R010-01
Zoom meeting B ：11/3 AM1 (9:00-10:30)
9:00〜9:15

磁気圏多点衛星観測時代に向けたデータ解析手法の開発

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Development of data analysis method for the era of magnetospheric multipoint satellite observation

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Until now, most direct magnetospheric surveys have been carried out using a single satellite. However, in recent years, missions using multiple satellites, such as the CLUSTER-II launched by ESA in 2000, have begun, and this trend is expected to increase in the future.

When the magnetic field is observed by a single satellite, the time-varying component of the magnetic field data recorded by the onboard magnetometer (Lagrange derivative) includes ”the time-varying component of the magnetic field at the fixed point where the satellite is located (Eulerian derivative)” and ” The magnetic field variation component caused by the satellite crossing a spatially non-uniform region of the magnetic field (cruising effect)” is superimposed. And these two elements cannot be distinguished in principle. The advantage of multi-satellite magnetic field observation is that it is possible to (1) derive the Eulerian derivative and (2) derive the basic information on the spatial geometry of the magnetic field (twist, curvature, and flux density gradient of the magnetic field lines) inside the formation flight of multi-satellites. We have developed a method to derive such basic information from a formation flight of four satellites. Aiming at the practical application of this method to satellite missions, we have started a study to estimate the phenomena actually occurring in computer space from the hypothetical acquired data by the formation flight of four satellites using MHD simulation. In this research, we are improving the open-source magnetohydrodynamic analysis software ”OpenFOAM” to reproduce the 3D space-time evolution of magnetic fields and plasmas, and verifying the above algorithm, with a view to testing it in repeatable experiments with high reproducibility. In this presentation, we will discuss the initial results of this experiment and its application to the magnetosphere-ionosphere coupled MHD simulator currently in operation.

これまで、ほとんどの磁気圏の直接探査は単一の衛星を使用して行われてきたが、近年では 2000 年に ESA が打ち上げた CLUSTER-⊠衛星を始め、複数の衛星を用いたミッションが開始され、将来この流れは益々活発化することが期待される。
巡航する単一の衛星で磁場を観測した場合、搭載された磁力計に記録される磁場データの時間変動成分（ラグランジュ微分）には、”衛星が位置する固定点での磁場の時間変化成分（オイラー微分）”と、”衛星が空間的に磁場の空間的非一様領域を横切ることによって生じる磁場変化成分（巡航効果）”が重畳しており、これらを原理的に区別することは出来ない。複数衛星による磁場観測のメリットは、各衛星の巡航情報と観測データ（ラグランジュ微分）を組み合わせて、(1）オイラー微分の導出と、(2）多点衛星が編隊飛行する領域の磁場の空間的幾何の基本情報（磁力線の捻れ、曲率、磁束密度勾配）の導出が、原理的に可能となることにある。我々は、こうした基本情報を 4 機の衛星編隊飛行から導出する手法を開発した。本研究では、この手法の衛星ミッションへの実用的応用を目指して、MHD シミュレーションを用いて、4 衛星の編隊飛行による仮想的な取得データから、実際に計算機空間で生じている現象を推定するための研究を開始している。本研究では、再現性の高い繰り返し実験によるテストを念頭において、オープンソースの電磁流体解析ソフトである”OpenFOAM”を改良して、磁場とプラズマの 3 次元時空発展を再現、上記アルゴリズムの検証を行っている。講演ではこの実験の初期結果と、現在稼働中の磁気圏電離圏結合 MHD シミュレータへの応用などについて議論する予定である。

R010-02
Zoom meeting B ：11/3 AM1 (9:00-10:30)
9:15〜9:30

3 次元全球電離圏静電ポテンシャルソルバーの開発

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Development of a three-dimensional global ionospheric electrostatic potential solver

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We are developing a global ionospheric electrostatic potential solver to investigate a magnetosphere-ionosphere-atmosphere coupling system. There are mainly two problems in previous studies. First, some potential solvers focus on the coupling of magnetosphere and ionosphere, and others focus on the coupling of atmosphere and ionosphere. However, only a few solvers that consider both couplings at the same time. Second, some solvers adopt the dipole magnetic field model and the thin shell model. The thin shell model regards the ionosphere as an infinitely thin layer assuming that the radial component has extremely low current density. These assumptions are valid at a high latitudinal ionosphere, but they are not suitable at a low and middle one.

To solve these problems, we implemented the International Geomagnetic Reference Field (IGRF) model and assumed the equipotentiality of the magnetic field line. The latter comes from the fact that parallel conductivity is much larger than Pedersen and Hall conductivity. Moreover, as the most important point of this solver, we can reconstruct the three-dimensional distribution of any quantities, such as electrostatic potential and current density, from the equipotentiality, even though the equation for electrostatic potential is a two-dimensional elliptic partial differential equation. The input parameters are distribution of conductivity, neutral wind, current density from magnetosphere (Region-1 FAC and Region-2 FAC), and date. We used the modified magnetic apex coordinate system for implement the equation. At the present stage, we calculate a distribution of conductivities by using NRLMSISE-00 and IRI-2016 for number densities and temperatures, and Ieda [2020] for collision frequencies. In this talk, we will introduce the development process of this solver and report the initial results of numerical simulations.

磁気圏-電離圏-大気圏結合系を再現し様々な問題を解き明かすため、電離圏全球ポテンシャルソルバーを開発している。従来のソルバーには大きく 2 つの問題点があると考えられる。第一に、磁気圏-電離圏結合のソルバーと大気圏-電離圏結合のソルバーは別個に開発されており、両方の結合を同時に考慮したソルバーはないということである。第二に、双極子磁場や薄層近似を用いることである。薄層近似とは、鉛直方向の電流密度が非常に小さいために、電離圏を無限に薄い層であるとみなすものである。これらの近似は高緯度電離圏では良い近似となる。しかし、双極子磁場からのずれが大きく、磁場の水平成分が大きな中低緯度では、現実とは離れた結果となる。

これらの問題を取り除くために、国際標準地球磁場（IGRF）モデルを用い、磁力線の等電位性を仮定したソルバーを実装した。後者の仮定は、平行電気伝導度がペダーセン伝導度やホール伝導度よりも非常に大きいということから導かれている。さらに、今回開発しているソルバーの最も重要なこととして、静電ポテンシャルについての 2 次元楕円型偏微分方程式を解いた後に、磁力線が等電位であることを用いて 3 次元分布を復元することができ、そのほかの物理量も 3 次元分布を得ることができる。インプットは電気伝導度、中性大気の風、磁気圏由来の沿磁力線電流（Region-1 FAC および Region-2 FAC）、時刻である。また、方程式を実装するにあたり modified apex coordinates を用いた。現時点では、伝導度分布を計算するために、NRLMSIS-00 と IRI-2016 から得られる各粒子の数密度と温度を、Ieda [2020] の衝突周波数を用いている。今回の学会では、ソルバーの開発状況と初期結果について報告する。

R010-03
Zoom meeting B ：11/3 AM1 (9:00-10:30)
9:30〜9:45

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A study on the geometrical evolution of magnetic fields

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The time evolution of the magnetic field as a vector field is characterized by the time evolution of the magnetic flux density and the time evolution of the magnetic field direction. In general, the magnetic field is not spatially uniform, the magnetic flux density has a spatial gradient, and magnetic field lines have geometrical structures such as curvature and twist. According to the Maxwell-Ampere law, the spatial structure of such a magnetic field is determined by the current distribution. At the same time, on a macroscopic scale, the current structure is accompanied by the Ampere force, which determines the spatial structure of the plasma velocity field through the force balance acting on the plasma motion, and the collapse of force balance triggers the time evolution of plasma motion. In particular, in MHD, the motion of the plasma across the magnetic field line excites the electric field and of which curl activates the time evolution of the magnetic field. Therefore, it is possible to uniquely determine what type of geometrical structure plasma motion causes the time evolution of magnetic flux density gradient, curvature and twisting of the magnetic field lines.

In this presentation, we will explain the general formulation describing the spatial geometry of the magnetic field as a vector field and its time evolution. By using this formulation, we will develop a discussion linking it to physical processes, in order to propose a more essential method of magnetic field analysis.

ベクトル場としての磁場の時間発展は、磁束密度の時間変化と、磁場方向の時間変化によって特徴づけられる。一般に磁場は空間的に一様でなく、磁束密度は空間勾配を持ち、磁場の単位ベクトルを連ねて定義される磁力線は曲率や捻じれといった幾何学的構造を持つ。従って、磁場の時間発展から磁場の幾何学的構造の時間発展を知ることは、曲率、捻れ、磁束密度勾配の時間発展を把握することと等価である。Maxwell-Ampere law によると、このような磁場の空間構造は電流分布によって決定される。同時に巨視的なスケールでは、電流構造には Ampere 力が付随し、それとバランスするプラズマの力学的構造をつうじて、プラズマ速度場の空間構造が決定され、力学バランスの崩れにより時間発展が発動する。特に MHD では磁場を横切るプラズマの運動が電場を励起し、その回転密度により磁場の時間発展が促されるため、どのようなプラズマの運動の幾何学的構造が、どのように磁力線の曲率や捻じれ、磁束密度勾配の時間発展をもたらすのか？という一意決定が可能となる。

本講演では、このようなベクトル場としての磁場の空間幾何とその時間発展を記述する一般的な定式化について説明し、それを物理過程と結びつけた議論を展開することにより、より本質的な磁場解析方法の提案を行う。

R010-04
Zoom meeting B ：11/3 AM1 (9:00-10:30)
9:45〜10:00

電離圏分極型PBIにおける電子加速メカニズム：3次元流体的電子加速シミュレータから得られる新機構

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Electron acceleration mechanism in ionospheric polarized PBI: A new solution using 3D fluid electron acceleration simulators

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The auroral oval poleward boundary auroral intensification (PBI) had been regarded the result of “distant neutral line reconnection” effects in the ionosphere. On the other hand, Ohtani and Yoshikawa., [2016] proposed a model in which PBI is the result of polarization process caused by plasma flows due to “dayside reconnection” approaching the conductivity gradient region of auroral oval. This model is an application of the theory of ionospheric polarization-Alfvenic field aligned current (FAC) proposed by Yoshikawa et al., [2013]. According to this model, Alfven waves upwelling from the ionosphere to the magnetosphere accelerate electrons downward and generating explosive auroral intensification. This is a new concept of the auroral process that has never existed in magnetospheric physics before. The purpose of our research is to investigate Alfven wave coupling between regions and 3D plasma wave-electromagnetic interaction, which explains the essential question of the above physical process, ” As a result of ionospheric polarization, how can upward Alfven waves upwelling from the cold ionosphere induce explosive downward electron acceleration?” Our goal is to reveal Alfven wave coupling between regions and 3D plasma wave-magnetic field interaction. As an initial step, we have developed 3D fluid electron acceleration simulators to recreate the auroral electron acceleration process associated with ionospheric polarized PBI and are constructing a more comprehensive auroral electron acceleration model. These simulators can reproduce the plasma oscillations as wave equilibrium solutions as well as the macroscopic dynamics of the electromagnetic field, however, the step width is limited to the plasma frequency band (10^5 ˜10^7/s) because of CFL conditions. Therefore, the computational cost is very high (˜(10^5 x N^3) where N is the number of cells and step=10^5). In our research, the following two simulators cover the propagation process of the reflected Alfven wave from the ionosphere to the magnetosphere with the interaction between the ion-electron fluid and magnetic field after the ionospheric response. (1) Form the initial structure of the Alfven wave propagated by Hall-MHD. (2) Reproduce the plasma wave-magnetic field interaction in the Hall-MHD wave by simulating the two-fluid model (e. g. Shumlak et al., [2003]), which makes fluid through the first principle Vlasov-Maxwell equations system by taking the distribution function moments. This method can track the evolution of the electromagnetic field and the detailed plasma behavior in the system within a realistic computational cost. The main purpose of our research is to obtain evidence of electron acceleration of 1 keV˜10 keV per particle of electron energy by using the above two simulators under the conditions of ionospheric polarized PBI.

In this presentation, we will start with a basic understanding of PBI, and explain the background, methods, and conditions of the Hall-MHD and the perfect two-fluid simulator introduced to prove the new PBI hypothesis, and then we will discuss the physics of the calculation results.

オーロラオーバル極域境界オーロラ増光現象（Poleward Boundary Intensification 以下 PBI）はこれまで distant neutral line reconnection の影響が電離層に現れた結果だと考えられてきた。これに対して、Ohtani and Yoshikawa., [2016] により PBI は dayside reconnection によるプラズマフローがオーロラ帯に接近し、電気伝導度勾配領域を分極させることに起因する一連の応答の結果であるというモデルが提案された。このモデルは Yoshikawa et al., [2013] によって提案された電離圏起源の polarization-Alfvenic FAC 励起の理論を、オーロラオーバルの極域境界領域で発生する PBI に適用したものである。このモデルでは、電離圏から湧き上がった Alfven 波が電離圏から磁気圏へと伝播する最中に電子を下向きに加速させ、爆発的なオーロラ増光を発生させるという、これまでの磁気圏物理学には存在しなかった全く新しい概念の物理プロセスの導入が必然となる。本研究の目的は、上記物理プロセスの根幹をなす「電離層分極の結果、冷たい電離圏から湧き上がった上向き Alfven 波が、如何に爆発的な下向き電子加速を引き起こすことが可能となるのか？」を説明する、Alfven 波による領域間結合と、3 次元プラズマ波動-電磁場間相互作用を解明する事にある。その初期段階として、「電離圏分極型 PBI」に伴うオーロラ電子加速過程を再現する「３次元流体的電子加速シミュレーター」を開発し、より包括的なオーロラ電子加速モデルの構築を進めている。このシミュレーターは、プラズマの波動的平衡解であるプラズマ振動から巨視的な電磁場のダイナミクスまで再現可能であるが、一方で CFL 条件により step 幅がプラズマ周波数帯 (105˜107/s) に制限されるため、3 次元で且つ見たい現象スケール (10-1˜s) まで時間発展するには莫大な計算コスト (˜(105 × N3):N はセル数,step 数=105) が要求される。そこで、「電離圏応答を得た後の電離圏から湧き上がる反射 Alfven 波がイオン-電子流体と相互作用しながら磁気圏方向に伝搬する」という過程を、(1) Hall-MHD により伝搬する Alfven 波の初期構造を形成し、(2)「Hall-MHD が形成した波の中で振る舞うプラズマ波動-電磁場間相互作用」を、第一原理的な Vlasov-Maxwell 方程式系の分布関数モーメントを取ることで流体

化した完全 2 流体方程式 (e.g. Shumlak et al., [2003]) のシミュレータにより再現することを試みた。この手法により、現実的な計算コスト内で、電磁場の発展と系で起こる詳細なプラズマの振る舞いを追うことができる。電離圏分極型 PBI の条件下で上記二つのシミュレータを駆使し、最終的に電子エネルギー 1 粒子当たり 1keV˜10keV の電子加速の証拠を掴むことが本研究の主旨である。

本講演では、PBI の基本的理解から、新 PBI 仮説立証のために導入した Hall-MHD と完全２流体シミュレータの背景、手法、各条件ついて解説し、計算結果についての物理的考察を行う。

R010-05
Zoom meeting B ：11/3 AM1 (9:00-10:30)
10:00〜10:15

磁気圏 MHD シミュレーションによる地磁気誘導電流（GIC）予測の検討

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Estimation of geomagnetically induced current (GIC) using the global MHD simulation of the magnetosphere

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The National Institute of Information and Communications Technology (NICT) is performing the real-time global magnetohydrodynamics (MHD) simulation of the magnetosphere by the improved REProduce Plasma Universe (REPPU) code to predict a risk of surface charging of satellites and aurora activities. As the input data, this simulation uses the data from the Deep Space Climate Observatory (DSCOVR) satellite, which observes solar wind at the L1 point of approximately 1,500,000 km in the solar direction from the Earth. As the result, it is possible to predict variations in the magnetosphere approximately an hour ahead. We will report on the estimation of geomagnetically induced current (GIC) using the global MHD simulation.

The electric field and current in the ionosphere are calculated by projecting the field-aligned current on the inner boundary of the simulation at 3 Re to the ionosphere. The variations of geomagnetic field on the ground can be obtained from the calculated ionospheric current using the Bio-Savart's law.

At high latitudes, GIC can be estimated using the geomagnetic field variations obtained by the simulation because contribution of the aurora electrojet to them is large. However, contribution of the ring current to geomagnetic field variations during geomagnetic storms is large at middle and low latitudes. We examined to estimate the variations by the ring current using the cross-polar cap potential obtained from the simulation and compared them with the GIC data. In this regard, the GIC observed at substations around the Kanto area in association with the geomagnetic storm was analyzed.

NICT では、衛星帯電リスクやオーロラ予測などのために改良した REPPU（REProduce Plasma Universe）コードによる磁気圏 MHD シミュレーションをリアルタイムで実行している。このシミュレーションでは、地球から太陽方向に約 150 万 km の L1 点で観測を行っている DSCOVR（Deep Space Climate Observatory）衛星のデータを入力しているため、約 1 時間程度先の磁気圏の変動を予測することができる。この磁気圏シミュレーションによる地磁気誘導電流（GIC, Geomagnetically Induced Current）予測の検討について報告する。

リアルタイム磁気圏シミュレーションでは、シミュレーションの内側境界を 3Re とし、そこでの沿磁力線電流を電離圏に投影して電離圏の電場と電流を計算する。この電離圏電流からビオサバールの法則を使って地上の磁場変動を計算することができる。

高緯度の GIC については、オーロラジェット電流による地磁気変動の影響が大きいため、計算で得られた地上の磁場変動を用いて予測を行うことができると考えられる。一方、磁気嵐時の中低緯度の地上での磁場変動については環電流の影響が大きい。そこで、磁気圏シミュレーションから得られる極冠電位の値を用いて環電流による地磁気変動を見積もり GIC の予測を行う検討を行った。これに関して関東周辺の変電所で磁気嵐に伴って観測された GIC について解析を行った。

R010-06
Zoom meeting B ：11/3 AM2 (10:45-12:30)
10:45〜11:00

What Condition is Necessary for the Large Solar Eruption of AR 12673 Before September 6 2017?

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The understanding of ”when”, ”where” and ”how” the solar flares take place is one of the long-standing issues in solar physics. The solar flares are widely considered as release phenomena of the free magnetic energy accumulated in the solar corona. Hence, sheared or twisted magnetic field lines are required but this is not a sufficient condition to produce solar flares. The understanding of how the sheared or twisted magnetic field lines before the flares destabilize or lose the equilibrium should be considered to clarify the trigger problem. If there are no any triggers, magnetic fields might stay in stable even though those accumulate enough free magnetic energy to cause flares.

Solar active region (AR) 12673, which appeared on September 2017, produced many M and C-class flares before the X-flares occurred. Yamasaki et al. found that highly twisted lines are already formed which have a potential to cause the X-flares as of September 4, but the magnetic field was stable for 2 days before the X-flares occurred. We conducted a hypothetical experiment by using a magnetohydrodynamic (MHD) simulation to explore a necessary condition for the eruption, as of September 4, in the region where the X-flares occurred on September 6th. We used a non-linear force-free field (NLFFF) as the initial condition of the simulation. The NLFFF was reconstructed from the photospheric magnetic field observed on September 4 which corresponds to 2 days before the first X-flare. As a result, although the NLFFF was stable to small disturbances where the residual force worked on the NLFFF, the eruption could be achieved if the strongly twisted lines with more than one-turn were formed through the reconnection and the magnetic flux reached more than about 7.0 x 10^{20} Maxwell. Moreover, we estimated a ratio of the magnetic flux of the highly twisted field lines and the overlying field lines which surround them. We found that when the flux ratio was approximately over 0.1, the twisted lines could be driven upward without depending on the decay index and eventually meet a condition of the torus instability.

R010-07
Zoom meeting B ：11/3 AM2 (10:45-12:30)
11:00〜11:15

Simulation study on the deformation of magnetic field in interplanetary CMEs

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Coronal mass ejections (CMEs) are the largest eruption in the solar system. CMEs carry huge plasmas in the solar corona of 10^11 to 10^13 kg into interplanetary space at velocities of a few hundred - thousand km/s. CMEs can affect a variety of space weather conditions when they collide with the magnetosphere of the earth. In particular, the magnetic field of CMEs is a serious factor of space weather disturbance, because the southward component of the magnetic field in CMEs could cause the geomagnetic field storm. In this study, we focus on the interaction between interplanetary CME (ICME) and the background solar wind, especially the deformation of ICME magnetic field structure due to the CME-solar wind interaction.

We performed three series of MHD simulations of ICME propagation in the inner heliosphere using SUSANOO-CME (Shiota & Kataoka, 2016) with the aim of elucidating the basic mechanisms of the deformation. In order to explore the basic processes, we adopted the following two assumptions: First, the velocity and magnetic field of the background solar wind were assumed to be isotropic to avoid the effect of the complicated anisotropy of the solar wind; Second, a CME with spheromak-type internal magnetic field is launched from a same position of the inner boundary of the computational domain. In Series 1, a CME with different magnetic field orientations was launched into the background solar wind with no magnetic field. The major axis of the internal spheromak field is assumed to be along the solar equator and facing west or east. Here, we used four different cases in which the toroidal and poloidal components of the spheromak magnetic field are inverted, respectively. In Series 2, an identical CME (the same as one of Series 1) was launched into the background solar wind with different magnetic field strengths. In Series 3, the same CME with different initial velocities was launched into the solar wind of standard magnetic field strength.

As the results of Series 1, it was found that the magnetic flux at the front part of the spheromak is compressed in the direction of motion and expands laterally due to the interaction with the solar wind in the early stage just after the CME injection. As the result of Series 2, we found that the magnetic flux of the CME rotates and the major axis of the spheromak tends to tilt in the radial direction. The stronger the solar wind magnetic field, the faster the rotation speed. This rotation of ICMEs may be caused by the tilting instability of spheromak. Finally, in Series 3 we measured the tilt angle in terms of the orientation of spheromak torus on the equatorial plane and investigated the dependency of the tilting on the CME speed. The result was consistent with the model of the tilting instability. These calculations imply that not only the hydrodynamic interaction with the solar wind but also the magnetohydrodynamic interaction has a significant impact on the magnetic field deformation of ICMEs. Based on the simulations, we will also discuss the prediction of the magnetic field of ICME.

R010-08
Zoom meeting B ：11/3 AM2 (10:45-12:30)
11:15〜11:30

アンサンブル SUSANOO-CME simulation による CME 到来予測：予測指標についての考察

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Prediction of arrival of CME and its magnetic field with ensemble SUSANOO-CME simulation: examination of prediction indices

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The predictions of CME arrival to the Earth and the southward magnetic field brought by the CME flux ropes are one of crucial tasks for space weather forecast. We recently have developed a new prediction system of CME impact (arrival of CME and magnetic field) with MHD simulation SUSANOO-CME (Shiota & Kataoka 2016). In this system, based on automatically collected real-time observations, we can conduct ensemble MHD simulation of different set of 10 input parameters of each CME. However, we still need to study how we should select and disperse the input parameters to obtain better prediction of CME arrival and its impact.

In this study, several time profiles of in situ observation of solar wind and IMF (V, dV/dt, |B|, Bz, etc.) were selected to examine their suitability for indices of space weather disturbances. For example, the profile of dV/dt is a candidate of the index of shock fronts, but, in the simulation, has uncertainty due to coarse spatial resolution of the simulation. We examined the relationship between the uncertainty and CME parameters. To increase ensembles members and compensate the uncertainty due to CME direction, we also use several sampling positions in vicinity of Earth positions in a single simulation. The ensemble results are combined to describe a prediction method as a probability distribution.

As similar to the profile of dV/dt, we also examined suitability of other indices and their sensitivities of the input CME parameters to the prediction results of each index.

CME の地球への到来予測や CME のフラックスロープによる南向き磁場の予測は宇宙天気予報の重要な課題の一つである。我々は最近、MHD シミュレーション SUSANOO-CME(Shiota & Kataoka 2016) を用いた CME の到来予測システムを開発した。このシステムでは、自動的に収集されたリアルタイム観測データに基づいて、各 CME の 10 個の入力パラメータを変更したアンサンブル MHD シミュレーションを行うことができる。しかし、CME の到達とその影響のより良い予測を得るためには、入力パラメータをどのように選択して分散させるかについてさらなる研究が必要である。

本研究では、太陽風と惑星間空間磁場のその場観測 (V,dV/dt,B,Bz 等) の時間プロファイルをいくつか選び、宇宙気象擾乱の指標としてどの程度適しているかについて検討した。例えば、dV/dt のプロファイルは衝撃波の指標の候補であるが、シミュレーションでは空間分解能が粗いために到来時刻に不確実性が生じる。この不確実性と CME のパラメータとの関係を調べた。またアンサンブルのメンバーを効率よく増やし CME の方向の不確実性を補償するために、1 回のシミュレーションで地球近傍のいくつかの位置での太陽風のサンプリングを行ったデータを利用する。これらのアンサンブル結果を総合して確率分布としての予報の手法について述べる。

dV/dt のプロファイルと同様に、他の指標の適合性と、各指標の予測結果に対する入力 CME パラメータの感度についても検討した結果を報告する。

R010-09
Zoom meeting B ：11/3 AM2 (10:45-12:30)
11:30〜11:45

A machine learning approach to fill the data gaps of the solar wind profiles causing large magnetic storms

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The solar wind data at the Earth's position have data gaps for many of large magnetic storms. The data gaps have prevented the detailed understanding of the solar wind structures which can drive large magnetic storms. We used a limited number of recent magnetic storms without data gaps in the solar wind parameters as the training data set for a machine learning technique called Echo State Network, to output the continuous solar wind data. The obtained metrics have merit and demerit, compared with the other gap-filling methods. Based on the continuous solar wind profiles via the machine learning technique, we discuss the solar wind structures causing large magnetic storms.

R010-10
Zoom meeting B ：11/3 AM2 (10:45-12:30)
11:45〜12:05

太陽風シミュレーション：物理ベースの宇宙天気予報に向けて

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Simulations of the solar wind: toward the physics-based space weather prediction

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Due to the widespread social infrastructures using space technologies, the human society becomes vulnerable to space weather disturbances that originate from the solar activities. Space weather forecasting, the technology to predict these disturbances in advance, will become increasingly important. One of the most important factors in space weather forecasting is the solar wind velocity and its spatial structure. To qualitatively and accurately predict them from other observables, it is necessary to we need to solve multiple unsolved problems, including: 1) the global structure of the solar magnetic field, 2) the density and velocity of the solar wind corresponding to each magnetic field structure (magnetic field line), and 3) the propagation of the solar wind from the vicinity of the Sun to the Earth. In the current widely used models, space weather forecasting is realized by predicting the global magnetic field by the potential-field source-surface method (PFSS method) and the empirical model of the solar wind velocity. Global MHD simulations of the heliosphere (e.g. SUSANOO) usually uses such empirical models as their inner boundary. However, it has been found that the optimal parameters of the empirical solar wind velocity, which is the basis of the space weather model of this kind, vary greatly with solar activity cycle and solar rotation phase. In addition, the empirical models are found to be incapable of reproducing the solar wind velocity in some specific magnetic configurations. The limited performance of the empirical model is one of the major obstacles to high-precision space weather forecasting.

In this study, we evaluate the performance of the first-principle solar wind simulations in predicting the solar wind velocity to investigate the possibility of a physics-based solar wind velocity model and space weather forecast model. In recent years, solar wind simulations have made rapid progress, and together with observations by the Parker Solar Probe, we have been able to reproduce the solar wind with very high accuracy. In particular, the model that the solar wind is heated and accelerated by magnetohydrodynamic waves has been found to be promising. In this study, we calculate the global magnetic field structure of the Sun using the PFSS method, simulated the solar wind acceleration along each magnetic field line based on wave scenario, and compared the obtained solar wind velocity with the IPS observation data to evaluate the velocity prediction performance of the simulation. The simulation results show that the physical model is able to predict the solar wind velocity at high latitudes with much higher accuracy than the existing WSA method. On the other hand, in the mid-to-low latitudes, the performance of the physical model was comparable to that of the WSA method. However, it cannot be said that the physical model is inapplicable in the mid-to-low latitudes because both the extrapolation of the magnetic field is prone to large errors in such regions. Our results imply that physics-based space weather forecasting, with the physics-based prediction of solar wind speed, is highly feasible.

宇宙を利用した社会インフラの充実に伴い、社会は太陽活動を起源とする宇宙天気の乱れに脆弱になる。したがって宇宙天気（の乱れ）を事前に予測する技術、宇宙天気予報は今後ますます重要になると考えられる。宇宙天気予報において最も重要なファクターの一つは太陽風速度およびその空間構造であるが、それらを定量的かつ正確に予測するには多くの課題が残されている。具体的には、1. 太陽の大局的磁場構造、2. それぞれの磁場構造（磁力線）に対応する太陽風の密度、速度、3. 太陽近傍から地球までの太陽風伝播の三点を正しく理解する必要があるがそのどれもが難しい。現状広く使われるモデルでは、大局磁場をポテンシャル磁場（PFSS 法）で、各々の磁力線に対応する太陽風速度を経験則（WSA 法）で予測する。また、太陽圏のグローバル磁気流体シミュレーションもこれらの経験則を内側境界として用いている（例えば SUSANOO）。しかしながらその根幹をなす太陽風速度の経験則は太陽活動周期ごと、太陽自転周期ごとに最適なパラメータが大きく異なることがわかっており、また、一部の磁場構造に対する再現性が悪いなど、、高精度宇宙天気予報の大きな障害の一つとなっている。

そこで私たちは太陽風の第一原理シミュレーションの速度予測性能を評価することで物理ベースの太陽風速度モデル、宇宙天気予報モデルの可能性を検討した。近年太陽風シミュレーションの進展は目まぐるしく、太陽風探査機（Parker Solar Probe）の観測と合わせて非常に高い精度で太陽風を再現できるようになってきた。特に太陽風が磁気流体波動で加熱、加速されるというモデルが有力であることがわかってきた。そこで本研究では、1. 太陽の大局磁場構造を PFSS 法で計算し、2. 各磁力線に沿って波動モデルに基づく太陽風加速シミュレーションを行い、3. 得られた太陽風速度を IPS 観測データと比較することでシミュレーションの速度予測性能の評価を行なった。シミュレーションの結果、物理モデルは高緯度の太陽風について既存の WSA 法に比べて遥かに高精度で速度を予測可能であることがわかった。一方中˜低緯度では WSA 法と同程度の性能しか得られなかったが、中˜低緯度は磁場の外挿法に大きな誤差が生じやすいため一概に物理モデルが適用できないとは言えない。私たちの計算結果は太陽風速度を物理モデルで予測する、物理ベース宇宙天気予報の可能性が十分高いことを意味する。

R010-11
Zoom meeting B ：11/3 AM2 (10:45-12:30)
12:05〜12:25

光赤外線波長における天文観測と宇宙天気

#佐野 圭 [1)]
(1 九工大

Astronomical observation in visible-infrared wavelength and space weather

#Kei Sano[1)]
(1Kyutech

For astronomical science, we have conducted electromagnetic observations in visible and infrared wavelengths with ground-based and space telescopes. Our main objective is to measure the extragalactic background light (EBL) in these wavelengths. The EBL consists of entire radiation emitted throughout the cosmic history and serves as a crucial quantity to reveal cosmological evolution of stars and galaxies. For example, we recently succeeded in first launch of Cosmic Infrared Background Experiment 2 (CIBER-2), which is an international sounding-rocket project to observe electromagnetic spectrum and spatial fluctuation of the EBL from space. To measure the EBL intensity accurately, it is important to study a foreground emission, zodiacal light, which is caused by scattering of sunlight by interplanetary dust and thermal emission from the dust. Therefore, we have also observed the detailed electromagnetic spectrum of the zodiacal light by using ground-based telescopes.

In observation of visible to infrared electromagnetic waves from space, some physical phenomena related to space weather can be observed as well. For one thing, the hydroxyl radical (OH) in the middle atmosphere is influenced by solar ultraviolet radiation and produces emission lines in near-infrared wavelengths. Such lines can be observed from ground-based telescopes with high spectral resolution. In analysis of the time variation, a strong positive correlation between OH and MgII index has been reported. For another thing, space infrared observation of zodiacal light reportedly found a moving interplanetary dust cloud which is likely associated with the solar coronal mass ejection.

In this presentation, we will introduce our astronomical observations and space whether phenomena which can be observed by visible to infrared electromagnetic waves.

R010-12
Zoom meeting C ：11/4 AM1 (9:00-10:30)
9:00〜9:15

Statistical study on the effect of solar flare emission spectra on the Earth's ionosphere using numerical simulations

#Shohei Nishimoto[1)],Kyoko Watanabe[1)],Hidekatsu Jin[2)],Toshiki Kawai[3)],Shinsuke Imada[3)],Tomoko Kawate[4)]
([1]NDA,[2]NICT,[3]ISEE, Nagoya Univ.,[4]NIFS

The X-rays and extreme ultraviolet (EUV) emitted during solar flares can rapidly change the physical composition of the Earth's ionosphere, causing sudden ionospheric disturbances and other space weather phenomena (Dellinger 1937). Therefore, to understand how solar flare emission spectra affects the ionosphere, it is important to have an accurate understanding of the solar flare emission spectra. Solar flares with a long duration have a large effect on the ionosphere due to the large total energy (Qian et al., 2010). So, it is also important to accurately estimate the emission profile of solar flare.

The model based on physical process of the flare is useful for this purpose. We verify the extent of reproducing the flare emission spectra using a newly developed simple method based on the physical process of the flare loop (Kawai et al., 2020). In this method, we convert the soft X-ray light-curves observed during flare events into EUV emission spectra using a one-dimensional hydrodynamic calculation and the CHIANTI atomic database (Dere et al., 2019). We examined the "EUV flare time-integrated irradiance" and "EUV flare line rise time" of the EUV emissions for 21 events by comparing the calculation results of the proposed method and observed EUV spectral data. Proposed method succeeded in reproducing the EUV flare time-integrated irradiance of Fe lines which have relatively higher formation temperature, as well as the 5.5-35.5 nm band. For the EUV flare line rise time, there was acceptable correlation between the proposed method estimations and observations for all Fe flare emission lines (Nishimoto et al., 2020).

We used the solar flare emission spectral models and the Earth's whole atmospheric model to study the effect of X-rays and EUV emissions from flares on the ionosphere. For the solar flare emission spectral models, we used the physical model described above and an empirical model, the Flare Irradiance Spectral Model (FISM; Chamberlin et al., 2020). For the Earth's whole atmospheric model, we used the Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy (GAIA; Jin et al., 2011). We compared the total electron content (TEC) variations corresponding to various solar flare emission spectra for 6 X-class flare events that occurred from 2010 to the 2021. The results show that the wavelengths of solar flare emissions that mainly affect TEC variations are soft X-rays ($<$10 nm) and EUV emissions (especially 28-30, 32-34 nm).

R010-13
Zoom meeting C ：11/4 AM1 (9:00-10:30)
9:15〜9:30

太陽フレア X 線・EUV・ライマンα線放射とデリンジャー現象の関係

#北島 慎之典 [1)], 渡邉 恭子 [1)], 西本 将平 [1)], 荒尾 宗睦 [1)], 垰 千尋 [2)], 西岡 未知 [2)]
([1] 防衛大,[2] 情報通信研究機構

Relationship between solar flare X-ray, EUV and Lyman-alpha emissions and the Dellinger phenomenon

#Shinnosuke Kitajima[1)],Kyoko Watanabe[1)],Shohei Nishimoto[1)],Munechika Arao[1)],Chihiro Tao[2)],Michi Nishioka[2)]
([1]NDA,[2]NICT

It is well known that the rapid increase in solar flare emissions ionizes atoms and molecules in the Earth's atmosphere, increases the electron density in the ionosphere, and causes space weather phenomena such as radio wave communication failures (e.g., Woods et al., 2000). In particular, X-rays (0.1-10 nm) and Extreme Ultraviolet (EUV, 10-120 nm) emissions are thought to mainly affect electron density fluctuations in the ionosphere. However, Lyman-alpha (121.6 nm) is also considered to be one of the wavelengths affecting the lower ionosphere (e.g., Nicolet and Aikin, 1960). The communication failure caused by the increase in electron density in the ionosphere D region (60-90 km) is called the Dellinger phenomenon (Dellinger 1937).

The occurrence of the Dellinger phenomenon can be known from the minimum reflection frequency (f_{min}) value observed by the vertical incident ionosonde. It has been reported that the f_{min} value increases when the Dellinger phenomenon occurs from statistical studies. And the f_{min} value fluctuation depends mainly on the peak X-ray intensity of flare (flare class) and the solar zenith angle (e.g., Tao et al., 2020). However, since there are several observations in which the f_{min} value is not proportional to the flare class, the relationship between flare emission spectra and the electron density in the ionosphere D region is not clearly understood.

In this study, we compared flare emissions (X-rays, EUVs and Lyman-alpha) observed by the Geostationary Operational Environmental Satellite (GOES) /X-ray Sensor (XRS), Extreme Ultraviolet Sensors (EUVS), the Solar and Heliospheric Observatory (SOHO)/Solar EUV Monitor (SEM) and the Solar Dynamics Observatory (SDO)/ EUV Variability Experiment (EVE) with the f_{min} values observed by the ionosonde operated by the National Institute of Information and Communications Technology (NICT) at Wakkanai, Kokubunji, Yamakawa and Okinawa. We studied 38 flare events which were larger than M3-class occurred during the daytime (9:00-18:00 JST and solar zenith angle <80 rad) between 2011 and 2014. First, we compared the f_{min} values with the GOES/XRS, EUVS and SOHO/SEM data. We found good correlation with shorter wavelength flare emission. However, Lyman-alpha emission did not contribute to the increase of f_{min}. These results suggest that (especially shorter) X-ray emission may be effective in the occurrence of the Dellinger phenomenon. Then next, to identify the flare emission wavelengths that mainly affect the increase in f_{min} values, we compared the variation of f_{min} values with the EUV spectra using the SDO/EVE data. In this presentation, we will report on these results in detail.

太陽フレア放射により地球大気中の原子・分子が電離し、電離圏の電子密度が増大することにより、電波通信障害などの宇宙天気現象が発生することが知られている（Woods et al., 2000 など）。特に、X 線（0.1-10 nm）と極端紫外線（EUV, 10-120 nm）放射が電離圏の電子密度変動に主に影響していると考えられているが、ライマンα（121.6 nm）も影響しているという報告がある（Nicolet and Aikin, 1960 など）。電離層 D 領域（60-90 km）の電子密度上昇に起因する通信障害はデリンジャー現象（Dellinger 1937）と呼ばれている。

デリンジャー現象の有無は、イオノゾンデで観測される最小反射周波数（f_{min}）の値で知ることができる。デリンジャー現象が発生すると f_{min} 値が上昇し、その変動量は主にフレアの X 線ピーク放射強度と太陽天頂角に依存することが報告されている（Tao et al., 2020 など）。しかし、f_{min} 値とフレアの規模が比例していない観測例も多数あることから、フレア放射スペクトルと電離圏 D 領域における電子密度の増大との関係は明確には分かっていない。

そこで、GOES/XRS, EUVS, SOHO/SEM 及び SDO/EVE などの機器で観測された太陽フレア時の X 線・EUV・ライマンα線データと、情報通信研究機構が運用しているイオノゾンデ（稚内・国分寺・山川・沖縄）で観測された f_{min} 値との比較を行なった。調査対象は 2011 年から 2014 年の間に日本の昼間（日本時間 9:00-18:00 かつ天頂角<80°）に発生した M3 クラス以上のフレアとした。まず、GOES/XRS, EUVS, SOHO/SEM のデータと f_{min} 値を比較したところ、f_{min} 値の増大には X 線放射のうち短波長の放射の影響が大きいことがわかった。一方、ライマンα線は f_{min} 値の増大には寄与していないことが分かった。これより、デリンジャー現象の発生には短波長の X 線放射が効いていると考えられる。次に、f_{min} 値の増大に主に影響している太陽フレア放射の波長を特定するため、SDO/EVE のデータを用いて、f_{min} 値の変動量と EUV 放射強度スペクトルとの比較を行なった。今回の発表では、これらの解析結果について報告する。

R010-14
Zoom meeting C ：11/4 AM1 (9:00-10:30)
9:30〜9:45

磁気赤道域における特異的な太陽フレア効果（SFE ＊）の発生要因の探究

#安永 朗宏 [1)], 藤本 晶子 [3)], 吉川 顕正 [2)]
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Research on the causes of specific solar flare effects (SFE∗) in the dip equator

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X-rays and ultraviolet rays associated with solar flares reach the Earth and stimulate an ionization of neutral particles in the daytime ionosphere, which changes the ionospheric current in a very short time, and this effect can be observed as drastically changing geomagnetic field perturbations [Campbell, 2003]. There are two types of magnetic field perturbations: positive SFE, in which the magnetic field becomes stronger than just before a solar flare, and negative SFE∗, in which the magnetic field becomes weaker [Yamazaki et al., 2009].

Rastogi et al. (1996) stated that the positive variation of the magnetic field (SFE) through the equatorial region is a result of the enhanced equatorial electrojet (EEJ), while the negative variation (SFE∗) in the morning and evening side of dip-equator is a result of the enhanced counter electrojet (CEJ).

However, generation of SFE∗around local noon dip equator is also reported [Rastogi et al., 2003; Yamazaki et al., 2009; Rastogi et al., 2013]. Yamazaki et al. (2009) reported two unique SFE∗events. They suggested that this phenomenon may be caused by an increase in electrical conductivity in the lower part of the E layer due to X-class flares and the penetration of a westward electric field into the magnetic equatorial region due to the northward turning of the interplanetary magnetic field (IMF) Bz. On the other hand, Rastogi et al. (2013) examined the same event and proposed that this type of SFE∗was enhanced partial CEJ by solar flares. However, reports on SFE∗to date are limited, and it remains an open question what kind of ionospheric environment causes SFE∗.

To clarify the generation mechanism of the unique SFE∗, it is indispensable to understand the detailed structure of the ionospheric current system. The purpose of this study is to understand the generation mechanism of unique SFE∗around noon time by developing a methodology that can quantitatively analyze the geomagnetic variations during solar flares times.

In this study, we investigated the relationship between the amplitude of equivalent current variations converted from the ground magnetic field and latitude for 6 cases of SFE and 4 cases of SFE∗. Data sets are magnetic field data from MAGDAS/CPMN and X-ray data from GOES satellite. As a first result, in the events where only SFE occurred, a W-shaped fluctuation was observed: the increase rate was the largest around the dip equator, the increase rate decreased as the latitude increased, reached a minimum around 20-30 degrees north-south, and the increase rate increased again toward higher latitudes. On the other hand, no such latitudinal dependence was observed in the event where SFE∗occurred. In this presentation, we will examine the initial results by increasing the number of cases and report the physical mechanism that causes the global structure of SFE and SFE∗.

太陽フレアに伴う X 線や紫外線が地球に到達することにより、昼側電離層内でプラズマの電離が促進され、電離層電流がごく短時間のうちに変化することによって、その影響が地上磁場観測に顕れることが知られている。このような突発的な地磁気擾乱は” 太陽フレア効果” (SFE) として知られている [Campbell, 2003]。

SFE が生じる直前の磁場に対して、磁場変化を強める作用を ‘ Positive SFE(SFE)’、反対に弱める作用を ‘ Negative SFE（SFE∗）’ と呼ぶ [Yamazaki et al., 2009]。

Rastogi et al., [1996] により、磁気赤道域において、Equatorial ElectroJet（EEJ）を強める磁場の正の変動現象と、朝・夕の Counter-ElectroJet（CEJ）を強める磁場の負の変動現象が報告され、それぞれ SFE, SFE∗として定義された。しかしその後、正午付近の EEJ 域において磁場が逆方向に発達する SFE∗現象が報告され、その要因について様々な議論が展開されている [Rastogi et al., 2003；Yamazaki et al., 2009；Rastogi et al., 2013]。

Yamazaki et al. [2009] では、2 つの特異的な SFE∗の解析が行われた。その結果、X クラスのフレアによる E 層下部の電気伝導度の上昇や惑星間空間磁場（IMF）北転による磁気赤道域への西向き電場の侵入、ローカルな電流系の形成が SFE∗の発生要因であると示唆された。一方、Rastogi et al. [2013] では、磁気赤道域の観測点を用いて同イベントを検証した結果、太陽フレアによって増強された partial CEJ が SFE∗の要因であるとの提案がなされた。現状、SFE∗現象に関する報告例は限られており、前出の SFE∗発生要因を含めて、どのような電離圏環境下で SFE∗が発生するかについては、未解決なままである。

先述した特異的な SFE∗の発生メカニズムを明らかにするためには、全球的な磁場解析を行い、電流構造の理解が必須である。本研究の目的は、正午付近に発生する特異的な SFE∗現象を定量的に分析可能な手法を開発し、その発生メカニズムを明らかにすることにある。

本研究では、SFE ６例、SFE ＊４例について、地上磁場から変換された等価電流の変動成分の振幅と緯度の関係について調査を行った。データセットは MAGDAS /CPMN の地上磁場観測データと GOES の X 線データを用いた。初期結果として、SFE のみ発生したイベントでは、磁気赤道域近辺で最も増大率が大きく、緯度があがるにつれて増大率は減少し、南北２０〜３０度付近で極小値を取り、高緯度に向かうにつれ再び増大率が大きくなっていく、W 型の

変動傾向が見られた。一方、SFE ＊が発生したイベントではそのような緯度依存性は見られなかった。講演では、解析事例の増やすことによる初期結果の検証と、SFE,SFE∗のグローバル構造をもたらす物理メカニズムについて報告する予定である。

R010-15
Zoom meeting C ：11/4 AM1 (9:00-10:30)
9:45〜10:00

太陽活動がスポラディックE層に与える影響

#品川 裕之[1)], 垰 千尋[1)], 陣 英克[1)], 三好 勉信[2)], 藤原 均[3)]
[1)] 情報通信研究機構,[2)] 九大・理・地球惑星,[3)] 成蹊大・理工

Effects of solar activities on sporadic E layers

#Hiroyuki Shinagawa[1)],Chihiro Tao[1)],Hidekatsu Jin[1)],Yasunobu Miyoshi[2)],Hitoshi Fujiwara[3)]
[1)]NICT,[2)]Dept. Earth & Planetary Sci, Kyushu Univ.,[3)]Faculty of Science and Technology, Seikei University

Sporadic E (Es) layers are narrow layers with high electron densities, and appear sporadically at altitudes between 90 km and 120 km. Among the many kinds of space weather disturbances, the Es layer is one of the most important phenomena because it significantly affects radio communication and broadcast systems as well as air-navigation systems, which use high-frequency (HF) and very high-frequency (VHF) radio waves. It is widely accepted that vertical wind shear generated by atmospheric waves such as atmospheric tides, planetary waves, and gravity waves propagating from the lower atmosphere play a primary role in the formation of Es layers. Although a number of studies about the effects of solar activities (X-ray and EVU variations) on Es layers have been done using observational data of the ionosphere, it is still not certain whether or not there is a relationship between solar activities and Es layers. We have employed the whole atmosphere-ionosphere coupled model GAIA to investigate the solar activity dependence of the physical conditions in the altitude region of Es layers. Initial results in our analysis indicate that the dependence of neutral wind in the region on solar activities is very weak, while there is a significant dependence of ionospheric electric field on the solar activities. We are now studying the dependence of Es layers on the neutral wind change as well as on the electric field change caused by solar activity conditions. We will report the results of studies of those problems using the GAIA simulation.

スポラディックＥ層（Ｅｓ層）は、高度９０ｋｍ〜１２０ｋｍに突発的に現れる高電子密度の薄い層であり、ＨＦ〜ＶＨＦ帯の電波を利用した通信・放送や航空機の管制などに混信を引き起こす場合があるため、宇宙天気研究において重要な現象の一つである。Ｅｓ層の形成には下層大気から伝搬してくる潮汐波、プラネタリー波、重力波などの大気波動で生成される水平風の鉛直シアが主要な役割を担っていると考えられている。一方、太陽活動（Ｘ線・ＥＵＶ変動）がＥｓ層に及ぼす影響に関しては、古くから電離圏の長期観測データを用いて多くの研究が行われてきたが、ある程度の影響があるとする説と、観測データに有意な影響は見られないとする説の両方があり、未だに結論が出ていない。そこで本研究では、全大気圏－電離圏結合モデルＧＡＩＡを用いて太陽活動の大きい場合と小さい場合についてＥｓ層発生領域の物理的状態の比較を行った。初期の解析結果では、Ｅｓ層の高度領域の中性風については太陽活動の依存性は非常に小さいが、電離圏電場に関しては有意な違いがあることがわかった。現在、（１）太陽活動変動によるＥｓ領域の中性風のわずかな違いがＥｓ層の長期変動に有意な影響を及ぼすのかどうか、（２）太陽活動による電場の変化がＥｓ層の太陽活動依存性につながるかどうか、について調べている。本講演では、これらの点についてＧＡＩＡを用いて調べた結果を報告する。

R010-16
Zoom meeting C ：11/4 AM1 (9:00-10:30)
10:00〜10:15

GBASの脅威となる低緯度電離圏電子密度急勾配パラメータ間の相関特性について

#中村 真帆[1)], 斎藤 享[1)], 吉原 貴之[2)]
([1] 電子航法研,[2] 電子航法研

Correlation of steep ionospheric delay gradient parameters as a threat to GBAS in the low magnetic latitude region

#Maho Nakamura[1)],Susumu Saito[1)],Takayuki Yoshihara[2)]
([1]ENRI, MPAT,[2]ENRI

Spatial gradient in the ionospheric electron density is a threat to differential GNSS systems such as the GNSS ground-based augmentation system (GBAS), because it may cause spatial decorrelation of differential correction between the reference station and a user. Steep spatial ionospheric gradients in the low magnetic latitude region are caused mainly by the equatorial plasma bubble (EPB). Past studies by the authors have also confirmed that the occurrence of steep electron density gradients is consistent with the occurrence characteristics of EPB. Although the mechanism of EPB development has been studied extensively for a long time, the development conditions under which a gradient with a width of several tens of kilometers that threatens GBAS have not been clarified.

Parameters that characterize the ionospheric delay gradients, which is called ionospheric threat model are used for the safety design of GBAS. The parameters include the slope, depth, width, and moving speed. GBAS has to be safe against the worst case combination of these parameters. The ionospheric delay gradient parameters are usually treated as independent ones, and therefore any possible combinations of them have to be considered, which may result in unrealistic extreme worst cases. To ensure integrity even for such extreme cases, availability of GBAS may be degraded. To reasonably exclude such unrealistic cases, it is effective to analyze the correlations of the parameters. Although we have collected and analyzed parameters of steep ionospheric delay gradients, correlations between all possible combinations of gradient parameters have not been analyzed yet. In addition, we try to clarify the conditions that the gradient develops to be a threat from the analysis.

We used the single-frequency-carrier-phase based and code-aided technique to precisely estimate the slope of ionospheric delay gradients. Ionospheric delays derived with dual-frequency observations are used to derive the width, depth, and speed. We presents the results of correlation analysis of the gradient parameters when the steep spatial gradients occur.

地上型衛星航法補強システム (GBAS) において電離圏脅威として想定されるのは、急な空間勾配を持ちながらそのスケールサイズの幅が航空機と GBAS 基準点との数十 km の距離の間に収まってしまい検知できないような電子密度急勾配である。電子密度急勾配は磁気低緯度においては主に赤道プラズマバブル (EPB: equatorial plasma bubble) の発達によって引き起こされると考えられており、著者らによる過去の研究でもこのような急な空間勾配の発生が EPB の発生特性と一致することも確認している。しかし EPB 発達のメカニズムは古くから数多く研究されているものの、GBAS に脅威となるような数十 km の幅を持つ勾配が発達する条件については明らかになっていない。

GBAS では運用上脅威となりうる電離圏空間勾配についてその勾配値、深さ、幅、移動速度をパラメータとして、GBAS の安全性設計を行う。現在これらのパラメータはそれぞれ相関のない独立なものとして扱われているため、極端な最悪ケースが想定されうる。それらの極端なケースにおいても安全性を保つため、運用可能条件が厳しくなり、可用性が制限されうる。極端なケースの発生可能性を評価し、非現実的なケースを排除するためには、パラメータ間の相関関係を調べることが有効である。筆者らはこれまでも電離圏急勾配事例の解析を行ってきたが、勾配パラメータ全ての組み合わせについての相関関係までは調べていなかった。また勾配パラメータの特性や相関から電離圏脅威となるような勾配が発達する条件等を明らかにできる可能性もある。

本研究では、GNSS の一周波搬送波位相観測をベースとして周波数間バイアス誤差の影響を受けずに 2 点間の電離圏遅延差を推定可能な Single-Frequency Carrier-Based and Code-Aided（SF-CBCA）法を用いて電離圏勾配を抽出し、GNSS の二周波観測による全電子数変動解析を加えて電離圏勾配パラメータを高精度に推定した。これらを用いて低緯度電離圏勾配が GBAS の脅威となり得るまでに発達するケースについて勾配パラーメタ解析から得られたパラメータ相関について解析を行ったので報告する。

R010-17
Zoom meeting C ：11/4 AM2 (10:45-12:30)
10:45〜11:00

Impacts of VHF anomalous propagation on aeronautical navigation systems and the Es layer structure and dynamics

#Susumu Saito[1)],Keisuke Hosokawa[2)],Jun Sakai[2)],Ichiro Tomizawa[2,3)]
([1]ENRI, MPAT,[2]UEC,[3]SSRE, Univ. Electro-Comm.

The sporadic E (Es) layer is an ionospheric layer with very high electron density and appears at altitudes around 100km. Due to its very high density, VHF radio waves from the ground can be reflected and propagate over a long distance. It has been well known that the FM radio signals with their frequency below 100 MHz can be reflected by the Es layer and propagate over anomalously long distances. Recently, even the aeronautical radio navigation signals such as the localizer (LOC) of instrument landing system (ILS) or VHF omni-directional radio range (VOR) in the frequency band from 108 to 118 MHz can also propagate over long distances via Es layer reflection. The ILS-LOC is an ground-based radio navigation system which is used to provide aircraft with its relative deviations with respect to the center of the designated course. The VOR provides the direction from the aircraft to the VOR station. In a specific geometry where the receiving station is in the main beam of an ILS-LOC, the signal strength of the anomalous propagation signals could exceed the maximum acceptable interference level.

We have been operating receivers of VHF anomalous propagation signals at 8 stations in Japan. We have installed an airborne ILS LOC/VOR receiver in May 2021 at Kure (34.25N, 132.53E) where strong signals at 110.3 MHz are often observed. We observed a number of events where the strength of the 110.3 MHz signals was significantly enhanced and the airborne receiver simultaneously indicated course deviations for the received signals. We identified the signal coming from Hualien Airport, Taiwan by their Morse tone signals. The indicated course deiviations were consistent with the geometry of Kure and Hualien. Thus, we confirmed that the anomalous propagation of the ILS-LOC signals by the Es layer could result in interference to the aeronautical radio navigation systems.

We also found that the indicated course deiviations fluctuate even when the signal strength is high enough for the airborne receiver to stably track the signals. The observed fluctuations in the course deviation may be due to the movement of the Es layer which reflects the signals. Structure and dynamics of the Es layer at the reflection point, which is usually around the mid-point between the transmitting and receiving stations, could be investigated by analyzing the variation of the course deviation indicated by an ILS-LOC receiver.

R010-18
Zoom meeting C ：11/4 AM2 (10:45-12:30)
11:00〜11:15

HF-START web tool: A web interface for HF radio wave users

#Hozumi Kornyanat[1)], 垰 千尋 [1)], 中田 裕之 [2)], 斎藤 享 [3)], 中山 健司 [1)], 西岡 未知 [1)], 永原 政人 [1)], 陣 英克 [1)], 津川 卓也 [1)], 石井 守 [1)]
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HF-START web tool: A web interface for HF radio wave users

#Kornyanat Hozumi[1)],Chihiro Tao[1)],Hiroyuki Nakata[2)],Susumu Saito[3)],Kenji Nakayama[1)],Michi Nishioka[1)],Masato Nagahara[1)], Hidekatsu Jin[1)],Takuya Tsugawa[1)],Mamoru Ishii[1)]
([1]NICT,[2]Grad. School of Eng., Chiba Univ.,[3]ENRI, MPAT

Communication and positioning technologies play an essential role in social ICT infrastructure today. The ”ionosphere” fluctuates greatly every day due to solar activity and the space environment and greatly influences radio wave propagation. Radio waves in the HF band have long been used in communications and broadcasting, but they are still widely used in shortwave broadcasting, aircraft communications, and amateur radio. Communication environments such as shortwave band communication range and available frequencies change dramatically due to ionospheric fluctuations. Therefore, shortwave broadcasting, aircraft communications, and amateur radio operations are affected by ionospheric fluctuations. In this talk, we will introduce the HF-START web tool, a web system that provides information on how radio wave propagation changes with realistic ionospheric conditions.

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R010-19
Zoom meeting C ：11/4 AM2 (10:45-12:30)
11:15〜11:30

Development of an autonomous FM-CW ionospheric observation system based on reinforcement learning

#Toru Mikuriya[1)],Akiko Fujimoto[1)],Shuji Abe[2)],Akihiro Ikeda[3)],Akimasa Yoshikawa[4)]
([1]Kyutech,[(2]ICSWSE, Kyushu Univ.,[(3]KNCT,[(4]ICSWSE/Kyushu Univ.

Equatorial Plasma bubbles (EPBs) of the ionospheric irregularities are known to cause GPS positioning errors and radio wave propagation abnormalities. Recently, numerical experiments have advanced the understanding of the local generation mechanism of EPBs, but the development of environmental field controlling the generation and suppression of EPBs has not yet been fully clarified. This study aims to reveal observationally the structure and generation mechanism of environmental fields in inner-magnetosphere and ionosphere that is linked to the development of EPBs.

We focus on a three-dimensional coupling system of ionospheric E-F regions controlling equatorial jet current (EEJ) as a model that connects the pre-sunset EEJ, pre-reversal enhancement (PRE) at near sunset, and EPBs after sunset. In order to detect this coupling system, we have developed a multi-ionospheric observation project with FM-CW (Frequency Modulated Continuous Wave) radar, MAGDAS (MAGnetic Data Acquisition System) magnetometer network and SDR-based scintillation detector. The FM-CW radar has two kinds of observation modes: one is Ionosonde mode and the other is Doppler mode. FM-CW radar enables continuous multi-mode ionospheric observation by switching between the detection of time evolution from PRE to plasma bubble by Ionosonde mode and the observation of F region electric field by Doppler mode. We have developed a new ”autonomous FM-CW control system” without the manual operation schedule. The new FM-CW system consists of the supervised machine learning and reinforcement learning by using several ionospheric disturbance triggers. In the presentation, we will explain the new FM-CW control system and show the result of examination.

R010-20
Zoom meeting C ：11/4 AM2 (10:45-12:30)
11:30〜11:45

Progress of the SDR-based dual-band scintillation detector development and its application for space weather study

#Shuji Abe[1)],Akiko Fujimoto[2)],Akimasa Yoshikawa[1,3)]
([1]ICSWSE, Kyushu Univ.,([2]Kyutech,([3]Kyushu Univ.

The upper part of Earth's atmosphere located from about 60km to 1000km altitude is ionized by solar ultraviolet and X-ray radiation, called the ionosphere. There are many disturbances in the ionosphere, and these fluctuations changes ionospheric condition temporally and spatially. As a result, waves passing through the ionosphere are affected by these disturbances. One of the phenomena caused by these disturbances is the ionospheric scintillation, which is a rapid intensity and phase changes of radio waves passing through the ionosphere. Therefore, the observation of ionospheric scintillation is equivalent to observing the state of the ionosphere, which is very important for space weather research.

We manage a worldwide magnetometer and FM-CW network, called MAGDAS, and produced many results related to space weather research by using these data. For further growth of our science, we are developing the SDR (Software-Defined Radio) -based scintillation detector system. The system is based on the USRP N210 with WBX daughter board from Ettus research as the front end. It uses two GPS antennas; one is large multiband antenna with multipath mitigation for observation and the other is small antenna for GPS Disciplined Oscillator. The signal processing software is based on some open-source products. For the initial observation, we installed the system at Ito, Fukuoka Japan (33.60N, 130.22E, in Geographic Coordinate), and the data quality observed by our system have confirmed by comparing it to nearby GEONET reference stations. In the second place, we installed the system at Sasaguri, Fukuoka, Japan (33.64N, 130.51E) where is one of the magnetometers and FM-CW radar station of MAGDAS. This composition enables us to observe GPS scintillation simultaneously with magnetic field variation and ionosphere plasma density profile, which helps our understanding about magnetosphere and ionosphere coupling during the upcoming solar maximum. In this paper, we will present the initial results of these observations.

R010-21
Zoom meeting C ：11/4 AM2 (10:45-12:30)
11:45〜12:00

SuperDARN北海道-陸別第一レーダーのイメージング化計画

#西谷 望[1)], 堀 智昭[1)], 濱口 佳之[1)]
(1 名大 ISEE

Plan of installing the imaging capability to the SuperDARN Hokkaido East radar for better spatial and temporal resolution

#Nozomu Nishitani[1)],Tomoaki Hori[1)],Yoshiyuki Hamaguchi[1)]
(1ISEE, Nagoya Univ.

The Super Dual Auroral Radar Network (SuperDARN) is a network of High-Frequency (HF) radars located at high- and mid-latitudes. It provides information on the global distribution of ionospheric convection and plasma density changes with a typical temporal resolution of 1 to 2 minutes, corresponding to the Nyquist frequency of 4 to 8 mHz. Sometimes this frequency range is insufficient to monitor ionospheric / upper atmospheric space weather phenomena with relatively short time scales (smaller than a few mins). The following are 2 examples:

1. SAPS wave structure. Sometimes SAPS contains temporal variations of the order of about 1 to a few tens of minutes. In order to consider their generation mechanisms, it is necessary to monitor the two-dimensional distribution of ionospheric convection with a temporal resolution of less than 1 min.
2. Coseismic ionospheric disturbances. Triggered by a big earthquake, the SuperDARN radar observed ionospheric plasma perturbations with a temporal scale of about 1 min or more and the propagation velocities up to several km/s. In order to discuss their generation and propagation mechanisms, it is necessary to operate the radar with a temporal resolution of less than 1 min.

Temporal resolution better than 1 min is difficult to achieve with the typical (traditional) SuperDARN operation modes covering the whole radar field of view. In order to overcome this difficulty, we are planning to install an imaging radar receiver system consisting mainly of USRP (Universal Software Radio Peripheral) receiver units, to the SuperDARN Hokkaido East radar. We succeeded in testing a 4-channel subset prototype receiver system in July 2020. Based on this achievement, we are planning to build a full-set 20-channel receiver system. The latest status and detailed scientific objectives of the imaging receiver system will be presented.

R010-22
Zoom meeting C ：11/4 AM2 (10:45-12:30)
12:00〜12:15

Seasonal and long-term variations in the Schumann Resonance observed at Kuju Japan

#Akihiro Ikeda[1)],Teiji Uozumi[2)],Akimasa Yoshikawa[3)],Akiko Fujimoto[4)],Shuji Abe[5)]
([1]KNCT,[2]ICSWSE, Kyushu Univ.,[3]ICSWSE/Kyushu Univ.,[4]Kyutech,[5]ICSWSE, Kyushu Univ.

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 frequency appears in ground magnetic field variation. Thus, the SR reflects both global lightning activity and ionospheric conditions and varies considerably with location.

In order to use the SR parameters for studying earth's climate and so on, we need a better understanding of SR parameters at a specific observatory. For the first step, we examine power and frequency of first-mode and second-mode of SR observed at Kuju, Japan (KUJ; M.Lat. = 23.4 degree, M. Lon. = 201.0 degree) during 10-years from 2003 to 2012.

The first mode and second mode of the Schumann resonance (SR1 and SR2) well reflected global lightning activity. The variation in the amplitude of SR in a day showed peaks which correspond with the three major thunderstorm centers, namely, African, Asian, and American. Also amplitudes of these peaks depended on season.

The long-term variation of SR frequency depended on the solar EUV flux. Especially SR1 frequency in H (horizontal northward component) well correlated with EUV flux. This suggests that the SR frequency is controlled by the electron density in the ionospheric D region. From the variation of SR frequency, we estimated that the density in the ionospheric D region changes by about 15% from the solar minimum to the solar maximum.

R010-23
Zoom meeting C ：11/4 PM1 (13:45-15:30)
13:45〜14:00

Characteristics of dusk-side IHFAC polarity during storm and quiet times

#Akiko Fujimoto[1)],Akimasa Yoshikawa[3)],Manjula Ranasinghe[2)],Chandana Jayaratne[2)]
[(1]Kyutech,[(2]University of Colombo,[(3]ICSWSE/Kyushu Univ.

The Inter-Hemispheric Field-Aligned Current (IHFAC) is one of the major current systems causing changes in the geomagnetic field at low and middle latitudes. IHFACs flow from the summer hemisphere to the winter hemisphere in the dawn sector and from the winter hemisphere to the summer hemisphere in the noon and dusk sectors (Fukushima, 1994). The recent in-situ satellite and ground-based observations have reported the dusk-side current polarity of IHFACs are often inconsistent with the Fukushima's IHFACs model. We investigated whether the dusk-side IHFACs polarity is consistent or not with the current direction predicted by Fukushima's IHFACs model, by using long-term ground-based equatorial magnetometer data at Davao (Philippines) from 1998 to 2020. We found that there were seasonal dependences of the appearance of the dusk-side IHFAC of the Fukushima model type (the same IHFAC polarity between the noon and dusk sectors). The polarities of dawn-side and noontime IHFACs agreed with the Fukushima model irrespective of season: the IHFACs during solstices flow from the summer hemisphere to the winter hemisphere in the dawn sector and from the winter hemisphere to the summer hemisphere around the noon sector. The occurrence rate of the dusk-side IHFAC of the Fukushima model type was high around June and December solstices. In contrast, the dusk-side IHFACs, which are inconsistent with the Fukushima model type, dominated from the September to November months and occurred at slightly rates around the March equinox. The remarkable solar cycle dependence of IHFACs were exhibited in the dusk sector. Especially, large IHFACs flowed in the dusk sector during the declining phase of the solar cycle. It is also clear that the noontime and dusk-side IHFACs polarities reversed at the different intersection months. Seasonal variations of dD showed asymmetry in both dawn and noon sectors. In contrast, the seasonal dusk-side dD variations were symmetric. In this paper, we will demonstrate the polarity of IHFAC during storm time and quiet time.

R010-24
Zoom meeting C ：11/4 PM1 (13:45-15:30)
14:00〜14:15

Feasibility Study of Space Weather Observation by CubeSat in LEO

#Kentarou Kitamura[1)],Mengu Cho[1)],Akimasa Yoshikawa[2,3)],Teiji Uozumi[3)],Shuji Abe[3)],Mariko Teramoto[1)],Akiko Fujimoto[1)]

[(1]LaSEINE/Kyutech,[(2]ICSWSE/Kyushu Univ.,[(3]ICSWSE/Kyushu Univ.

Recently the concept of "Lean Satellite" has been proposed to emphasize that the essential advantages of the nano-satellites are a short-period development and an affordability, rather than their size and weight themselves.

Conducting the science observations, especially lean satellites enable us to implement the experimental test in orbit and preliminary observations prior to conventional satellite missions. The EU conducted the QB50 program which is an international network of CubeSat for multi-point, in-situ observation in the lower ionosphere (Thoemel et al., 2014). Total 36 CubeSats have been launched into orbit in 2017 by QB50 program.

Kyushu Institute of Technology (Kyutech) has developed and launched 19 satellites since 2006, including several science missions such as the observation of the plasma density in the ionosphere by Double Langmuir Probe, the observation of Total Electron Content (TEC) by using Chip Scale Atomic Clock (CSAC), and experimental test of store and forward of the data observed on the ground stations. Moreover, the bus system developed for the series of CubeSat (Birds Satellites) has been disclosed as open-source protocol from Kyutech in 2021.

Based on these achievements, we newly start the ionospheric observation project by 2U size CubeSat under collaboration with Kyushu University as part of human resource development program from 2021. The program will be conducted by mainly under-graduate students to focus on the nature of Interhemispheric Field Aligned Current (IHFAC) (Fukushima 1979, Tomas et al., 2009). We propose the CubeSat which make in-situ observation of the Sq current system including IHFAC at the LEO in the altitude of ˜400km. The feasibility of CubeSat with 2U-size structure is considered for the electric power budget, communication capability, and specification of the magnetometer.

In this paper, we discuss the science of the hemispheric asymmetry of potential associated with Sq current system and resultant IHFAC from the concept of lean satellites applications, and implications of the program for the future observation of space weather sciences.

R010-25
Zoom meeting C ：11/4 PM1 (13:45-15:30)
14:15〜14:30

NICT 宇宙天気予報の中長期計画と将来構想

#津川 卓也 [1)], 石井 守 [1)], 久保 勇樹 [1)], 長妻 努 [1)], 坂口 歌織 [1)], 塩田 大幸 [1)], 陣 英克 [1)], 中溝 葵 [1)], 西岡 未知 [1)], 垰 千尋 [1)], 西塚 直人 [1)],Hozumi Kornyanat[1)], 大辻 賢一 [1)], 齊藤 慎司 [1)], 品川 裕之 [1)],PERWITASARI SEPTI[1)], 高橋 直子 [1)], 田光江 [1)], 穂積 裕太 [1)]
(1 情報通信研究機構

Mid-term research plan and future vision of NICT space weather forecast

#Takuya Tsugawa[1)],Mamoru Ishii[1)],Yuki Kubo[1)],Tsutomu Nagatsuma[1)],Kaori Sakaguchi[1)],Daikou Shiota[1)],Hidekatsu Jin[1)], Aoi Nakamizo[1)],Michi Nishioka[1)],Chihiro Tao[1)],Naoto Nishizuka[1)],Kornyanat Hozumi[1)],Kennichi Otsuji[1)],Shinji Saito[1)], Hiroyuki Shinagawa[1)],SEPTI PERWITASARI[1)],Naoko Takahashi[1)],Mitsue Den[1)],Yuta Hozumi[1)]
([1]NICT

The National Institute of Information and Communications Technology (NICT) has started the 5th mid-term research plan (FY2021-2025) in April 2021. In order to steadily operate space weather monitoring and forecasting, Space Weather Forecast Service Group has been established in Space Environment Laboratory of NICT, and a new R&D plan was launched to improve the accuracy of space weather monitoring and forecasting, and to provide information that meets the user needs.

For monitoring space weather information, we will upgrade and stabilize the domestic solar and ionospheric observation systems, and expand the ionospheric observation network in Southeast Asia through international cooperation projects. We will also promote researches to develop space environment sensors onboard geostationary satellites. For providing more accurate space weather forecasting information, we will develop forecasting systems using numerical models of the solar wind, magnetosphere, and ionosphere, as well as data assimilation and AI technologies, and use them in forecasting operations. For providing space weather information that meets the user needs, we will keep the communication with users by space weather users' committee which was established in 2015.

Some of specific outcome goals would be stable use of high-precision positioning/navigaion with QZSS, support for lunar and planetary exploration by providing space weather information, and mitigation of space weather disasters by providing benchmarks. We would like to discuss about future visions for space weather forecasting.

情報通信研究機構（NICT）では、2021 年 4 月から第 5 期中長期計画（2021 － 2025 年度）が開始された。宇宙天気予報業務を着実に実施するため、NICT 宇宙環境研究室に新たに宇宙天気予報グループが設置されるなど新しい体制となり、宇宙天気の監視・予報の精度向上及びユーザーニーズに沿う情報提供を目指した研究開発計画がスタートした。

宇宙天気情報の現況把握のための観測として、国内の太陽・電離圏観測システムの高度化及び安定化を進めるとともに、国際協力プロジェクトによる東南アジア域電離圏観測網の拡大を進めて行く。また、静止衛星搭載宇宙環境センサーの開発を目指した取組を進める。精度の高い宇宙天気予報を行うため、太陽風・磁気圏・電離圏の各領域モデルの高度化を進めるとともに、データ同化や AI 技術等を用いた予測システムの研究開発を進め、予報業務に利用していく。ユーザーニーズに沿う宇宙天気情報の提供としては、2015 年に発足した宇宙天気ユーザー協議会等を活用し、より多様なユーザーとコミュニケーションを図り、ニーズに沿う情報提供を目指していく。具体的には、準天頂衛星を利用した高精度測位の安定利用、月・惑星探査への宇宙天気情報提供による支援、宇宙天気ベンチマークを利用した宇宙天気災害の軽減等を想定している。

更なる民間主導の宇宙開発・宇宙利用や、多数の小型・超小型衛星による衛星コンステレーション計画、一般人の宇宙旅行の実現が進む将来に向け、宇宙天気予報の将来構想についても議論する。

R010-26
Zoom meeting C ：11/4 PM1 (13:45-15:30)
14:30〜14:45

静止軌道の宇宙放射線・帯電量計測の将来計画：CHARMS (CHarging And Radiation Monitors for Space weather) mission

#坂口 歌織 [1)], 石井 守 [1)], 津川 卓也 [1)], 久保 勇樹 [1)], 長妻 努 [1)], 大辻 賢一 [1)], 齊藤 慎司 [1)], 穂積 裕太 [1)], 三谷 烈史 [2)], 高島 健 [2)], 三宅 弘晃 [3)]
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CHARMS (CHarging And Radiation Monitors for Space weather) mission

#Kaori Sakaguchi[1)],Mamoru Ishii[1)],Takuya Tsugawa[1)],Yuki Kubo[1)],Tsutomu Nagatsuma[1)],Kenichi Otsuji[1)],Shinji Saito[1)], Yuta Hozumi[1)],Takefumi Mitani[2)],Takeshi Takashima[2)],Hiroaki Miyake[3)]
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Spacecrafts in space are always exposed to the risk of malfunctions and failures due to changes of space environment. Particularly, geostationary satellites are inevitably exposed to severe risks such as electrostatic discharge (ESD), total ionizing dose effect (TID), and single event effect (SEE) because of high space radiation environment. To mitigate and avoid risks, it is necessary to monitor space environment constantly near satellites, issue forecasts and warnings promptly based on latest observation to encourage specific actions, and secure time for operators to respond before a catastrophic failure occurs. In addition, by monitoring accumulated charges in a satellite as well as space environment, it is possible to directly identify changes of a satellite's material in response to changes of space environment. Such results can be reflected in the guideline of satellite design standards for designing satellites that are resistant to changes of actual space environment. As of 2021, Japan's space weather forecast is based on space radiation data observed by the U.S. meteorological satellite GOES. However, there is a difference between space environment over the U.S. and that over Japan. In order to protect Japanese satellites, which are responsible for our social infrastructure like communication, navigation, weather service, it is necessary to monitor status of space environment around them. So, we have started to develop onboard sensors to measure high-energy electrons and protons existing in radiation belts, plasma sheets, solar energetic particles, and galactic cosmic rays, and an internal charging sensor to measure charges in satellite materials as CHARMS (CHarging And Radiation Monitors for Space weather) mission. This mission aims to improve monitoring and forecasting of space weather by installing these sensors on the next geostationary satellite launched into a longitude where Japanese satellites are densely located.

宇宙空間の人工衛星は、宇宙環境変動による誤動作や不具合が発生するリスクと常に隣り合わせで運用される。特に静止軌道衛星は強い宇宙放射線環境中を飛翔するため、静電放電（ESD）, トータルドーズ効果（TID）シングルイベント効果（SEE）等の高いリスクに曝さらされている。このリスクを軽減、回避するためには、衛星近傍の宇宙環境を定常的に計測すると共に具体的な対処を促すための予報・警報を発出し、致命的な障害が発生する前に事業者が対応するための時間を確保する必要がある。更に環境と同時に衛星の帯電状況等を常に監視することで、宇宙環境変動に対する衛星固有の状態変化を直接的に把握すること、また、衛星設計標準にその結果を反映して、宇宙環境変動に強い衛星を設計する指針を得ること等が期待できる。2021 年現在、我が国の宇宙天気予報は、米国の気象衛星 GOES が計測する宇宙放射線のデータを基準として利用している。しかし、米国上空と我が国上空の宇宙環境には差異がある、我が国の社会インフラを担う人工衛星の保全のためには、その衛星近傍の静止軌道の環境を把握する必要がある。そこで、宇宙環境変動に対する我が国の静止衛星の抗たん性の向上を目的として、放射線帯やプラズマシート、太陽高エネルギー粒子、銀河宇宙線等の高エネルギー電子線・陽子線を測定する衛星搭載センサーと、衛星材料の帯電状態を監視する内部帯電センサーの開発に着手した。これらの装置を、我が国の衛星が最も密な経度への打ち上げ予定されている次期静止衛星に搭載することにより、我が国上空の宇宙天気の状況監視及び予報の高度化を目指す。

R010-27
Zoom meeting C ：11/4 PM1 (13:45-15:30)
14:45〜15:00

静止軌道衛星の放射線帯電子に対する内部帯放電リスクの検証

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(1 情報通信研究機構

Verification of internal charging/discharging risk of radiation belt electrons on spacecraft in geostationary orbit

#Shinji Saito[1)],Tsutomu Nagatsuma[1)],Kaori Sakaguchi[1)]
(1NICT

Highly energetic electrons with energies from several tens keV to MeV, referred as electron radiation belts, are quasi-permanently trapped in the magnetosphere. It is well known that co-rotational interaction region (CIR) associated with fast solar winds and coronal mass ejection (CME) causes the electron flux enhancement/depletion in hours to days. These energetic electrons induce internal charging by accumurating in spacecraft materials. The discharge occurs by reaching at a threshold value of the electric field associated with the charge accumulation, which causes the degradation of materials and influences on electronic equipment by electromagnetic emmision from the discharge. In order to grasp the risk of damage due to the discharge, it is necessary to directly observe the charge accumulation or to utilize an internal charging model using actual observation data.

In this study, we develop an internal charging model, which is modeled by an equvalent circuit of a resistor (R) and a capacitor (C), to verify the discharge risk in the spacecraft dielectric materials. We apply electron flux data obtained from GOES satellite in solar cycles 23 and 24 to the RC charging model and find that the charge accumulation in the materials becomes faster during the decline phase of solar cycles than other solar phase.By assuming a threahold level of the accumulation triggering the discharge, we found that the discharge risk by the internal charging in solar cycle 24 was higher than cycle 23. This corresponds to a period when Himawari, a meteorological satellite currently in operation, had several problems. In this presentation, we report the verification of charge/discharge risk of spacecraft in the geocynclonous orbit using actual long-term observation data.

地球磁気圏には数十 keV から数 MeV に至る高エネルギー電子が捕捉されている。高エネルギー電子のフラックス量は、高速太陽風に伴う共回転領域（CIR）や太陽コロナ質量放出（CME）によるじょう乱に伴い数時間から数日の時間で数桁のフラックスの変動が生じることが知られている。これら高エネルギー電子は衛星材料へ侵入/蓄積することで内部帯電を引き起こす。電荷蓄積によって電界強度がしきい値に達し放電が発生すると、放電による材料の劣化や電磁放射による周辺電子機器への影響によって人工衛星の不具合や致命的な障害を引き起こす可能性がある。内部帯電による障害リスクを把握するためには、帯電状況を直接観測するか、実際の観測データをもとにした帯電モデルが必要となる。

本研究では、衛星材料を抵抗（R）とコンデンサ（C）の等価回路でモデル化した RC 帯電モデルへ GOES 観測による長期データ（第 23、24 太陽活動周期）を適用し、衛星絶縁材料内部の帯放電リスクの検証を行った。帯電量はそれぞれの太陽活動の下降期で増加し、第 23 太陽活動周期より 24 太陽活動周期の下降期の方が多く帯電する傾向があることが確認された。また、発生する電界による放電しきい値を仮定し放電頻度を検証すると、第 24 太陽活動周期下降期には放電頻度が大きく増加することがわかった。これは現在運用中の気象衛星ひまわりが複数回の不具合を起こしている時期と一致する。本発表では人工衛星に用いられる複数の材料に対して、実際の観測データを適用することで帯放電リスクの検証を行い、その検証結果を報告する。

R010-28
Zoom meeting C ：11/4 PM1 (13:45-15:30)
15:00〜15:15

Development of radiation belt forecast model based on the recurrent neural network

#SATOSHI FUKUOKA[1)],Yoshizumi Miyoshi[2)],Tomoaki Hori[2)],Takefumi Mitani[3)],Takeshi Takashima[4)],Nana Higashio[5)], Iku Shinohara[6)],Daikou Shiota[7)],Shinji Saito[7)],ChaeWoo Jun[8)]
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The relativistic/sub-relativistic electron flux variations often cause serious damage to the satellites operating in space through the dielectric charging. In order to forecast flux variations of these hazardous electrons, various forecast methods have been developed, based on physical-based simulations and empirical models for the high energy electrons. As a method with physics-based simulations, the SUSANOO, which operates a code-coupling simulation of the heliosphere and radiation belts, provides MeV electron flux variations for the next couple of days. As those employing the empirical modeling, the linear prediction filter (LPF) and the auto-regressive moving average (ARMA) have been commonly used for the forecast of MeV electrons at geosynchronous earth orbit (GEO). Recently, machine learning techniques have widely been used for the space weather forecast, for example, ionospheric variations, the flare prediction, etc. In this study, we have developed a forecast system of relativistic/sub-relativistic electron flux variations based on a long short-term memory recurrent neural network (LSTM-RNN). As the training data, we used the solar wind data and energetic electron flux data observed by Arase/HEP and XEP instruments at different L-shells of the outer belt. The developed network provides time variations of the energetic electron flux at L = 4, 5 and 6 using the solar wind data as input parameters. In this presentation, we evaluate how the solar wind parameters affect the temporal variation of the high-energy electron flux on the basis of the developed neural network model. We also report the results from another network developed using the nearly-real-time space weather data of Arase, with a view to the real time space weather forecast.

R010-29
Zoom meeting C ：11/4 PM2 (15:45-18:15)
15:45〜16:00

大振幅 SC の特性

#荒木 徹 [1)]
(1 京大理

Characteristics of large amplitude SCs

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When the magnetosphere is suddenly compressed by a strong solar wind shock wave which produces a geomagnetic sudden commencement (SC) , the magnetopause near the geocentric distance R = 10Re on the day side sometimes crosses the geosynchronous orbit (R = 6.6Re) and enters the inside. At this time, the dayside size of the magnetosphere is reduced to about half producing large SCs, and properties of the observed SCs are expected to be different from those of ordinary amplitude SCs. Here we make analyses of the large-amplitude SCs to study the response of the magnetosphere to strong compression.

The Kakioka Observatory has published a list of SCs from 1924 to the present. The large amplitude SC events for the analysis are selected from this list. According to it, the H component amplitude of most SCs is in the range of 10-30nT. The SCs of 50nT or more are less than 5%, and SCs of 100nT or more are about 1% (18 by March 2021, 3 of 200nT or more).

太陽風衝撃波によって磁気圏が急圧縮されて地磁気急始変化（SC）が生じる時、圧縮が強ければ、昼側の地心距離 R=10Re 付近にあった磁気圏界面が静止軌道（R=6.6Re）を越えて内側に入ってくることがある。この時には、磁気圏の昼側サイズが半分位に縮小されることになり、観測される SC も大きくなって、その性質が通常の中・小振幅の SC とは異なると思われる。SC は磁気圏の非定常応答の研究に役立ってきたが、この大振幅 SC を解析すれば、通常の SC からは判らない強い圧縮への磁気圏応答を明らかにできるであろう。この予想の下に、大振幅 SC を解析した。

柿岡観測所は 1924 年から現在までの SC のリストを公開している。それによれば、大半の SC の H 成分振幅は 10-30nT の範囲にあり、50nT 以上の SC は 5 %弱、100nT 以上は約 1 %（2021 年 3 月までで 18 個、200nT 以上は 3 個）になる。

R010-30
Zoom meeting C ：11/4 PM2 (15:45-18:15)
16:00〜16:15

磁場・電界観測に基づく極域・中緯度電離圏の応答の解明

#林 萌英 [1)], 吉川 顕正 [2)], 藤本 晶子 [3)],Ohtani Shinichi[4)]
(1 九大,(2 九州大学地球惑星科学専攻,(3 九工大,(4 なし

Research on the Poler to Mid-latitude Ionospheric Response During Substorm Based on Magnetic and Electric Field Observations

#Moe Hayashi[1)],Akimasa Yoshikawa[2)],Akiko Fujimoto[3)],Shinichi Ohtani[4)]
(1Kyushu Univ.,(2ICSWSE/Kyushu Univ.,(3Kyutech,(4The Johns Hopkins University Applied Physics Laboratory

The purpose of this study is to comprehensively understand the evolution of global 3D current system from polar to equatorial ionosphere during substorms.

There are two types of current systems in the polar ionosphere: the R1-current linked to the magnetospheric convection system, and the R2-current linked to the pressure gradient in the inner magnetosphere [Iijima and Potemra, 1976, 1978]. In addition to these currents, when a substorm onset is occurred by a strong plasma injection, a current wedge (CW) is generated by the plasma vorticities at the edge of the plasma flow. It has the same current polarities as the R1-current system. At the lower latitude of the CW, an R2-type current system develops by increasing the plasma pressure. It weakens the effect of ionospheric current associated with the CW system reaching low latitudes and equatorial regions. This is called a shielding effect. Furthermore, it sometimes overcomes the effect of CW, and grows of current systems in the opposite direction. This is called an over-shielding effect. (Kikuchi et al.,1996 ; Nishida.,1968).

The ground magnetic field disturbances during substorms are generated by not only the ionospheric currents, but also the field-aligned currents (FACs) accompanied by the growth of the CW. These effects are particularly large in the mid- and low-latitude. It is difficult to determine from the magnetic field data alone whether the magnetic field variation is due to the ionospheric current system or to the remote field effect of the CW current system. A direct comparison of ionospheric electric and magnetic field data is essential for a better understanding of the causes of magnetic disturbances.

In this presentation, we report the results of a study of poler to mid-latitude ionospheric variability during auroral substorm using electric field data from the HF Doppler radar and magnetic field data from SuperMag and MAGDAS installed by Kyushu University in Palatunka, Russia, and ionospheric plasma convection data from SuperDARN. We found that there are two patterns of electric field variations at mid-latitudes, near the upward of the current wedge. This variation is expected to reflect the polar electric field polarity. In this presentation, we compare and analyze the pattern of polar ionospheric plasma convection by SuperDARN with the electric field fluctuations in the mid-latitudes.

本研究の目的は、サブストーム時の極域から赤道域までのグローバルな 3 次元電流システムの進化を包括的に理解することにある。

極域電離圏の電流システムには、磁気圏対流系の消長と連動する R1-電流と、内部磁気圏の圧力勾配領域の消長と連動する R2-電流が存在することが知られている [Iijima and Potemra, 1976, 1978]。サブストームのオンセットとともに成長する極域カレント・ウェッジ電流系は、R 1 電流系同じセンスの磁気圏ー電離圏電流クロージャーを形成しており、より低緯度側で発達する R2 型電流系は、この R2 電流系と同じセンスの電流クロージャーを形成している。この R2 型電流の成長はサブストームに伴う内部磁気圏の圧力増加と連動しており、その消長はカレント・ウェッジ電流系の消長と必ずしも一致しない。その結果 R2 型電流系は、カレント・ウェッジ電流系の成長に伴う巨視的な電離層電流系が低緯度・赤道域まで到達する効果を弱めるシールディング効果をもたらすだけでなく、時にはそれを卓越し、逆方向の電流系を成長させるオーバーシールディング効果をもたらすことが知られている（Kikuchi et al [1996]; Nishida [1968]）。

一方、サブストーム時に観測される地上磁場変動は電離層電流の効果だけでなく、カレントウェッジの成長に伴う沿磁力線電流そのものが作る磁場変動も大きな影響をもたらしている。特にこの影響が大きい中低緯度領域では、サブストーム時に変動する磁場変化が電離層電流系の形成によるものなのか、カレントウェッジ電流系の遠隔磁場効果であるのかを磁場データのみから同定することは難しく、より本質的な理解の為には電離層電場の直接観測との比較が不可欠となる。

本発表では、ロシアのパラツンカに設置した HF ドップラーレーダーによる電場データと SuperMag, MAGDAS の磁場データ、SuperDARN による電離圏プラズマ対流のデータを用いて、サブストーム時の極域・中緯度域の電離圏変動を調査した結果を報告する。現在、中緯度の電場変動は、カレントウェッジの upward 付近で、２つのパターンがあることを発見した。この電場変動は極域の電場極性を反映していると考えられる。そこで、本発表では SuperDARN で観測する極域電離圏プラズマ対流のパターンと中緯度の電場変動を比較し、その相関を解析した結果を報告する。

R010-31
Zoom meeting C ：11/4 PM2 (15:45-18:15)
16:15〜16:30

夜側オーロラオーバルの極側境界で発生するオーロラ増光現象における電離圏分極の数値解析

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Numerical analysis of ionospheric polarization to reveal the generation mechanism of poleward boundary intensification

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We numerically investigated ionospheric polarization for revealing the generation mechanism of PBI, which stand for poleward boundary intensification, an auroral intensification at the poleward boundary of the auroral oval. PBI is generally considered to be the ionospheric manifestation of the distant reconnection in the magnetotail [e.g., Lyons et al., 2011], but this theory cannot explain the recent reports of PBIs characteristics [e.g., Zou et al., 2014]. That's why Ohtani and Yoshikawa [2016] proposed the new idea that PBI occurred associated with ionospheric polarization due to fast polar cap flows. To prove this new theory, they conducted a numerical analysis and confirmed that ionospheric polarization causes reflected Alfven waves larger than incident Alfven waves.

However, their analysis did not consider the effect of the evolution of ionospheric conductivity, so only the initial process of PBI was investigated. In this study, our model includes it and can investigate not only the initial process but also the time evolution of ionospheric polarization. In general, the evolution of the conductivity only considered the effect induced by precipitated electrons associated with field-aligned currents (FAC) [e.g., Sato, 1978]. In addition to this, the effect of the advections in the perpendicular direction of magnetic lines was also considered in our study. Moreover, while previous studies have been analyzed in the electrostatic process, this study eliminated the process by introducing the induction effect in the rotating current system.

As a result, noticeable changes were found in the time variations of electric conductivity and induced FAC. For the time variation of electric conductivity, the precipitated electrons are more significant than the advection effect. Because of that, induced upward FAC changed in space, and we successfully reproduced the north-south structure of PBI. Also, in contrast to the small contribution of the Hall polarization in the initial process, upward FAC induced by Hall polarization is comparable to the one induced by Pedersen polarization in the evolution process, suggesting the importance of the Hall polarization. In this presentation, we will discuss the above results, including future issues.

本研究では、PBI の発生機構解明に向けた電離圏分極の数値解析を行った。PBI とは”Poleward Boundary Intensification”の略で、夜側オーロラオーバルの極側境界で起こるオーロラ増光現象のことである。PBI は従来夜側の磁気リコネクションに関連した現象であると考えられてきた。しかしながら、この説に反する観測事実が近年報告されており [e.g., Zou et al., 2014]、これを説明できる新たな説が提唱された。それが Ohtani and Yoshikawa, [2016] による、PBI が電離圏分極によって発生するという考えである。この新説を立証するために行われた数値解析では、電離圏分極により入射 Alfven 波よりも大きな反射 Alfven 波が電離圏から湧き上がることを確認した。

しかし、その解析では電気伝導度の時間発展を考えられていないため、発生の初期過程しか調べられていない。そこで、本研究ではこれを考慮することで、PBI の初期過程以降の進化過程を調べた。従来電気伝導度の時間発展方程式には沿磁力線電流に伴う降り込み電子の効果のみを考慮したもの [e.g., Sato, 1978] が多いが、本研究ではこれに加えて、磁力線に垂直方向の移流の効果も考慮した。さらに、先行研究では静電過程で解析が行われたが、本研究では回転電流系における誘導効果を導入することでその過程を排除した。

以上を取り入れた結果、電気伝導度と誘導 FAC に顕著な変化が見られた。電気伝導度の時間変化には移流の効果よりも降り込み電子の寄与の方が大きいことが判明した。この効果により上向きの誘導 FAC の空間構造が変化し、PBI の南北構造を再現することに成功した。また、初期過程ではホール分極の寄与が小さかったのに対して、進化過程ではペダーセン分極に匹敵する上向きの沿磁力線電流を誘導しており、ホール分極の重要性を示唆した。本発表では、今後の課題点を含めて以上の結果を述べる。

R010-32
Zoom meeting C ：11/4 PM2 (15:45-18:15)
16:30〜16:50

Quasistatic mesoscale field-aligned currents embedded in the diminished large-scale Region 1 current: Dawn-dusk asymmetry

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Irregular magnetic perturbations embedded in the diminished large-scale Region 1 current are prominent during prolonged northward IMF conditions. Our recent study for the duskside sector (Yokoyama et al., 2020) has shown that there occur relatively low-energy ion precipitation (down to a few hundred electron volts) and low-energy electron precipitation (lower than 200 eV) in the regions of the quasistatic mesoscale field-aligned currents that produce these irregular magnetic perturbations, and that the solar wind proton density is a controlling factor for the current density of the FAC. We have suggested an interpretation, which states that several pairs of FACs are generated in the duskside LLBL through a mechanism related to the solar wind plasma entry processes that can be more easily attained as the northward component of the IMF increases. A probable explanation is the phenomenon of reconnection inside the vortices of the Kelvin- Helmholtz (KH) waves. In this study we extend our previous research by examining the dawnside mesoscale FACs. By utilizing magnetic data obtained by SWARM satellites during the period from January 2017 to December 2020, we investigated the dependence of the dawnside FACs on the IMF, and solar wind plasma parameters. The results of the analysis show that the occurrence ratio of the mesoscale field-aligned current in the dawnside sector also has a strong dependence on the northward IMF condition. The results also show that there are weak dawn-dusk asymmetries in the occurrence ratio against the IMF B_Y; as for the dawnside sector, the occurrence ratio is higher for negative IMF B_Y than for positive IMF B_Y, while there is no clear tendency in the duskside sector. We also show that for our dawnside sector events the IMF with negative B_Y more often forms the Parker-Spiral orientation. This tendency agrees with the

one from an earlier study, i.e., the KH instability preference for the dawn flank during the Parker-Spiral orientation, which consolidates our interpretation.