as galactic cosmic rays or F10.7 for the one-month periodicity. This fact suggests further and extensive studies, involving scientists in broader research fields, are needed to understand the global climate.

キーワード：台風、太陽活動、27日周期、積乱雲、西太平洋暖水プール
Keywords: typhoon, solar activity, 27-day, thunderstorm, WPWP

