S002-01
A 会場 ：11/25　AM2 （10:30-12:00）
10:35〜10:50

2024 年 5 月の大規模宇宙天気現象発生時における NICT 宇宙天気予報と日本の社会的影響

#津川 卓也 [1)]
([1] 情報通信研究機構

NICT Space Weather Forecast and Social Impact on Japan during the May 2024 Severe Space Storm

#Takuya Tsugawa[1)]
([1]National Institute of Information and Communications Technology

Thirteen X-class solar flares occurred between May 8 and 15, 2024, the first time in the history of GOES satellite observations that seven flares of X-class or higher occurred in 72 hours. The largest of the series of solar flares was X8.7 on May 15, which was the largest solar flare observed to date since the beginning of the current solar cycle 25. These large-scale solar flares caused the Dellinger phenomena, in which HF radio waves are absorbed in the ionosphere. In addition, several CME emissions toward the earth were observed during the solar flares from May 8, and the first CME arrival and a large-scale magnetic storm were predicted from the night of May 10 to May 11. On May 10, we posted an article on the NICT website for the media and held an online press conference to explain the space weather phenomena and its expected social impacts.

The first CME was observed to arrive around the Earth at around 01:30 JST on May 11, and a severe geomagnetic storm occurred at 02:05 on May 11. During the geomagnetic storm, a large-scale ionospheric negative storm was observed over Japan from May 11 to 13, and an ionospheric positive storm was temporarily observed during the nighttime of May 11. During the time when the positive storm was observed, an increase in the ROTI was observed over Japan, and the positioning error calculated by post-processing kinematic analysis was confirmed to have increased.

During these severe space weather phenomena, observations of low-latitude auroras were reported in various parts of Japan, and the effects on satellite operations, GNSS positioning, and HF radio communications were also reported in Japan. Based on the experience of this event, we would like to improve our methods of disseminating space weather forecast information and collecting information on social impacts in order to respond to the occurrence of large-scale flares with large social impacts.

2024 年 5 月 8 日から 15 日にかけて、X クラスの太陽フレアが 13 回発生した。X クラス以上のフレアが 72 時間で 7 回発生したことは GOES 衛星による観測史上初めてである。一連の太陽フレアで最大の規模は 5 月 15 日に発生した X8.7 であり、これは現在の太陽活動周期 25 が始まってから現在までに観測された最大規模の太陽フレアとなった。これらの大規模太陽フレアの発生に伴って、短波帯での電波が電離圏で吸収されるデリンジャー現象が発生した。また、5 月 8 日からの太陽フレアに伴って地球方向への CME 放出が複数回観測され、5 月 10 日夜間から 5 月 11 日にかけて最初の CME 到来と大規模な磁気嵐が予測された。そのため、5 月 10 日に当該宇宙天気現象と予想される社会的影響について、私たちは NICT ウェブサイトにてメディア向けに記事を掲載するとともに、オンラインによる記者発表会を実施した。

最初の CME は日本時間 5 月 11 日 1 時半頃に地球周辺に到来したことが観測され、5 月 11 日 2 時 5 分に急始型地磁気嵐が発生した。地磁気嵐の発生に伴い、日本上空では 5 月 11 日から 13 日かけて大規模な電離圏負相嵐の発生が確認された他、一時的に 5 月 11 日の夜間には電離圏正相嵐の発生が確認された。電離圏正相嵐が観測された時間帯には、電離圏じょう乱指数（ROTI）の増大が日本上空で発生し、後処理キネマティック解析により算出した測位誤差の増大が確認された。

今回の宇宙天気現象において、日本各地で低緯度オーロラの観測が報告された他、衛星運用、衛星測位、短波通信への影響についても報告されたが、幸い大きな社会的影響はなかった。今回のイベントの経験を踏まえて、社会的影響が大きい大規模フレア発生時の対応について、宇宙天気予報情報の周知や社会的影響の情報収集の方法を改善していきたい。

S002-02
A 会場 ：11/25　 AM2 （10:30-12:00）
10:50〜11:05

活動領域 13663,13664 における連続 X クラスフレアのトリガ解析

#伴場 由美 [1), 草野 完也 [2), 塩田 大幸 [1)
[1 情報通信研究機構, [2 名古屋大学

Flare trigger analysis for successive X-class flares in solar active regions 13663 and 13664

#Yumi Bamba[1)], Kanya Kusano[2)], Daikou Shiota[1)]
[1]National Institute of Information and Communications Technology, [2]Nagoya University

2024 年 5 月に現れた太陽活動領域 13663 群および 13664 群では、5 月 8 日から 15 日までの 8 日間に 13 回もの X クラスフレアが発生した。特に、5 月 8 日から 11 日にかけては、GOES 衛星による観測史上初めて、72 時間以内に 7 回の X クラスフレアが発生した。一連の X クラスフレアにより、短波伝搬通信や衛星測位システムへの影響があったこと、また、一部の航空事業者では航路変更などの対応がとられたことが報告されている。本研究では、活動領域 13663 群および 13664 群における連続した X クラスフレアの発生過程を明らかにすることを目的に、NICT で現在実装を進めている、物理モデルに基づくフレア予測スキームである「κ スキーム」（Kusano et al. 2020）による解析と SDO 衛星によるフレア観測データの解析を行なった。κ スキームでは、非線形フォースフリー磁場（NLFFF）モデリングにより活動領域の 3 次元構造の進化を考察した。また、SDO 衛星によるフレア観測データの詳細解析（e.g., Bamba et al. 2013, 2020）から、X クラスフレアのトリガとなった構造を特定した。両者の結果と比較することで、連続した X クラスフレアの発生過程、およびそれらがどのように予測できるのかを考察する。

S002-03
A 会場 ：11/25　AM2 （10:30-12:00）
11:05～11:20

#西塚 直人 [1)], 久保 勇樹 [1)], 塩田 大幸 [1)]
[(1] 情報通信研究機構

Observations of Solar Radio Bursts Associated with Solar Flares in May 2024

#Naoto Nishizuka[1)], Yuki Kubo[1)], Daikou Shiota[1)]
[(1]National Institute of Information and Communications Technology (NICT)

Solar activity has reached its maximum, and a total of 20 large-scale (X-class) solar flares occurred in May 2024. In particular, 12 large-scale solar flares occurred in the active region NOAA 13664, including the most intense flare of X8.7 in this solar cycle. The coronal mass ejections (CMEs) released by these solar flares caused the first major geomagnetic storm in 19 years, and Dellinger phenomena, ionospheric disturbances, and low-latitude auroras were observed in various parts of Japan. It is known that Type II and Type III solar radio bursts are observed in association with CMEs and accelerated electron beams. By analyzing the spectrum of radio bursts observed in the frequency range of 70 MHz to 9 GHz, it is possible to derive near real-time CME velocities by assuming solar atmospheric density (Naoi et al. 2018 Fall Meeting of the Astronomical Society of Japan, M05a). The National Institute of Information and Communications Technology (NICT) conducts steady-state observations of solar radio bursts with the Solar Radio Observation System at the Yamagawa Radio Observatory.

The system successfully observed more than 17 cases of solar radio bursts associated with numerous X- and M-class solar flares in May 2024. Specifically, the system successfully observed the following solar radio bursts: M1.8-class solar flare on May 1, X1.7, M4.4, and M1.1 flares on May 3, M9.1 and M1.5 flares on May 4, M8.8, and X1.3 flares on May 5, two X1.0 flares on May 8, X2.3 flare on May 9, X4.0 flare on May 10, X5.8 flare on May 11, X1.7 flare on May 14, C9.9, and X3.5 flares on May 15, and X2.9 flare on May 27. These events were detected in real time by an automatic detection program and an automatic warning system. Furthermore, the directions and velocities of CMEs have been estimated from radio burst observations and coronagraph images taken by LASCO/SOHO, which were input into the SUSANOO simulation to estimate the arrival time of CMEs at Earth. In this talk, we will show observation data of solar radio bursts taken by the Yamagawa Radio Observatory in May 2024, and the analysis of CME velocity estimations.

S002-04
A 会場 ：11/25 AM2 （10:30-12:00）
11:20～11:40

X 線分光撮像衛星 XRISM 搭載 Xtend を用いた宇宙嵐に伴う地球磁気圏からの太陽風電荷交換 X 線放射の探索

#伊師 大貴 [1], XRISM チーム [1]
([1]JAXA 宇宙研

XRISM/Xtend Observations of Solar Wind Charge Exchange X-ray Emission from the Earth's Magnetosphere Associated with Space Storms

#Daiki Ishi[1], XRISM team[1]
([1]Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science

Solar activity in Solar Cycle 25 is currently at its peak, with frequent solar flares and coronal mass ejections (CMEs). These solar eruptive events cause temporally disturbances in the Earth's atmosphere and magnetosphere, e.g., atmospheric drag and geomagnetic storms. Space weather is important not only for predicting disruptions to ground-based and satellite systems due to atmospheric and magnetospheric disturbances but also for X-ray astronomical observations. During solar flares, X-rays reflected from satellite structures and fluorescent X-rays from the Earth's atmosphere can be observed. During geomagnetic storms, detector noise increases due to more charged particles penetrating through the satellite housing.

Recent observations by X-ray astronomy satellites like Suzaku have detected enhanced soft X-rays originating from the Earth's magnetosphere during space storms (e.g., Ishi et al. 2023 PASJ). These soft X-rays are produced by charge exchange (CX) reactions between highly charged solar wind ions and neutral materials in the Earth's exosphere or geocorona. This emission creates temporally variable foregrounds that often contaminate signals from astronomical objects. The magnetosheath and cusps are expected to emit strong soft X-rays due to dense populations of solar wind plasma and exospheric neutrals (e.g., Sibeck et al. 2018 Space Sci. Rev.), making this a new remote sensing method that complements in-situ observations by satellites like Arase.

The XRISM satellite, launched in September 2023, moved to its nominal observation phase in February 2024 and is currently observing selected objects as part of its performance verification phase. The X-ray CCD camera Xtend features a larger effective area and a wider imaging field of view (38 × 38 arcmin) compared to Suzaku, providing higher sensitivity to diffuse X-rays like CX emission in geospace.

Utilizing Xtend's high-sensitivity background observations, we have formed a new team to investigate X-ray enhancements associated with space storms. By removing astronomical objects from the field of view and searching for significant temporal variations in soft X-ray backgrounds, we have detected about 10 events that strongly correlate with solar wind variations during about 100 observations (each lasting 3-7 days), including those from the commissioning phase. The most pronounced event occurred during the massive geomagnetic storm in May 2024. Bright events were also observed during other geomagnetic storms. The enhanced spectra were characterized by emission lines from oxygen and carbon, consistent with CX emission. Neon and magnesium emission lines were also observed during CME arrivals. In this talk, we report on X-ray enhancements associated with space storms observed by XRISM and discuss the synergy between these phenomena and space weather.

現在、第 25 太陽活動周期の極大期に入りつつあり、太陽フレアやコロナ質量放出 (Coronal Mass Ejection; CME)、それに伴う巨大磁気嵐が頻発している。宇宙天気は、地磁気や大気擾乱による地上や衛星への障害といった社会生活だけでなく、X 線天文観測にも影響を及ぼす。太陽フレア発生時には、衛星の姿勢や軌道に擾乱が生じるほか、衛星構体で反射された太陽 X 線や地球大気からの蛍光 X 線が観測される。磁気嵐時には、荷電粒子によって検出器ノイズが増大する。一方、日本の「すざく」を含む最近の X 線天文衛星の観測によって、宇宙嵐に伴う地球磁気圏起因と考えられる軟 X 線が発見されてきた (Ishi et al. 2023 PASJ など)。太陽風に含まれる重イオンが地球周辺に薄く広がる超高層大気である外圏の水素原子から電子を奪い発光する電荷交換反応 (Charge eXchange; CX) に伴う放射である。本放射は天文観測の前景放射として重要であり、太陽風密度が増す衝撃波後方の遷移領域やカスプ領域で強く放射されると予想されている。すなわち、X 線は目には見えない磁気圏構造を可視化する全く新しい手段になり得る (Sibeck et al. 2018 Space Sci. Rev. など)。「あらせ」衛星などによる「その場」観測と相補的であり、宇宙天気分野からも注目されている。

2023 年 9 月に打ち上げられた X 線分光撮像衛星 XRISM は、2024 年 2 月から定常運用を開始し、初期性能確認フェイズとして事前に選択した天体を観測している。観測装置の一つである X 線 CCD カメラ Xtend は、「すざく」よりも大きな有効面積と広い撮像視野 (38 × 38 分角) を持ち、広がった放射に対して世界最高の感度を誇る。我々は Xtend による天体以外の領域の高感度バックグラウンド観測を活かし、横断的なチームを結成し、宇宙嵐に伴う X 線放射の探索を進めてきた。視野内から天体を除去し、軟 X 線バックグラウンドの有意な時間変動を調べた結果、コミッショニング期間を含む約 100 観測 (1 観測 3-7 日程度) の中で、太陽風変動と有意に相関する X 線増光を約 10 例発見した。2024 年 5 月の巨大磁気嵐が最も顕著であったが、それ以外の磁気嵐でも明るい増光が見られた。増光スペクトルには酸素や炭素からの輝線が含まれており、CX 放射と考えられる。CME 到来時には、ネオンやマグネシウムの輝線も観測された。本講演では、XRISM 衛星が天体観測中に捉えた宇宙嵐に伴う X 線増光例を紹介し、関連現象と宇宙天気分野とのシナジーに

ついて述べる。

S002-05
A 会場 ：11/25　AM2 （10:30-12:00）
11:40〜11:55

XRISM 搭載軟 X 線撮像検出器 Xtend による 2024 年 5 月の巨大宇宙嵐の X 線観測

#小林 翔悟 [1), 福島 光太郎 [2), 伊師 大貴 [2), 山崎 典子 [2), 佐藤 浩介 [3), the XRISM team[2,4)
([1 東理大, ([2ISAS JAXA, ([3 埼玉大学, ([4NASA

XRISM/Xtend observation of the intense space storm in 2024 May

#Shogo Kobayashi[1)], Kotaro Fukushima[2)], Daiki Ishi[2)], Noriko Yamasaki[2)], Kosuke Sato[3)], the XRISM team[2,4)]
([1]Tokyo University of Science, ([2]ISAS JAXA, ([3]Saitama University, ([4]NASA

The XRISM satellite, launched in September 2023, is equipped with a microcalorimeter (Resolve) and an X-ray CCD camera (Xtend/SXI; hereafter SXI) at the focal planes of two X-ray telescopes, enabling high-resolution spectroscopy and imaging in the soft X-ray band of 0.5 − 10 keV. The former offers a spectral resolution of E/Δ E ~ 1000 at 6 keV, which is 5 − 10 times higher than that of the other X-ray satellites, albeit with imaging capabilities limited to a 3′ × 3′ field of view with a 6 × 6 pixel mosaic. The latter, SXI, consists of four X-ray CCD chips arranged in a 2 × 2 configuration, achieving wide-field observations of 38′ × 38′ with an energy resolution of E/Δ E ~ 35, making it complementary to Resolve. Japanese satellites, including XRISM, have traditionally been placed below the Van Allen belts in low-altitude orbits. The primary goal of this orbit is to utilize geomagnetic shielding to reduce background noise from charged particles originating from the solar wind and low-energy cosmic rays, thereby achieving the highest sensitivity to faint and diffuse X-ray emissions. On the other hand, in such a low orbit, phenomena such as solar wind charge exchange where heavy ions in the solar wind capture electrons from hydrogen atoms in the Earth's upper atmosphere and emit X-rays, rapid increases in charged particle events, and solar X-ray radiation scattered by the satellite structure can be observed during periods of high solar activity. In fact, in the Suzaku satellite, emission lines of oxygen and carbon, considered to be originating from the solar wind charge exchange, have been reported (e.g., Fujimoto et al., 2007; Ezoe et al., 2011; Ishi et al., 2023), and the SXI's field of view, which is nearly four times larger than that of Suzaku, is also useful for observing such phenomena occurring near the upper atmosphere associated with these geomagnetic storms.

The Sun is currently entering the peak of the 25th solar cycle, frequently causing solar flares, coronal mass ejections, and massive geomagnetic storms. In particular, an enormous space storm occurred in May 2024, during which XRISM, conducting performance verification observations, was observing M81 and M82 (with exposure of 240 ks and 170 ks, respectively). By excluding X-ray emissions from celestial objects associated with each galaxy, we analyzed the background-dominated events in the observation data. The SXI X-ray spectrum exhibited emission lines from ionized oxygen and carbon due to solar wind charge exchange reactions, an increase in X-ray continuum components from charged particles, and events caused by solar X-ray flares scattered by the satellite structure, all detected with the highest statistical quality, showing a strong correlation with solar wind variations. In this presentation, we will focus on the SXI observation data during the massive geomagnetic storm in May and discuss the radiation mechanisms based on the temporal evolution of X-ray events associated with the storm.

2023 年 9 月に打ち上げられた XRISM 衛星は、2 つの X 線望遠鏡の各焦 点面にマイクロカロリメータ (Resolve) と X 線 CCD カメラ (Xtend/SXI; 以降 SXI) を搭載しており、0.5 − 10 keV の軟 X 線帯域における高精度分光および撮像を実現している。前者は、撮像能力が 3′ × 3′ の視野で 6 × 6 のピクセルモザイクに制限される代わりに、6 keV で E/Δ E ~ 1000 と従来の X 線衛星の 5 − 10 倍の分光性能を有する。後者の SXI は、2 × 2 で 配置した X 線 CCD 素子 4 枚で構成され、E/Δ E ~ 35 のエネルギー分解能で 38′ × 38′ の広視野観測を実現しており、Resolve と相補的な関係にある。日本の衛星は伝統的にヴァン・アレン帯以下の低高度軌道に投入されており、XRISM 衛星もこの例に漏れず高度 550 km の円軌道に投入されている。これは主に地磁気による遮蔽を利用し、太陽風由来の荷電粒子 や低エネルギー宇宙線によるバックグラウンドノイズを低減することで、 天球上に広がった微弱な X 線放射に対して世界最高感度を実現すること が目的である。一方で、このような低軌道では、太陽活動が活発な時期 において、太陽風に含まれる重イオンが地球超高層大気の水素原子から 電子を奪い X 線を発光する電荷効果反応、荷電粒子によるイベントの急激な上昇、衛星構体で散乱された太陽 X 線放射などが観測される。実際 に「すざく」では、太陽風電荷効果反応によると考えられる酸素や炭素の 輝線が報告されている (e.g., Fujimoto et al., 2007; Ezoe et al., 2011; Ishi et al., 2023) おり、「すざく」よりも 4 倍近くある SXI の広視野は、これらの磁気嵐に伴う超高層大気付近で発生する現象を観測する上でも有用となる。

太陽は現在第 25 回周期の活動極大期に入りつつあり、太陽フレア、コロナ質量放出、巨大磁気嵐を頻発させている。特に 2024 年の 5 月には巨大 な宇宙嵐を発生させており、打ち上げ後の性能評価観測を実施中であった XRISM は、当時 M81 および M82 銀河の観測中 (それぞれ露光時間 240 ks と 170 ks) であった。観測データから、各銀河に付随する天体由来の X 線放射を除去したバックグラウンドイベントが支配的なデータに対して解析を行なったところ、SXI の X 線スペクトル中に、太陽風電荷交換反応による電離した酸素および炭素からの輝線群の他に、荷電粒子による X 線連続成分の増光、そして衛星構体などで散乱された太陽 X 線フレアに よるイベントが、かつてない統計で検出され、またそれらが太陽風変動 と強く相関する様子も見られた。本講演では、この 5 月の巨大磁気嵐中 における SXI の観測データについて着目し、磁気嵐に伴 X 線イベントの時間発展から、その放射メカニズムについて議論する。

S002-06
A 会場 ：11/25　PM1 （13:15-15:15）
13:15〜13:35

あらせ衛星の観測による 2024 年 5 月の巨大磁気嵐時のリングカレントの発達の研究

#北村 成寿 [1)], 山本 和弘 [2)], 横田 勝一郎 [3)], 笠原 慧 [4)], 松岡 彩子 [5)], 海老原 祐輔 [6)], 桂華 邦裕 [7)], 新堀 淳樹 [8)], 三好 由純 [9)], Kistler Lynn[1,10)], 浅村 和史 [11)], 堀 智昭 [12)], 田 采祐 [13)], 寺本 万里子 [14)], 家田 章正 [1)], 平原 聖文 [15)], 能勢 正仁 [16)], 関 華奈子 [17)], 篠原 育 [18)]
([1] 名大・宇地研, ([2] 名大・宇地研, ([3] 大阪大, ([4] 東京大学, ([5] 京都大学, ([6] 京大生存圏, ([7] 東大・理, ([8] 名大・宇地研, ([9] 名大・宇地研, ([10]Inst. for Earth, Oceans, and Space, Univ. of New Hampshire, ([11] 宇宙研, ([12] 名大・宇地研, ([13] 名大・宇地研, ([14] 九工大, ([15] 名大・宇地研, ([16] 名市大・DS 学部, ([17] 東大理・地球惑星科学専攻, ([18] 宇宙機構／宇宙研

Ring current development observed by the Arase satellite during the May 2024 super geomagnetic storm

#Naritoshi Kitamura[1)], Kazuhiro Yamamoto[2)], Shoichiro Yokota[3)], Satoshi Kasahara[4)], Ayako Matsuoka[5)], Yusuke Ebihara[6)], Kunihiro Keika[7)], Atsuki Shinbori[8)], Yoshizumi Miyoshi[9)], Lynn Kistler[1,10)], Kazushi Asamura[11)], Tomoaki Hori[12)], ChaeWoo Jun[13)], Mariko Teramoto[14)], Akimasa Ieda[1)], Masafumi Hirahara[15)], Masahito Nose[16)], Kanako Seki[17)], Iku Shinohara[18)]
([1]Institute for Space-Earth Environmental Research, Nagoya University, ([2]Institute for Space-Earth Environmental Research, Nagoya University, ([3]Osaka University, ([4]The University of Tokyo, ([5]Graduate School of Science, Kyoto University, ([6]Research Institute for Sustainable Humanosphere, Kyoto University, ([7]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, ([8]Institute for Space-Earth Environmental Research, Nagoya University, ([9]Institute for Space-Earth Environmental Research, Nagoya University, ([10]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, ([11]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science, ([12]Institute for Space-Earth Environmental Research, Nagoya University, ([13]Institute for Space-Earth Environmental Research, Nagoya University, ([14]Kyushu Institute of Technology, ([15]Institute for Space-Earth Environmental Research, Nagoya University, ([16]School of Data Science, Nagoya City University, ([17]Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, ([18]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science

During the super geomagnetic storm that took place on May 10, 2024, the ring current intensified remarkably, and the SYM-H index reached -518 nT at the minimum peak. The reduction of the horizontal component of the geomagnetic field on the ground is the core feature of the ring current. The spatial distribution and the composition of the ring current ions during super geomagnetic storms, however, are still unclear due to a limited number of in-situ observations of ring current ions even during large geomagnetic storms. In addition, simultaneous observations of the solar wind parameters were not obtained with ring current observations near the equator during geomagnetic storms with a minimum SYM-H smaller than -250 nT. One of the best achievements during the present super geomagnetic storm is that the solar wind parameters were obtained almost continuously during the entire storm period. The Arase satellite is the only satellite currently available for comprehensive observations in the inner magnetosphere, and has observed ring current ions with the Medium-Energy Particle experiments-Ion mass analyzer (MEPi) and the Low-Energy Particle experiments-Ion mass analyzer (LEPi) with an orbital period of about 9.5 hours. Arase has successfully measured the energy density profile and temporal and spatial variations of the composition of ring current ions from the magnetopause to the L shell of 2.0 during the super geomagnetic storm. In this presentation, we report on the first in-situ observations of ring current ions with an energy density peak at the low L shell of 2.5-3.0 during the super geomagnetic storm, focusing on the observations in the dusk side magnetosphere where the 3-D velocity distribution function data (H^+, He^{++}, He^+, O^{++}, O^+, and molecular ions) of MEPi (9.6-184 keV/q) are available near the magnetic equator despite the orbital inclination of about 31 degrees.

2024 年の 5 月 10 日に開始した巨大磁気嵐は非常に顕著なリングカレントの発達がみられ、SYM-H 指数が − 518 nT に達した。リングカレントは地上磁場の水平成分の減少を引き起こす磁気嵐の主要因となる部分であるが、これまでの大磁気嵐時のリングカレントの赤道面付近での衛星による直接観測は非常に限られており、SYM-H 指数が − 250 nT を下回るようなイベントでは、リングカレントの直接観測と同時に磁気嵐を駆動する太陽風パラメータを連続的に得ること自体が実現されていなかった。今回の巨大磁気嵐では、後述するリングカレントの観測と同時に太陽風パラメータをほぼ連続的に得ることができた初めての例となった。あらせ衛星は中間エネルギーイオン質量分析器 (MEPi) と低エネルギーイオン質量分析器 (LEPi) をはじめとして多数の計測器を搭載し、現状唯一の内部磁気圏の総合観測衛星として観測を継続している。本磁気嵐においても軌道周期約 9.5 時間で内部磁気圏のリングカレントイオンを繰り返し観測し、リングカレントイオンの圧力、組成の時空間変動を観測することに成功した。本発表では内部磁気圏で磁気赤道付近を通過し、MEPi のノーマルモードで H^+、He^{++}、He^+、O^{++}、O^+、分子イオンの速度分布関数の観測データが連続的に得られた夕方側の内部磁気圏の観測を中心に、初めて直接観測された巨大磁気嵐時の深内部磁気圏 (L ~2.5-3.0) に圧力ピークを持つリングカレントイオンの圧力分布、組成変動を報告する。

S002-07
A 会場 ：11/25 PM1 （13:15-15:15）
13:35～13:50

#三好 由純 [1), 篠原 育 [2), 高島 健 [2), 浅村 和史 [2), 三谷 烈史 [2), 東尾 奈々 [2), 笠原 慧 [3), 横田 勝一郎 [4), 片岡 龍峰 [5), 田 采祐 [1), Kumar Sandeep[1), Porunakatu Radhakrishna Shreedevi[1), カリオコスキ ミラ [1), 栗田 怜 [6), 加藤 雄人 [7), 堀 智昭 [1), 桂華 邦裕 [3), 風間 洋一 [8), ウォング シャンユー [8), 土屋 史紀 [7), 熊本 篤志 [7), 笠原 禎也 [9), 松田 昇也 [9), 新堀 淳樹 [1), 北村 成寿 [1), 松岡 彩子 [10), 寺本 万里子 [11), 今城 峻 [12), 山本 和弘 [1)
([1] 名大 ISEE, ([2] 宇宙機構／宇宙研, ([3] 東京大学, ([4] 大阪大, ([5] 極地研, ([6] 京都大学 生存研, ([7] 東北大・理・地球物理, ([8]ASIAA, ([9] 金沢大, ([10] 京都大学, ([11] 九工大, ([12] 京大・地磁気センター

Arase satellite observations of the inner magnetosphere and radiation belts during the May 2024 geospace storm

#Yoshizumi Miyoshi[1), Iku Shinohara[2), Takeshi Takashima[2), Kazushi Asamura[2), Takefumi Mitani[2), Nana Higashio[2), Satoshi Kasahara[3), Shoichiro Yokota[4), Ryuho Kataoka[5), ChaeWoo Jun[1), Sandeep Kumar[1), Shreedevi Porunakatu Radhakrishna[1), Milla Kalliokoski[1), Satoshi Kurita[6), Yuto Katoh[7), Tomoaki Hori[1), Kunihiro Keika[3), Yoichi Kazama[8), Shiang-Yu Wang[8), Fuminori Tsuchiya[7), Atsushi Kumamoto[7), Yoshiya Kasahara[9), Shoya Matsuda[9), Atsuki Shinbori[1), Naritoshi Kitamura[1), Ayako Matsuoka[10), Mariko Teramoto[11), Shun Imajo[12), Kazuhiro Yamamoto[1)
([1]Institute for Space-Earth Environement Research, Nagoya University, ([2]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science, ([3]The University of Tokyo, ([4]Osaka University, ([5]National Institute of Polar Research, ([6]Research Institute for Sustainable Humanosphere, Kyoto University, ([7]Department of Geophysics, Graduate School of Science, Tohoku University, ([8]Academia Sinica Institute of Astronomy and Astrophysics, ([9]Emerging Media Initiative, Kanazawa University, ([10]Graduate School of Science, Kyoto University, ([11]Kyushu Institute of Technology, ([12]Graduate School of Science, Kyoto University

In May 2024, during the largest geomagnetic storm of Solar Cycle 25, the Arase satellite successfully conducted comprehensive observations, observing significant phenomena in the inner magnetosphere and radiation belts. Arase often exited the dayside magnetosphere and entered the magnetosheath near its apogee, indicating substantial compression of the magnetosphere. After the storm's main phase, a rapid flux increase in energetic electrons (several MeV) was observed at L <3, marking the largest such event since Arase's launch. Additionally, the plasmasphere shifted earthward to L ~2. The enhanced electron flux at L <3 persisted for 10 to 30 days, significantly changing the near-Earth radiation environment. By analyzing Arase's data, we estimated the decay time constant of the electron flux and compared it with pitch angle scattering rates induced by plasma waves, including hiss, EMIC waves, VLF transmitters, and lightning whistlers. The initial findings suggest that continuous scattering driven by plasmaspheric hiss predominantly controls the decay of energetic electrons. In this presentation, we will report various observations made by Arase related to radiation belt and inner magnetosphere variations during this historic geomagnetic storm.

S002-08
A 会場 ：11/25　 PM1 （13:15-15:15）
13:50～14:05

第 25 太陽活動周期の低緯度オーロラに関連して観測された電離圏対流の特性: SuperDARN HOP レーダー観測を中心として

#西谷 望 [1], 堀 智昭 [1], 細川 敬祐 [2], 新堀 淳樹 [3], 尾花 由紀 [4], 寺本 万里子 [5], 塩川 和夫 [6], 片岡 龍峰 [7]
([1] 名大 ISEE, ([2] 電通大, ([3] 名古屋大学宇宙地球環境研究所, ([4] 九州大学 国際宇宙惑星環境研究センター, ([5] 九工大, ([6] 名大宇地研, ([7] 極地研

Ionospheric convection associated with low-latitude auroras during 25th solar cycle - SuperDARN HOP radars observations

#Nozomu Nishitani[1)], Tomoaki Hori[1)], Keisuke Hosokawa[2)], Atsuki Shinbori[3)], Yuki Obana[4)], Mariko Teramoto[5)], Kazuo Shiokawa[6)], Ryuho Kataoka[7)]
([1]Institute for Space-Earth Environmental Research, Nagoya University, ([2]Graduate School of Communication Engineering and Informatics, University of Electro-Communications, ([3]Institute for Space-Earth Environmental Research, Nagoya University, ([4]International Research Center for Space and Planetary Environmental Science, Kyushu University, ([5]Kyushu Institute of Technology, ([6]Institute for Space-Earth Environmental Research, Nagoya University, ([7]National Institute of Polar Research

The SuperDARN HOP radars (consisting of Hokkaido East and West radars), currently located at the lowest geomagnetic latitude, have been in operation since 2006 and 2014, respectively, and successfully obtained the ionospheric convection flow data during several geomagnetic storm events of the 25 Solar Cycle, such as those in November 2023, December 2023, and May 2024, when low-latitude auroras were observed at the Hokkaido East radar site, Rikubetsu Town, Hokkaido (37° geomagnetic latitude). In general, low-latitude auroral precipitation regions are accompanied by sheared zonal ionospheric flows, but detailed flow patterns vary from event to event. In addition, the brief (<~10 min) variations in line-of-sight velocity observed by the SuperDARN HOP radars appear to have a characteristic time scale similar to auroral variability. More detailed analysis, discussion, and interpretation of the ionospheric flow patterns associated with these low-latitude auroras will be presented.

低・中地磁気活動時のオーロラ降り込みに関連する電離圏対流の特性は、過去数十年間、地上や探査機のデータを用いて精力的に研究されてきた。一方、観測データが少ないため、オーロラ降り込み境界がより低緯度側（地磁気緯度 50 度付近）まで拡大するような巨大な地磁気嵐時におけるオーロラ降下に関連した電離層対流特性に関する研究はほとんど行われていない。

現在、SuperDARN の中で最も低い地磁気緯度に位置する SuperDARN HOP レーダー（北海道-陸別第一レーダーおよび北海道-陸別第二レーダー）は、それぞれ 2006 年と 2014 年から運用されている。北海道陸別町の第一レーダーサイト（地磁気緯度 37 度）に設置したカメラで低緯度オーロラが観測されたのは第 25 太陽活動周期だけでも大磁気嵐時の 2023 年 11 月、2023 年 12 月、2024 年 5 月などがあるが、いずれについても SuperDARN HOP レーダーで電離圏対流データを取得することに成功している。一般に、低緯度オーロラ降り込み領域は電離圏のフローシアー構造を伴っているが、詳細なフローのパターンはイベントによって異なる。さらに、SuperDARN HOP レーダーによって観測されたプラズマ速度の短時間（～10 分未満）の変動は、オーロラ変動と同様の特徴的な時間スケールを持っているようである。これらの低緯度オーロラに関連した電離圏フローの特性について、より詳細な解析および解釈の結果を報告する予定である。

S002-09
A 会場 ：11/25　PM1 （13:15-15:15）
14:05～14:20

2024 年 5 月磁気嵐中に観測されたプラズマ質量密度の異常増加について

#尾花 由紀 [1], 新堀 淳樹 [2], 土屋 史紀 [3], 熊本 篤志 [4], 笠原 禎也 [5], 松岡 彩子 [6], 三好 由純 [7], 篠原 育 [8]
([1] 九州大学 国際宇宙惑星環境研究センター, ([2] 名古屋大学宇宙地球環境研究所, ([3] 東北大・理・惑星プラズマ大気, ([4] 東北大・理・地球物理, ([5] 金沢大, ([6] 京都大学, ([7] 名大 ISEE, ([8] 宇宙機構／宇宙研

Anomalous Increase in Plasma Mass Density Observed during the 2024 Mother's Day Storm

#Yuki Obana[1)], Atsuki Shinbori[2)], Fuminori Tsuchiya[3)], Atsushi Kumamoto[4)], Yoshiya Kasahara[5)], Ayako Matsuoka[6)], Yoshizumi Miyoshi[7)], Iku Shinohara[8)]
([1]International Research Center for Space and Planetary Environmental Science, Kyushu University, ([2]Institute for Space-Earth Environmental Research, Nagoya University, ([3]Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, ([4]Department of Geophysics, Graduate School of Science, Tohoku University, ([5]Emerging Media Initiative, Kanazawa University, ([6]Graduate School of Science, Kyoto University, ([7]Institute for Space-Earth Environement Research, Nagoya University, ([8]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science

The geomagnetic storm, which began at 17:00 UT on 10 May 2024, reached a Dst index of -412 nT, making it the largest geomagnetic storm since November 2003 and named "Mother's Day Storm." In this study, we investigate the behavior of the plasmasphere during this geomagnetic storm, primarily using multipoint geomagnetic observation data.

By examining the amplitude ratio and phase difference of geomagnetic pulsations between two points with slightly different latitudes, the resonance frequency of magnetic field lines can be precisely determined, and this frequency can be used to estimate the plasma mass density near the equatorial plane of the magnetosphere. However, since field line resonance is a phenomenon that predominantly occurs in the dayside magnetosphere, this method is limited to investigating the dayside magnetosphere.

Plasma mass density calculations for L ~2.5 across multiple longitudinal sectors from 9 to 12 May 2024, revealed that, during the main phase and early recovery phase, mass densities up to nearly ten times the usual values were observed in some longitudinal sectors. The most prominent density increase was observed in the New Zealand meridian (170°　E) between 21:00 and 24:00 UT on 10 May, where the density reached up to 25,000 amu/cc. For comparison, the average plasma mass density on quiet days in May over the past decade at the same observation point was approximately 2,500?3,000 amu/cc. Similar density increases were observed in Eastern Europe (20°　E, 8:30?12:30 UT on 11 May, 19,000 amu/cc) and Western Europe (4°　W, 9:00?14:00 UT on 11 May, ~13,000 amu/cc), while in Eastern America (75°　W, 21:00?23:00 UT on 11 May, ~11,000 amu/cc), the increase was observed for a shorter duration, but it was not observed in Western America (110°　W). This suggests that the anomalous density increase was observed when the magnetic flux tubes, after passing through the post-midnight to dawn sector during the main phase of the storm (17:10 UT on 10 ? 2:10 UT on 11), rotated into the dayside magnetosphere.

During this geomagnetic storm, the ERG satellite, which was in an orbit with an apogee on the dayside, passed through L=2.5 near 9 MLT and 18 MLT. An investigation of electron density derived from UHR frequencies showed no significant density increase similar to that observed in the mass density, suggesting that the increase in mass density was likely due to an increase in heavy ions. In the presentation, we will discuss more detailed analysis results and interpretations related to these density increases.

2024 年 5 月 9 日から 11 日にかけて放出された X クラスのフレアは、一連の高速コロナ質量放出（CME）を引き起こし、これらが地球磁気圏に作用することで大規模な磁気嵐を発生させた。2024 年 5 月 10 日 17 時から始まった磁気嵐は、Dst 指数が-412 nT に達して、2003 年 11 月以来最も大規模な磁気嵐となり、「母の日嵐」と名付けられた。本研究では、この磁気嵐の前後における、プラズマ圏の挙動を主に地磁気多点観測データを用いて調査した。

緯度がわずかに異なる二点間で地磁気脈動の振幅比や位相差を調べることで、磁力線共鳴振動周波数を精密に決定することができ、またその周波数を使って磁気圏赤道面付近のプラズマ質量密度を推定することができる。ただし、磁力背共鳴振動は昼側磁気圏に卓越する現象であるため、この手法で調査できるのは昼側の磁気圏に限られる。

2024 年 5 月 9 日ー 12 日の、複数の経度帯における L~2.5 のプラズマ質量密度を算出したところ、主相期間中～初期回復期間中に、いくつかの経度帯で通常の 10 倍近い質量密度が得られた。もっとも顕著な密度増加は、NZ 経度帯（170°E）で 5 月 10 日 21 － 24 時に観測され、密度は最大 25000amu/cc に達した。同一の観測点データを使って求められた、過去十年間の 5 月の静穏日のプラズマ質量密度の平均はおよそ 2500 － 3000amu/cc である。密度の異常増加は、、ヨーロッ

パ東部 (20°　E, 5 月 11 日 8:30-12:30 UT, 19000amu/cc)、ヨーロッパ西部（4°　W, 5 月 11 日 9 － 14 時, ~13000amu/cc）でも観測され、アメリカ東部（75°　W, 5 月 11 日 21 － 23 時、~11000amu/cc）では短時間観測されたが、アメリカ西部（110?W）では観測されなかった。すなわち密度の異常増加は、磁気嵐主相（5 月 10 日 17:10 UT ー 11 日 2:10 UT）の期間中に磁束管が post-midnight - dawn side を追加したのち、昼側磁気圏へ回ってきた際に観測されているように見える。

またこの磁気嵐期間中、ERG 衛星は昼側に遠地点を持つ軌道を飛行しており、9MLT, 18MLT 付近で L=2.5 を通過していた。UHR 周波数から求めた電子数密度を調べたところ、質量密度に見られたような密度の増大は見られなかった。よって質量密度の増大は、重イオンが増加したために生じたものと推測される。
講演では、これらの密度以上増加に関連する、より詳細な分析結果や解釈について議論する。

S002-10
A 会場 ：11/25　 PM1 （13:15-15:15）
14:20～14:35

2024 年 5 月の磁気嵐時におけるプラズマ圏・電離圏の電子密度の時間・空間変動について

#新堀 淳樹 [1], 北村 成寿 [2], 山本 和弘 [3], 熊本 篤志 [4], 土屋 史紀 [5], 松田 昇也 [6], 笠原 禎也 [7], 寺本 万里子 [8], 松岡 彩子 [9], 惣宇利 卓弥 [10], 大塚 雄一 [2], 西岡 未知 [11], PERWITASARI SEPTI[12], 三好 由純 [13], 篠原 育 [14]
([1] 名古屋大学宇宙地球環境研究所, ([2] 名大・宇地研, ([3] 名大 ISEE, ([4] 東北大・理・地球物理, ([5] 東北大・理・惑星プラズマ大気, ([6] 金沢大学, ([7] 金沢大, ([8] 九工大, ([9] 京都大学, ([10] 京大　RISH, ([11] 情報通信研究機構, ([12]NICT, ([13] 名大 ISEE, ([14] 宇宙機構／宇宙研

Temporal and spatial variation of electron density in the plasmasphere and ionosphere during the May 2024 storm

#Atsuki Shinbori[1], Naritoshi Kitamura[2], Kazuhiro Yamamoto[3], Atsushi Kumamoto[4], Fuminori Tsuchiya[5], Shoya Matsuda[6], Yoshiya Kasahara[7], Mariko Teramoto[8], Ayako Matsuoka[9], Takuya Sori[10], Yuichi Otsuka[2], Michi Nishioka[11], SEPTI PERWITASARI[12], Yoshizumi Miyoshi[13], Iku Shinohara[14]
([1]Institute for Space-Earth Environmental Research, Nagoya University, ([2]Institute for Space-Earth Environmental Research, Nagoya University, ([3]Institute for Space-Earth Environmental Research (ISEE), Nagoya University, ([4]Department of Geophysics, Graduate School of Science, Tohoku University, ([5]Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, ([6]Kanazawa University, ([7]Emerging Media Initiative, Kanazawa University, ([8]Kyushu Institute of Technology, ([9]Graduate School of Science, Kyoto University, ([10]Research Institute for Sustainable Humanosphere, Kyoto University, ([11]National Institute of Information and Communications Technology, ([12]National Institute of Information and Communications Technology, ([13]Institute for Space-Earth Environement Research, Nagoya University, ([14]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science

Due to the arrival of strong southward interplanetary magnetic field (IMF) to the Earth's magnetosphere, a strong magnetospheric convection is driven by the dayside magnetic reconnection between the IMF and Earth's magnetic field. The magnetospheric convection electric field penetrates the plasmasphere and equatorial ionosphere together with the development of a ring current in the inner magnetosphere. The electric field changes a spatial distribution of the electron density in the plasmasphere and ionosphere. However, details of the temporal and spatial variation of the electron density have not fully been understood during a super geomagnetic storm such as the May 2024 storm with a SYM-H minimum value of -512 nT. In this study, we analyzed global navigation satellite system - total electron content (GNSS-TEC) and Arase satellite observation data to clarify the generation mechanism of the electron density variation in the plasmasphere and ionosphere during the May 2024 storm. To identify the electron density variation in the ionosphere, we calculated the ratio of the TEC difference (rTEC) defined as a difference from a 10 quiet-day average TEC normalized by the average value. Further, we obtained the electron density in the plasmasphere and inner magnetosphere from the upper limit frequency of upper-hybrid resonance (UHR) waves observed by the Arase satellite. As a result, an L-t diagram of the electron density shows a shrink of the plasmasphere from L=6.0 to L=2.0 after the onset of the storm. It persisted for 4 days, which is much longer than a usual CME-driven storm. This result suggests that the erosion of the plasmasphere is caused by the penetration of a strong convection electric field. Interestingly, the electron density in the inner plasmasphere of less than L=2.0 increased by a factor of 3-5 during the main and early recovery phases of the geomagnetic storm. This phenomenon is thought to be caused by the uplift of the lower altitude plasmaspheric and ionospheric plasmas due to the penetration of the eastward electric field or heating of the ionospheric plasmas by heat flux from the inner magnetosphere. On the other hand, a polar map of rTEC in the Northern Hemisphere shows that an enhancement of the rTEC value occurred around the cusp (12-13 h in magnetic local time (MLT)) approximately 1 hour after the onset of the storm sudden commencement. The enhanced rTEC region extended in the magnetic latitude (MLAT) and MLT directions as the geomagnetic storm developed. After that, a tongue of ionization (TOI) was form in the polar cap due to the enhancement of the two-cell convection in the high-latitude ionosphere. During the recovery phase of the geomagnetic storm, a spatial distribution of rTEC showed a large depletion of the rTEC value in the entire region of the ionosphere from the high to low latitudes. This phenomenon persisted at least for more than 4 days. The depletion suggests the occurrence of a negative storm due to the neutral composition (O/N2) change driven by energy input from the magnetosphere at the high-latitude thermosphere. Further, it is thought that the long duration of the negative storm prevents the plasmaspheric refilling process.

S002-11
A 会場 ：11/25　PM1 （13:15-15:15）
14:35～14:50

2024 年 5 月の磁気嵐時に日本から観測された青いオーローラ

#南條 壮汰 [1], 塩川 和夫 [2]
([1]IRF, ([2] 名大宇地研

Blue aurora observed from Japan during the May 2024 geomagnetic storm

#Sota Nanjo[1], Kazuo Shiokawa[2]
([1]Swedish Institute of Space Physics, ([2]Institute for Space-Earth Environmental Research, Nagoya University

On May 11, 2024, an extreme G5-class geomagnetic storm triggered a spectacular and unusual display of colorful auroras in mid- to low-latitude regions all over the world. In Japan, auroras were seen not only from Hokkaido but also from the northern and central parts of Honshu. The widespread availability of commercial digital cameras among the public led to a flooding of high-resolution auroral images on social media. This study reports on the appearance of a blue aurora during a storm-time substorm on this day and its magnetic field-aligned and longitudinal structures captured by citizen scientists. Observations from two photographers at different locations revealed that the aurora was located at approximately 40 degrees magnetic latitude and magnetic local time (MLT) of 23 h, spanned about 1200 km (1-h MLT) in the longitudinal direction with three separated structures, and ranged in altitude from 400 km to at least 900 km. Simultaneous photometric measurements suggested that this blue aurora likely included emissions at 427.8 nm. While previous studies have noted the existence of emissions at 427.8 nm in low-latitude auroras, this is the first time that a blue low-latitude aurora has been spatially visualized and shown to have longitudinal and field-aligned structures. Additionally, previous studies suggested that blue emissions in low-latitude auroras are produced by energetic neutral atoms precipitating from the ring current. However, identifying longitudinal and field-aligned structures in this study may need an alternative explanation.

2024 年 5 月 11 日に起こった G5 クラスの巨大な磁気嵐により、北海道はもちろんのこと、東北地方や中部地方においてもオーロラが観測された。感度の高いデジタルカメラが多くの人々に行き渡っていることもあり、日本中の市民科学者が撮影した高繊細な画像がソーシャルメディアを賑わせた。本研究は、この日に起きたサブストーム中に出現した青色のオーロラと、それが持つ磁力線沿いの構造、および経度方向の広がりについて報告する。二人の写真家がこのオーロラを別々の場所（石川県および長野県）から観測した結果により、このオーロラは磁気緯度 40 度付近で、経度方向の幅が 1200 km (1 MLT) 程度、高度は 400 km から少なくとも 900 km 程度まで発光していたことがわかった。また、フォトメータの同時計測により、この青色のオーロらは 427.8 nm の発光を含む可能性が高いことが分かった。低緯度オーロラが 427.8 nm の発光を伴うことがあることは過去の研究で明らかになっているが、青色の低緯度オーロラが空間的に可視化され、磁力線沿いの構造を持つことが分かったのは初めてのことである。また、低緯度オーロラの 427.8 nm の発光はリングカレントから大気圏に降り込んだ高エネルギー中性粒子（ENA）が作り出す二次電子によるという学説が提唱されているが、本研究においては経度方向に小規模な構造、磁力線沿いの構造が見つかったため、この学説はより詳しい検討を要すると思われる。

S002-12
A 会場 ：11/25　 PM1 （13:15-15:15）
14:50〜15:10

#片岡 龍峰 1)
(1 極地研

Magnetic storm-time auroras as seen from Japan

#Ryuho Kataoka[1)]
[(1]National Institute of Polar Research

I would like to report a citizen science-motivated studies on the cause of an unusually bright red aurora as witnessed from Hokkaido, Japan during a magnetic storm on 1 December 2023 (Kataoka et al., 2024, GRL), as well as a vast magenta aurora as observed from wide area of Japan, including Kyoto, during a severe storm on 11 May 2024 (Kataoka et al., 2024, under review). Another latest citizen science example of 12 Aug 2024 storm (Dst peak at -203 nT) will also be shown for comparison.

S002-13
A 会場 ：11/26 AM1 （9:00-10:15）
9:00〜9:15

#長妻 努 [1], Monham Andrew[2], Talaat Elsayed[3], Andries Jesse[4]
([1] 情報通信研究機構, ([2] 欧州気象衛星開発機構, ([3] 米国海洋大気庁, ([4] 世界気象機関

Space weather impact on meteorological satellites and their operations during May 10-13, 2024 severe geomagnetic storm

#Tsutomu Nagatsuma[1], Andrew Monham[2], Elsayed Talaat[3], Jesse Andries[4]
([1]NICT, ([2]EUMETSAT, ([3]NOAA, ([4]WMO

The Coordination Group for Meteorological Satellites (CGMS) is the group that globally coordinates meteorological satellite systems including space weather matter. This includes protection of in orbit assets, contingency planning, improvement of quality of data, support to users, facilitation of shared data access and development of the use of satellite products in key application areas.

CGMS's coordination is pursued from an end-to-end perspective between meteorological satellite operators and user communities such as WMO. Members are meteorological and space agencies that are current and prospective developers and operators of meteorological satellites and R&D satellites contributing to WMO programs, and WMO. The scope of its activities to include space weather was expanded in 2018.

Space weather matters are coordinated by SWCG. There are three active task groups on spacecraft anomaly database, improving data access to space-based space weather observations operated by CGMS agencies, and ionospheric RO optimization. SWCG also working together with GSICS space weather subgroup which handles inter-calibration of space weather sensor, and with a task group on space environment sustainability under WG I which handles space traffic control. CGMS recommends reporting spacecraft anomalies caused by space weather in Plenary meeting once in a year.

Geomagnetic storm occurred during May 10-13, 2024 is the largest storm in the last 19 years since August 2005. Since the magnitude of the storm was comparable to the 2003's Haloween event, which initiated large numbers of spacecraft anomalies, there were concerns about the space weather impact on meteorological satellites and their operations.

After the storm event, we have asked CGMS member agencies to give some information about the following questions. 1) Please let us know if severe space weather disturbances over the past few days have had an impact on your satellite operations or the satellite itself. 2) Please let us know if you have implemented any measures for the satellite or satellite operations due to severe space weather disturbances over the past few days. We have received feedback from the members.

The summaries of feedback from CGMS agencies about space weather impact on spacecraft anomalies and operations, and its relationship with the conditions of space environment observed by meteorological satellite will be discussed in our presentation.

S002-14
A 会場 ：11/26　 AM1 （9:00-10:15）
9:15～9:30

2024 年 5 月のシビアな宇宙天気における地球低軌道 4 層構造と宇宙物体の高度変化

#玉置 晋 [1)], 野澤 恵 [1)]
[(1] 茨城大学

Four Layer Structure of LEO and Altitude Change of Space Objects in Severe Space Weather in May 2024

#Susumu Tamaoki[1)], Satoshi Nozawa[1)]
[(1]Ibaraki University

One of the space weather hazard risks in satellite operation is aerodynamic drag. Aerodynamic drag increases due to the ascending phase of the solar activity, and space objects fall, which can reduce the life in orbit and increase the risk of permissible orbital holding range deviations. On the other hand, in the case where drag is small, space objects in orbit increase the production risk of space debris. We classify Low Earth Orbits (LEO) into four layers based on the characteristics of the aerodynamic drag in the satellite orbit, deriving from the change in the orbital altitude of the satellites. In the severe space weather event in May 2024, we report whether space objects flying in each layer structure of LEO fell.

衛星運用における宇宙天気のハザードリスクの一つは大気ドラッグである．太陽活動の活発化により大気ドラッグが増加し，宇宙物体が落下するため，軌道上の寿命が短くなり，許容軌道保持範囲の偏差のリスクが高まる可能性がある．一方で，大気ドラッグが小さい場合は，軌道上の宇宙物体は宇宙ごみの生成リスクを高める．地球低軌道（LEO）は，衛星は，宇宙物体の軌道高度の変化から導き出される大気ドラッグの特性に基づいて 4 つの層に分類される．2024 年 5 月のシビアな宇宙天気イベントにおいて，4 層を飛行する宇宙物体が落ちたかどうか報告する．

S002-15
A 会場 ：11/26　AM1 （9:00-10:15）
9:30〜9:50

2024 年 5 月イベントにおける JAXA 低高度衛星の状況と放射線環境について

#木本 雄吾 [1), 古賀 清一 [1), 松本 晴久 [1)
(1JAXA

Status of JAXA Low Altitude Satellite and Radiation Environment in May 2024 Event

#Yugo Kimoto[1)], Kiyokazu Koga[1)], Haruhisa Matsumoto[1)]
(1Japan Aerospace Exploration Agency

This presentation describes the operations of JAXA's low earth orbit satellites (GCOM-C, GCOM-W1, GOSAT, GOSAT-2, and XRISM) following a large-scale space weather event that occurred in early May 2024. GOSAT is also equipped with a light particle telescope (LPT) for the purpose of high-energy charged particle environments that can cause spacecraft anomalies. The impact of this event will be discussed along with the status of the high-energy radiation environment during this period.

2024 年 5 月上旬に発生した大規模宇宙天気現象に伴う JAXA 低軌道衛星（GCOM-C、GCOM-W1、GOSAT、GOSAT-2、XRISM）の運用状況について報告する。また GOSAT には衛星の障害につながる高エネルギー荷電粒子環境を目的として軽粒子観測装置（LPT）が搭載されている。当該期間の高エネルギー放射線環境の状況と合わせ、今回のイベントの影響について議論する。

S002-16
A 会場 ：11/26　AM1 （9:00-10:15）
9:50〜10:10

2024 年 5 月の大規模宇宙天気現象に伴う社会影響について

#石井 守 [1,2)]
(1 情報通信研究機構, (2 名古屋大学宇宙地球環境研究所

Social Impact by Extreme Space Weather Events during May 2024

#Mamoru Ishii[1,2)]
(1National Institute of Information and Communications Technology, (2Institute for Space-Earth Environmental Research, Nagoya University

The solar flares and associated proton events, CMEs, that occurred in sunspot groups 13663 and 13664 since May 8, 2024 (Japan Standard Time) were the largest in the 25th solar cycle. It is the first time to observe 13 solar flares of X-class or higher occurred continuously since the current observational techniques were established. International Space Environment Services (ISES) is the only international organization formed by space weather forecasting organizations and currently consists of 21 Regional Warning Centers (RWCs) and 3 Collaborative Expert Centers (CECs). To become an ISES member, each country must be providing space weather information operationally, have national endorsement, and adhere to an open data policy. One of the strengths of ISES is its close relationships with end users in each country. In Japan, NICT has been promoting user communication through the Space Weather User Forum and the Space Weather User Council, and similar activities are being promoted by ISES members around the world. For this large-scale space weather phenomenon, we are utilizing these user communications to compile the social impacts. Many of the social impacts include confidential information, and we select this information with the consent of the provider of the information. In Japan, it has already been reported that shortwave communications and satellite positioning have been severely affected, and it has also been reported that aviation operations have been forced to change in high latitude areas. In this presentation, more detailed information will be presented.

2024 年 5 月 8 日（日本時間）より太陽黒点群 13663 および 13664 で発生した太陽フレアおよびそれに伴うプロトン現象、CME の発生は、第 25 太陽周期の中で最大のものとなった。X クラス以上の太陽フレアが継続的に 13 回発生したことは、現在の観測手法が確立されて以来、初めてのことである。国際宇宙環境サービス (International Space Environment Services: ISES）は、宇宙天気予報業務を担う組織によって結成された唯一の国際機関であり、現在 21 の正会員（Regional Warning Center：RWC）および３つの準会員（Collaborative Expert Center: CEC）からなる。各国において宇宙天気情報を定常的に提供していること、国からの承認を受けていること、データのオープンポリシーが順守されていることなどが会員となるための条件である。ISES の強みの一つに、各国の事業者との関係が密であることが挙げられる。わが国においては NICT が宇宙天気ユーザーフォーラム、宇宙天気ユーザー協議会等を通じてユーザーコミュニケーションを図っているが、同様の活動が ISES の会員によって世界各地で進められている。今回の大規模宇宙天気現象において、これらのユーザーコミュニケーションを生かし、社会影響についての取りまとめを行っている。社会影響の中には秘匿情報が含まれる場合も多いが、今回の情報については提供者の同意を得たものについて公開するものである。既に我が国においては、短波通信や衛星測位に大きな影響が出ていることが報告されているが、高緯度地域では航空運用等も変更を迫られたとの報告がある。
講演では、より詳細な情報について報告する。

S002-17
A 会場 ：11/26　AM2 （10:30-12:00）
10:30～10:50

2024 年 5 月の大規模太陽フレアによる高精度 GNSS 測位の測位精度への影響

#藤原 智 [1), 細谷 素之 [1), 来田 倍周 [1)
[1 ジェノバ

Impact of a Large Solar Flare in May 2024 on the Positioning Accuracy of High-Precision GNSS

#Satoshi Fujiwara[1), Motoyuki Hosoya[1), Masunori Kitada[1)
[1JENOBA CO., LTD.

1. Introduction

GNSS radio waves, such as those used in GPS, are subject to delays and other effects when they pass through the ionosphere. In this presentation, we will report on the impact of the large solar flare in May 2024 on high-precision GNSS positioning accuracy.

2. GNSS Positioning and Ionospheric Disturbances

GNSS positioning for navigation and smartphones generally uses a code (with a wavelength equivalent of about 300 m) modulated onto a GNSS carrier wave, resulting in positioning accuracy of a few meters. In contrast, high-precision positioning, used in surveying and other applications, relies on the phase of the GNSS carrier wave (wavelength of about 19 cm) to achieve accuracy within a few centimeters or less.

The ionospheric delay is a significant issue for high-precision positioning. Using two frequencies, L1 (1575.42 MHz) and L2 (1227.60 MHz), can mitigate ionospheric delays by taking advantage of the fact that delay amounts differ depending on the frequency. However, disturbances in the ionosphere caused by solar flares, among other factors, can lead to irregular GNSS signals, resulting in reduced positioning accuracy.

In high-precision positioning, determining the integer number of radio waves (integer ambiguity) between the satellite and receiver is crucial for accurate distance measurement. The state in which this integer value is correctly determined is called a FIX solution (accuracy: within several centimeters), as opposed to a FLOAT solution (accuracy: ranging from tens of centimeters to several meters). The FIX solution is a key indicator of positioning accuracy, which can be affected not only by ionospheric disturbances but also by a decrease in the number of usable satellites, multipath effects, and radio wave interference.

3. Positioning Status from May 11, 2024

We provide a service that enables position measurements with an accuracy of a few centimeters every second throughout Japan using the network RTK method, leveraging GSI's continuously operating reference station network (GEONET). Beginning around 22:00 JST on May 11, 2024, our monitoring detected a phenomenon where the FIX solution became unavailable in certain areas, gradually moving southward from Hokkaido to Kyushu.

This issue first appeared in eastern Hokkaido around 22:00. By 23:00, parts of the Tohoku region were also experiencing a loss of FIX solutions. By midnight on May 12, the disturbance had spread across nearly the entire Tohoku region, moving westward to Kanto by 1:00 a.m. and then to Kansai by 2:00 a.m. The disturbance reached its peak by 4:00 a.m., affecting a wide area from Tohoku to Kyushu. It gradually subsided, becoming confined to southern Kyushu by 7:00 a.m., and was no longer observed by 9:00 a.m. This phenomenon appears to have affected not only our service but also RTK positioning services in general.

Since the disturbance occurred from late Saturday night to early Sunday morning, the impact on general users was minimal. Although advancements in equipment and software have improved our ability to mitigate such large-scale disturbances, some phenomena, such as this one, cannot yet be fully prevented. Therefore, further countermeasures and public awareness, including advance warning of anticipated impacts, are essential.

１．はじめに

GPS に代表される GNSS の電波は電離圏を通過する際に遅延等の影響を受ける。本講演では、2024 年 5 月に発生した大規模太陽フレアの影響を受けた高精度 GNSS 測位の測位精度の状況について報告する。

２．GNSS 測位と電離圏擾乱

一般にナビゲーションやスマホで用いられる GNSS 測位は GNSS 搬送波に変調し載せられたコード（波長換算約 300m）を使っており、測位精度は数 m 程度である。これに対して、測量等の高精度測位には GNSS 搬送波（波長約 19cm）の位相を用いることで数 cm 以下の精度が得られる。

高精度測位では電離圏における遅延が問題になり、周波数によって遅延量が異なる性質を利用して L1（1575.42MHz）と L2（1227.60MHz）の 2 周波を用いることで電離圏での遅延をキャンセルできる。しかしながら、太陽フレア等に伴

う電離圏の各種擾乱では、GNSS 信号が不規則になってしまうことで測位精度の低下が発生する。
高精度測位においては、衛星と受信機の間の電波の波の数（整数値アンビギュイティ）の決定が絶対距離を求めるために必須である。この整数値が正しく決定されている状態を FIX 解（精度数 cm）と呼び、そうでない状態の FLOAT 解（精度数 10cm～数 m）と区別する。電離圏擾乱のみならず、利用衛星数減少、マルチパス、電波障害等で測位精度低下の有無を判断する基準が、FIX 解が得られているかどうかである。

３．2024 年 5 月 11 日からの測位状況

当社は国土地理院の電子基準点網（GEONET）を用いて、毎秒ごとに数 cm 精度の位置測定が全国どこでもできるサービス（ネットワーク型 RTK）を提供しており、2024 年 5 月 11 日 22 時（日本時間。以下同じ）ごろから、FIX しづらい地域が、北海道から九州に南下する現象を当社の監視で確認した。
この現象は 22 時頃に北海道東部で始まった。23 時過ぎには東北地方の一部で FIX しなくなった。翌 12 日 0 時には東北地方ほぼすべてに影響が広がり、1 時過ぎに関東、2 時過ぎには関西へと西に移動した。4 時頃には東北から九州の広域で最大規模の擾乱となっている。その後徐々に収まり、7 時には九州南部のみとなり、9 時前には擾乱はみられなくなった。こうした現象は当社のサービスだけではなく RTK 測位全般でみられたようである。
今回は擾乱の時間が土曜深夜～日曜早朝であったため、一般的なユーザーへの影響は小さかった。機器やソフトウエアの向上でこうした大規模な擾乱への対策は進んでいるものの、今回のように防ぎきれない現象が存在するため、影響が予測される場合の事前注意喚起を含め、さらなる対策と周知は必須である。

S002-18
A 会場 ：11/26　 AM2 （10:30-12:00）
10:50～11:05

太陽活動活発化に伴う電離圏擾乱の CLAS ユーザ精度への影響

#齊藤 亮介 [1], 斎藤 享 [2], 早瀬 夏子 [1], 佐藤 一敏 [1], 藤田 征吾 [1], 宮 雅一 [1]
[1] 三菱電機, [2] 電子航法研

The impact of ionospheric disturbances due to solar activity on the user position accuracy by CLAS.

#Ryosuke Saito[1], Susumu Saito[2], Natsuko Hayase[1], Kazutoshi Sato[1], Seigo Fujita[1], Masakazu Miya[1]
[1]Mitsubishi Electric Corporation, [2]Electronic Navigation Research Institute

Centimeter Level Augmentation Service (CLAS) utilizes the L6D signal of Quasi-Zenith Satellite System (QZSS) to transmit positioning augmentation information. This information provides centimeter-level positional accuracy, consistent with the Japanese geodetic system, available for the main islands of Japan and its surrounding ocean area. CLAS employs PPP-RTK as its positioning method and estimates correction such as satellite clock, satellite orbit, satellite signal bias, ionospheric delay, and tropospheric delay. These corrections are mapped onto a grid with an interval of approximately 60 km. The user can calculate augmentation data at his or her location by using information from the nearest three or four grid points.

When localized ionospheric disturbances occur, the disparity in augmentation data between neighboring grids becomes significant, impacting the precision of CLAS users across these grids. CLAS users are particularly susceptible to the effects of plasma bubbles and Middle Scale Traveling Ionospheric Disturbances (MSTIDs). In fact, a trend of degraded positioning accuracy has been observed during the occurrence of plasma bubbles and MSTIDs.

In recent years, due to increased solar activity, the number of ionospheric disturbance events has risen, and their impact on PPP-RTK positioning by using CLAS has become more significant. In particular, the intense magnetic storm caused by the solar flare in May 2024, reaching Dst<-400nT, and associated ionospheric disturbance caused noticeable impact on the user position accuracy by CLAS. This paper evaluates and reports the results of ionospheric disturbances associated with recent solar activity and their impact on PPP-RTK performance by using CLAS.

センチメータ級測位補強サービス（Centimeter Level Augmentation Service; CLAS）は、準天頂衛星システム（QZSS）の L6D 信号を使用して、日本の測地系と整合可能なセンチメータ級の位置精度が得られる測位補強情報を、日本全国およびその近海に送信するサービスである。CLAS の測位方式としては、PPP-RTK 方式を採用している。補強情報は、衛星測位における誤差要因である衛星時計誤差、衛星軌道誤差、衛星信号バイアス、電離圏遅延誤差、対流圏遅延誤差などを各々推定しており、これを約 60km 間隔のグリッドにマッピングすることにより配信している。ユーザは近傍の 4 点または 3 点のグリッド情報を使用して、自己位置の補正項を算出する。

局所的な電離圏擾乱現象が発生すると、隣り合ったグリッド間の補正項の差が大きくなり、グリッド間で CLAS を利用するユーザ精度へ影響を及ぼす。このような電離圏擾乱現象には、プラズマバブルや中規模伝搬性電離圏擾乱（MSTID：Middle Scale Traveling Ionospheric Disturbance）などがある。実際にプラズマバブルや MSTID の発生時期に測位精度が劣化する傾向にあることを確認している。

近年、太陽活動の活発化に伴い電離圏擾乱現象が増加している。特に、2024 年 5 月に発生した太陽フレアによる宇宙嵐は、Dst<-400 nT に達する巨大なものであり、これに起因した電離圏擾乱の影響が CLAS を利用したユーザ測位精度において確認された。本稿では、最近の太陽活動に伴う電離圏擾乱と、CLAS を利用するユーザ測位精度への影響を評価し、その結果を報告する。

S002-19
A 会場 ：11/26　 AM2 （10:30-12:00）
11:05〜11:25

#斎藤 享 [1], 吉原 貴之 [1], 高橋 透 [1], 野崎 太成 [2], 山本 衛 [3]
([1] 電子航法研, ([2] 京大・情・通信, ([3] 京大・生存圏研

Ionospheric disturbances and their impact on aeronautical GNSS applications following the geomagnetic storms occurred in 2023-2024

#Susumu Saito[1], Takayuki Yoshihara[1], Toru Takahashi[1], Taisei Nozaki[2], Mamoru Yamamoto[3]
([1]ENRI, National Institute of Maritime, Port, and Aviation Technology, ([2]Course of Communications and Computer Engineering, Kyoto University, ([3]Research Institute for Sustainable Humanosphere, Kyoto University

Global Navigation Satellite System (GNSS) is now widely used in the society. In the field of air navigation, GNSS is now one of the essential elements. However, ionospheric disturbances are major error sources in GNSS-based air navigation in which only single-frequency GNSS equipment is available.

Since the safety is very important for air navigation, strict standards are defined by International Civil Aviation Organization (ICAO). To provide safe GNSS-based services, the standards defines how to mitigate the ionospheric impacts. To design safe and available systems, how the ionosphere can change must be defined, which is threat model. In other words, air navigation systems are designed to be safe within the defined, usually very conservative, threat models.

Even if the threat models are defined with the best available historical data and knowledge, it is still necessary for the threat models to be checked against newly occurring phenomena. It is also important to check if the geophysical mechanisms behind the new phenomena is consistent with our common knowledge on which the threat model is based.

As the solar activity approaches to its peak, different types of ionospheric disturbances occur over Japan. Occurrence of equatorial plasma bubble occur frequently in low latitude Japan. Even in the lower mid-latitude Japan, strong ionospheric disturbances are frequently observed associated with severe geomagnetic storms.

One of the GNSS-based air navigation systems which requires stringent bounding of ionosphere-induced errors is the GNSS ground-based augmentation system. It can support precision approach and landing guidance of aircraft which is the critical phase of aircraft operation. Since it is based on the range-domain differential GNSS technique, spatial gradients in the ionospheric delay (or equivalently total electron content (TEC)) is the critical error source. We have evaluated ionospheric delay gradients for the three unusual ionospheric disturbances on 5 November 2023, 1 December 2023, and 11 May 2024, all of which are associated with severe geomagnetic storms and compared with the existing threat model for the Asia-Pacific region recommended by ICAO. Furthermore, we have evaluated impacts of the ionospheric disturbances on the aircraft surveillance system called ADS-B (Automatic Dependent Surveillance - Broadcast), although it would not be expected to be significantly impacted, because the required error levels for ADS-B is not so stringent.

Mechanisms of the ionospheric disturbances are investigated by using the three-dimensional ionospheric tomography based on a dense GNSS network.

S002-20
A 会場 ：11/26 AM2 （10:30-12:00）
11:25〜11:40

#高橋 透 [1)], Pongpeaw Anurak[2)], 斎藤 享 [1)], 古賀 禎 [1)], Supnithi Pornchai[2)], Budtho Jirapoom[2)]
([1] 電子航法研, ([2]KMITL

Impact of ionospheric activity on air navigation integrity and accuracy in ADS-B

#Toru Takahashi[1)], Anurak Pongpeaw[2)], Susumu Saito[1)], Tadashi Koga[1)], Pornchai Supnithi[2)], Jirapoom Budtho[2)]
([1]Electronic Navigation Research Institute, ([2]Telecommunications Engineering Department King Mongkut's Institute of Technology Ladkrabang

The Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance technology primarily used by aircraft and airport vehicles. The ADS-B message includes a position derived from GNSS satellite positioning, barometric altitude, aircraft speed, and the aircraft's identity. It also broadcasts integrity and accuracy information known as the Navigation Integrity Category (NIC) and Navigation Accuracy Category - position (NACp). Typically, NIC and NACp values are greater than 7 and 8, respectively, indicating that the radius of containment around the aircraft (Rc) is less than 185.2 meters and the Estimated Position Uncertainty (EPU) is less than 30 meters. However, during periods of high geomagnetic activity, NIC and NACp occasionally degrade to values below 7 and 8.

Since 2020, the Electronic Navigation Research Institute (ENRI) has been recording ADS-B messages at locations including Iwanuma, Minami-Soma, Chofu, and Ishigaki. At Ishigaki, an All-sky airglow imager (ASI) and a GNSS receiver have been installed. The ASI enables the detection of plasma bubbles, which appear as regions of plasma density depletion, causing amplitude or phase fluctuations in GNSS signals known as scintillation. Strong scintillation can lead to the loss of lock on GNSS signals, resulting in the GNSS receiver losing the signal. The GNSS receiver used is the Septentrio PolaRx5S, which provides phase and amplitude scintillation indices with a 1-minute sampling rate. Therefore, the degradation of NIC and NACp due to ionospheric activity can be investigated on Ishigaki.

In this presentation, we will show cases of NIC and NACp degradation during periods of high geomagnetic activity, particularly in May 2024. We calculate the Ionospheric Pierce Point (IPP) of the GNSS satellite signals for the aircraft that broadcasted the degraded NIC and NACp, to compare the scintillation indices and the horizontal structure of the plasma bubble. Finally, we discuss the contribution of geomagnetic activity to the degradation of NIC and NACp.

S002-21
A 会場 ：11/26　AM2 （10:30-12:00）
11:40〜12:00

気象キャスターが考えるオーロラ報道の功罪

#斉田 季実治 [1,2], 玉置 晋 [1], 石田 彩貴 [1]
[1]（一社）ABLab 宇宙天気プロジェクト, [2]NPO 法人気象キャスターネットワーク

A weather caster's thoughts on the merits and demerits of aurora reporting

#Kimiharu Saita[1,2], Susumu Tamaoki[1], Saki Ishida[1]
[1]ABLab Space Weather Project, [2]Weather Caster Network

Space weather events such as solar flares that occurred in May 2024 were widely featured in news programs because aurora borealis were seen in various parts of Japan. On the other hand, there is little news about the negative impact on social systems, and it is thought that many people are optimistic about space weather events. We will examine how this space weather event was reported from the perspective of a weather caster, and consider how to convey it to the general audience in the future.

2024 年 5 月に発生した太陽フレアなどの宇宙天気イベントでは、日本の様々な場所でオーロラが見られたことから、ニュース番組でも多く取り上げられた。その一方で、社会システムへの悪影響についてのニュースは少なく、宇宙天気イベントを楽観的に捉えた人が多いと考えられる。気象キャスターの観点から今回の宇宙天気イベントがどのように報道されたのかを検証し、今後の一般視聴者への伝え方などについて考察する。

S002-P01
ポスター１：11/24　PM1/PM2 （13:15-18:15）

2024 年 5 月巨大宇宙嵐を引き越した複数 CME 間相互作用についての考察

#塩田 大幸 [1), 八代 誠司 [2), 岩井 一正 [3)
(1 情報通信研究機構, (2 米国カトリック大学, (3 名大 ISEE

Interaction among multiple CMEs to result in May 2024 Superstorm

#Daikou Shiota[1), Seiji Yashiro[2), Kazumasa Iwai[3)
(1National Institute of Information and Communications Technology (NICT), (2Catholic Unversity of America, (3Institute for Space-Earth Environmental Research, Nagoya University

The space storm that occurred in May 2024 became a phenomenon of a scale rarely seen in history, with aurora visible in extremely wide areas of the world, including Japan. One of the reasons for this event is that the solar wind that arrived at the Earth on May 10-12 was in a state far from normal, with a maximum density of more than 50 particles/cc and a maximum southward magnetic field of more than 50 nT. This solar wind structure is considered to be generated by multiple CMEs associated with solar flares, including the X-class flares occurred continuously in a short period of time of May 8-10. It is thought that the high-speed CMEs interacted with each other and arrived at the Earth as a single complex body, but the details are difficult to clarify.

In this study, we analyzed solar flares and CMEs that propagated toward the Earth during this period, which were observed by the SDO satellite and SOHO/LASCO, and calculated the propagation of the CMEs in the solar wind with MHD simulation (SUSANOO-CME), and examined the correspondence between the solar wind structure observed in situ and the solar flares and CMEs. In the multiple CMEs that occurred on May 8-9, the propagation speed of the succeeding CMEs was higher than that of the preceding CMEs, and it was seen that they caught up and interacted with each other during propagation in interplanetary space. As a result, it showed that compression occurred in the shock waves of the succeeding CMEs and a prevention of the expansion of the middle CMEs caught between other CMEs, leading to the formation of a high-speed, high-density, and high-magnetic field structure. However, since it is difficult to identify the correspondence between phenomena observed in the solar corona and in situ measurement, we report the results of comparison and consideration of simulation results in which data of different CMEs were input.

2024 年 5 月に発生した宇宙嵐は、日本をはじめとした世界各地でオーロラが見えるなど、歴史上稀に見る規模の現象となった。その要因として、5 月 10～12 日に地球に到来した太陽風が、瞬間的に密度が最大で 50 個/cc を超え、南向き磁場が最大で 50nT を超えるような、通常とはかけ離れた状態であったことが挙げられる。この太陽風構造は、5 月 8～10 日太陽で発生した X クラスフレアを含む複数の太陽フレアとそれに伴う CME が、短期間に連続して発生し相互作用をした結果ではないかと考えられる。これらの CME が一体となって地球に到来し、この宇宙嵐に至ったと考えられるが、その詳細については明らかにすることが難しい。

本研究では、SDO 衛星及び SOHO/LASCO による太陽コロナの観測で観測された当該期間の地球に向かって伝搬した太陽フレア・CME をリストアップし、太陽風中を一連の CME が伝搬する様子を MHD シミュレーション（SUSANOO-CME）によって計算し、in situ で観測された太陽風の構造と、太陽フレア・CME との対応関係についての考察を行った。5 月 8～9 日に発生した複数の CME は、後続の CME の伝搬速度が先行する CME の伝搬速度よりも高く、惑星間空間を伝搬中に追いついて相互作用する様子がみられた。この結果、後続 CME の衝撃波による圧縮が多段階に発生するとともに、3 つ以上の複数の CME が連なった状態で伝搬することで中央に位置する CME の伝搬が阻害され、高速、高密度、強磁場の構造が形成に至る可能性が示唆された。しかし、コロナと in situ で観測された現象の対応関係の同定は難しいため、異なる CME のデータを入力したシミュレーション結果を比較した考察について報告する。

S002-P02
ポスター１：11/24　PM1/PM2 （13:15-18:15）

2024 年 5 月の CME 群の惑星間空間シンチレーション観測と到来予測の可能性

#岩井 一正 [1), 塩田 大幸 [2), 藤木 謙一 [1), 磯貝 拓史 [1)
[(1] 名大 ISEE, [(2] 情報通信研究機構

Interplanetary scintillation observation and predictability of coronal mass ejections in May 2024

#Kazumasa Iwai[1)], Daikou Shiota[2)], Kenichi Fujiki[1)], Hirofumi Isogai[1)]
[(1]Institute for Space-Earth Environmental Research, Nagoya University, [(2]National Institute of Information and Communications Technology（NICT)

Coronal mass ejections (CMEs) cause various disturbances in the solar-terrestrial system. However, their propagation in interplanetary space has not been understood well. In early May 2024, multiple CMEs were generated and some of them arrived at the Earth, that caused severe solar-terrestrial storms. We have investigated these CMEs using the Interplanetary scintillation (IPS) observations. The IPS is a radio scattering phenomenon generated by the disturbances in the solar wind. IPS observation has been one of the most important tools for observing CMEs propagating in interplanetary space. The Institute for Space and Earth Environmental Research (ISEE), Nagoya University has observed IPS at 327 MHz using an observation system consist of three large radio telescopes. We found that an increasing number of large-amplitude IPS responses on 10 May, just before the shock arrival at the Earth. Large-amplitude IPS responses were detected especially in the line of sight in the direction of large solar separation angles, where the ICMEs of interest supposed to be located. Enhancements on IPS responses can be associated with the high-density region where the fast-propagating ICMEs pile up the background solar wind.

The propagation of CMEs observed during this period have been reproduced using the magnetohydrodynamic simulations (SUSANOO-CME). The results suggest that multiple CMEs were generated in a short period of time in the inner heliosphere, forming a dense region with multiple CME-CME interactions. These high-density regions are considered to scatter radio waves significantly and can explain the enhanced IPS response. These results suggest that IPS observations are effective in predicting the time of arrival of the complex CMEs observed in this study. On the other hand, the line of sight of the observed IPS responses were located ahead of the high-density region suggested by the simulation. This discrepancy could be explained by some possibilities, for example, (1) small-scale CMEs that are not included in the magnetohydrodynamic simulations preceded the interplanetary space, (2) the actual CMEs may have been more pushed in the direction of travel than the spheromak used in the modelling, (3) CME propagation could not be reproduced correctly due to poor model accuracy of the background solar wind.

コロナ質量放出（CME）は、太陽地球系に様々な擾乱を引き起こす一方、惑星間空間におけるその伝播については十分に理解されていない。2024 年 5 月初旬、複数の CME が発生し、その一部が地球に到達したことで顕著な磁気嵐を発生させた。本研究では惑星間空間シンチレーション（IPS）観測を用いて、これらの CME の伝搬を調査した。IPS は太陽風の擾乱によって発生する電波の散乱現象であり、惑星間空間を伝播する CME を検出できる有効な観測手法の一つである。名古屋大学宇宙地球環境研究所では、3 台の大型電波望遠鏡からなる観測システムを用いて、327MHz 帯域において IPS 観測を連続的に実施している。その観測結果から CME が地球に到達する直前の 5 月 10 日には、多くの天体から大振幅の IPS 反応が得られていたことがわかった。大振幅の IPS 反応は、観測時間帯に CME が存在すると考えられる太陽離角の大きい視線方向で検出された。観測された IPS 反応の増大は、高速で伝播する CME によって太陽風が圧縮されて形成される高密度領域を検出したものと考えられる。

観測された CME の伝播を電磁流体シミュレーション (SUSANOO-CME) を用いて再現した。その結果、複数の CME が短期間に発生したことで、複数の CME-CME 相互作用を伴う高密度領域が内部太陽圏に形成されていたことが示唆された。このような高密度領域は電波を大きく散乱させると考えられ、強い IPS 反応を説明できる。本結果から、IPS 観測は今回観測された複合した CME 群の観測および到来予測にも効果があることが示唆された。一方、実際観測された IPS 反応の視線は、シミュレーションで示唆された高密度領域に対して前方に位置していた。この違いは例えば、(1) 磁気流体シミュレーションに含まれていない小規模な CME が惑星間空間に先行して存在した、(2) 実際の CME はモデリングで使用したスフェロマクよりも進行方向に押しつぶされた形をしていた、(3) 一部の領域で背景太陽風のモデル精度が悪く CME の伝搬が正しく再現できなかった、などの要因で説明できると考えられる。

S002-P03
ポスター１：11/24　 PM1/PM2 （13:15-18:15）

MHD シミュレーションによる 2024 年 5 月に発生した巨大太陽フレア時の地球磁気圏構造の調査

#深沢 圭一郎 [1], 加藤 雄人 [2], 三宅 洋平 [3], 南里 豪志 [4]
([1] 京大・メディアセンター, ([2] 東北大・理・地球物理, ([3] 神戸大学, ([4] 九州大学・情報基盤研究開発センター

Investigation of Earth's Magnetospheric Structure During the Massive Solar Flare of May 2024 with MHD Simulations

#Keiichiro Fukazawa[1], Yuto Katoh[2], Yohei Miyake[3], Takeshi Nanri[4]
([1]Academic Center for Computing and Media Studies, Kyoto University, ([2]Department of Geophysics, Graduate School of Science, Tohoku University, ([3]Graduate School of System Informatics, Kobe University, ([4]Research Institute for Information Technology Kyushu University

The giant solar flare that occurred in May 2024 was significant enough to generate auroras not only at high latitudes but also at various locations at low latitudes, which indicates a substantial impact on Earth. However, the Earth's magnetosphere cannot be visually observed, and its three-dimensional structure is difficult to comprehend, then the changes of magnetosphere's structure during this solar flare unconfirmed.

In this study, we performed an MHD simulation of the Earth's magnetosphere using the solar wind corresponding to this solar flare as input to see the spatiotemporal variations in the magnetospheric structure. Due to the magnitude of the solar flare, the solar wind fluctuations were significant and it makes challenging to execute the simulation with numerical stability. The simulation model was adjusted accordingly, and a four-day simulation from May 9 to May 12, 2024 (UT) was performed. To obtain preliminary results quickly, the spatial resolution was set to 0.2 Re, and the inner boundary was set at 3.5 Re.

The simulation results showed that the dayside magnetopause was highly compressed and pushed close to the inner boundary. While some results near the inner boundary might not accurately reflect reality, the simulation is considered sufficient for a preliminary global assessment of the magnetospheric structural variations.

2024 年 5 月に起きた巨大な太陽フレアによって、高緯度のオーロラだけで無く様々な場所で低緯度オーロラが観測されており、その太陽フレアの地球に対する影響が非常に大きかったことを示している。一方で、地球磁気圏は可視では確認できず、3 次元的全体構造の理解が難しいため、この太陽フレアに対する磁気圏の構造変化がどのようであったかは確認できていない。

そこで、本研究ではこの太陽フレアに対応する太陽風を入力に地球磁気圏 MHD シミュレーションを行い、磁気圏構造の時空間的変動を調査した。巨大な太陽フレアであったため、太陽風の変動が大きく、数値安定的にシミュレーションを実行することは難しく、シミュレーションモデルを調整しながら、2024 年 5 月 9 日〜5 月 12 日（UT）の 4 日間分のシミュレーションを行った。速報的に計算を行うため、空間解像度は 0.2Re、内側境界を 3.5Re と設定している。

シミュレーション結果では、非常にダイナミックに昼側磁気圏界面が圧縮される様子が確認でき、内側境界に近いところまで圧縮されている場合もあった。内側境界に近づくことでシミュレーション結果が現実的には正しくない場合も含む結果もあると考えられるが、グローバルな磁気圏構造の変動を速報的に確認するには十分と考えられる。

#堀 智昭 [1), 新堀 淳樹 [2), 三好 由純 [3), 桂華 邦裕 [4), 笠原 慧 [5), 横田 勝一郎 [6), 松田 昇也 [7), 笠原 禎也 [8), 松岡 彩子 [9), 篠原 育 [10)
[(1 名大 ISEE, [(2 名古屋大学宇宙地球環境研究所, [(3 名大 ISEE, [(4 東大・理, [(5 東京大学, [(6 大阪大, [(7 金沢大学, [(8 金沢大, [(9 京都大学, [(10 宇宙機構／宇宙研

Transient electric and magnetic field fluctuations and particle acceleration upon the sudden commencement of the May 2024 storm

#Tomoaki Hori[1), Atsuki Shinbori[2), Yoshizumi Miyoshi[3), Kunihiro Keika[4), Satoshi Kasahara[5), Shoichiro Yokota[6), Shoya Matsuda[7), Yoshiya Kasahara[8), Ayako Matsuoka[9), Iku Shinohara[10)
[(1]Institute for Space-Earth Environmental Research, Nagoya University, [(2]Institute for Space-Earth Environmental Research, Nagoya University, [(3]Institute for Space-Earth Environemental Research, Nagoya University, [(4]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, [(5]The University of Tokyo, [(6]Osaka University, [(7]Kanazawa University, [(8]Emerging Media Initiative, Kanazawa University, [(9]Graduate School of Science, Kyoto University, [(10]Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science

Energetic particle acceleration associated with electric and magnetic field fluctuations upon the sudden commencement of a super magnetic storm is investigated by primarily analyzing particle and field data obtained by the Arase satellite. An interplanetary shock that arrived at the Earth late May 10, 2024 strongly compressed the dayside magnetosphere and resulted in a geosynchronous magnetopause crossing, kicking out several other satellites located sunward from Arase (at L ~4.7) to the magnetosheath. Arase, which had barely stayed in the magnetosphere at a magnetic latitude of ~21 deg, observed a stepwise increase of the magnetic field intensity and subsequently transient, huge fluctuations of the electric (~50 mV/m peak to peak) and magnetic (~several tens of nT) field with a period of several minutes. In association with each of the transient field fluctuations, both energetic electrons and ions (~a few tens to a few hundreds of keV) showed transient flux increases with higher energy (>30 keV) protons exhibiting clear pitch-angle dispersions (PADs). The very short (~a few tens of seconds) time scale of each PAD indicates that energetic protons are generated over a wide range of pitch angle around the magnetic equator, then travel along a field line, and finally arrive at the satellite at different timings depending on their parallel velocity. A detailed examination reveals that the PAD appears repeatedly with a period of a few tens of seconds during each of the minute-scale flux increases. The observed repetition signature of PADs strongly suggests that such repeated acceleration processes are embedded even in a single flux increase.

#田 采祐 [1], Miyoshi Y.[1], Hori T.[1], Shiokawa K.[1], Kim K.-H.[2], Bortnik J.[3], Lyons L.[3], Shinohara I.[4], Matsuoka A.[5], Kasahara Y.[6], Matsuda S.[6], Kasaba Y.[7], Teramoto M.[8], Yamamoto K.[1]
([1] 名大 ISEE 研, ([2]Kyung-Hee University, Suwon, Korea, ([3]Atmospheric and Oceanic Sciences, University of California Los Angeles, Los Angeles, USA, ([4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan, ([5]Kyoto University, Kyoto, Japan, ([6]Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan, ([7]Graduate School of Science, Tohoku University, Sendai, Japan, ([8]Kyushu Institute of Technology, Iizuka, Japan

Observations of EMIC waves during the May 2024 geomagnetic storm observed by the Arase satellite and PWING network

#ChaeWoo Jun[1], Y. Miyoshi[1], T. Hori[1], K. Shiokawa[1], K.-H. Kim[2], J. Bortnik[3], L. Lyons[3], I. Shinohara[4], A. Matsuoka[5], Y. Kasahara[6], S. Matsuda[6], Y. Kasaba[7], M. Teramoto[8], K. Yamamoto[1]
([1]Institute for Space-Earth Environmental Research, Nagoya University, ([2]Kyung-Hee University, Suwon, Korea, ([3]Atmospheric and Oceanic Sciences, University of California Los Angeles, Los Angeles, USA, ([4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan, ([5]Kyoto University, Kyoto, Japan, ([6]Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan, ([7]Graduate School of Science, Tohoku University, Sendai, Japan, ([8]Kyushu Institute of Technology, Iizuka, Japan

During the main phase of the storm, electromagnetic ion cyclotron (EMIC) waves are known to origin in the lower L-shell ($L<5$) regions in the afternoon sector. This is due to the developing ring current caused by the strong convective electric field in the inner magnetosphere. We present observations of EMIC wave activities during the great geomagnetic storm on May 2024, using data from Arase satellite and PWING ground-based observation network. For the May 2024 storm, the minimum Dst index was around -403 nT, making it the largest geomagnetic storm of the past decade. The Arase satellite detected several magnetopause crossings at L ˜5-6 during the main and early recovery phase, suggesting that the magnetosphere was significant compressed. This observation indicates that energetic particles are able to penetrate to regions close to the Earth. PWING ground-based observations exhibit special types of Pc1 pulsations such as the dayside interval of pulsations of the demisting period (IPDP) during the main and early recovery phases at sub-auroral and low-latitudinal stations and several continuous Pc1 pulsations with frequencies of 1-2 Hz during the late recovery phase. In particular, the Arase observations show that high-frequency EMIC waves have a frequency range of 5-36 Hz at L ˜2 during the early recovery phase at 18 MLT and 7-8 MLT. We will investigate their characteristics (e.g., polarization sense, wave normal angle, Poynting vector, spatial distributions) and possible free energy sources for these waves by comparing our observations with model calculations (e.g., dispersion relation, the minimum resonant energy for protons and electrons). Our observations provide new insights into the generation processes of EMIC waves and the dynamics of the inner magnetosphere during an intense geomagnetic storm.

S002-P06
ポスター１：11/24　PM1/PM2 （13:15-18:15）

2024年5月磁気嵐に伴った西向き地磁気変化

#小河 勉 [1)]
(1 東大・地震研

Westward geomagnetic change accompanying a magnetic storm in May 2024

#Tsutomu OGAWA[1)]
(1Earthquake Research Institute, the University of Tokyo

Accompanying the magnetic storm in May 2024, appearance and disappearance of westward geomagnetic change in the end of the main phase or the beginning of the recovery phase were observed at geomagnetic observatories and stations in Japan including Yatsugatake Geoelectromagnetic Observatory (YAT), Earthquake Research Institute, the University of Tokyo. Its quantitative description is presented.

Provisional geomagnetic records from 18:00, May 10 to 18:00, May 11, 2024, in UT at 32 geomagnetic observatories and stations which are YAT, 11 observatories and stations of Geospatial Information Authority of Japan, and 20 INTERMAGNET observatories of which longitudes are close to that of Japanese island arc and geomagnetic latitudes are between -50 and 50 degrees are analyzed. Identifying in the geomagnetic records for 24 hours both the trend components by polynomial approximations, and the shorter-period components which correlate at observatories and stations by the empirical orthogonal function analysis, these components are removed from original geomagnetic records.

The residuals show that the westward geomagnetic change between approximately 03:00 and 09:00 on May 11 is found at the observatories and stations remarkably in the northern hemisphere. Its amplitude at YAT amounts to approximately 90nT. It took approximately 10 and 30 minutes for the appearance and disappearance, respectively, of the westward geomagnetic change, while for approximately 320 minutes the change was stably holded. The amplitude was larger at higher latitude in the northern hemisphere: 30nT par 10 geomagnetic latitudes, while almost unseen in the southern hemisphere. As for the vertical component, downward change which amounts approximately to 40nT at YAT is found. Geomagnetic latitude dependency is less dominant. Since at Hawaii the westward and downward geomagnetic change is not clearly seen, it is presumed that the geomagnetic change appears in the dayside region.

Clarification of the electric current system causing the westward geomagnetic change which is prominent in the dayside is expected.

2024年5月の磁気嵐に伴い、東大地震研究所八ヶ岳地球電磁気観測所 (YAT) を初めとする国内の地磁気観測所・観測点において、主相の終盤ないし回復相の初期に西向き地磁気変化の発生と消滅が確認された。本発表はその特徴を定量的に抽出し、その結果を記述するものである。

東大1点、国土地理院11点、及び INTERMAGNET から日本列島と経度が近く磁気緯度が± 50 度以内の南北半球の20点を選び、合計32地点の地磁気データ暫定値の3成分について、世界時5月10日18時から11日18時までを解析した。24時間のデータからトレンド成分を多項式近似で、また全点の3成分で相関のある短周期成分を経験的直交関数解析で同定し除去した。

その結果、11日3時頃に始まり9時頃に終わる西向き地磁気変化が、北半球の地点において特に顕著に見出された。YAT における西向き地磁気の変化量は約 90nT であった。西向き地磁気の発生と消滅の所要時間はそれぞれ約10分及び約30分で、継続時間約5時間20分の間、概ね一定の値をとる特徴があった。振幅は、南半球では顕著には見られない一方、北半球では高緯度ほど大きく、磁気緯度10度につき 30nT 程度の増加量であった。地磁気鉛直成分では下向き変化を伴い、YAT では約 40nT、磁気緯度による顕著な変化はない。ハワイでは西向きかつ下向きの顕著な地磁気変化が見られないため、昼側の領域で見られた現象と推測される。

この昼側で顕著な西向き地磁気変化の要因となる電流系の解明が期待される。

S002-P07
ポスター１：11/24　PM1/PM2 （13:15-18:15）

2024年5月イベント時の南極昭和基地における電離圏変動

#垰 千尋 [1), 西岡 未知 [1), 近藤 巧 [1), 永原 政人 [1), 前野 英生 [1), 津川 卓也 [1)
(1 情報通信研究機構

Ionospheric variations observed at Syowa Station, Antarctica during the May 2024 space weather event

#Chihiro Tao[1), Michi Nishioka[1), Takumi Kondo[1), Masato Nagahara[1), Hideo Maeno[1), Takuya Tsugawa[1)
(1National Institute of Information and Communications Technology

The National Institute of Information and Communications Technology (NICT) has been conducting continuous ionospheric observations at the Syowa Station in Antarctica for over 60 years. Currently, vertical ionospheric observations using ionosondes and ionospheric scintillation observations are being carried out. The major space weather event in May 2024 included frequent occurrence of solar X-class flares, solar wind disturbances caused by multiple coronal mass ejections, and high-energy solar proton particles. This resulted in significant geomagnetic storms and ionospheric disturbances observed globally. Ionospheric observations at Syowa Station in Antarctica, located at 39.58°　E and 69°　S, shows shortwave radio absorption on May 10, 11, and 16 local time (= UTC+3h), and negative phase storms from May 11 to 13. Phase scintillation index also increases from May 10 to 13. We will introduce and discuss the relationship between these ionospheric variations and energy input, as well as comparisons with medium- and small-scale space weather events in this presentation.

情報通信研究機構では、南極昭和基地において60年以上にわたり電離圏定常観測を行っている。現在、イオノゾンデを用いた電離圏垂直観測と衛星電波シンチレーション観測を実施している。2024年5月の巨大宇宙嵐イベントは、数日間にわたり頻発したXクラスを含む太陽フレアや、複数のコロナガス放出による太陽風擾乱、太陽高エネルギー粒子の地球環境への到来があり、大きな地磁気嵐および電離圏擾乱が全球的に観測された。東経39.58度、南緯69度に位置する南極昭和基地における電離圏観測では、現地時間(=UTC+3時間)5/10・11・16に短波帯電波吸収が見られ、5/11-13にかけて負相嵐が見られた。位相シンチレーションも5/10-13にかけて増大が見られた。エネルギー流入や印加電場との対応関係や、中低規模の宇宙嵐イベントとの比較について本発表で紹介する。

S002-P08
ポスター１：11/24　PM1/PM2 （13:15-18:15）

#細川 敬祐 [1), ジャッケリー ピーター [2), 尾花 由紀 [3)
[(1] 電通大, [(2] ダニーデン天文協会, [(3] 九州大学 国際宇宙惑星環境研究センター

Southern hemispheric aurora during the Mother's day storm: a color all-sky camera observation in New Zealand

#Keisuke Hosokawa[1)], Peter Jaquiery[2)], Yuki Obana[3)]
[(1]University of Electro-Communications, [(2]Dunedin Astronomical Society, [(3]International Research Center for Space and Planetary Environmental Science, Kyushu University

We have been operating a small color all-sky camera at Middlemarch (－ 45.6°　S, 170.1°　E, MLAT = － 52.75°　, L = 2.77) in the South Island of New Zealand. This optical system consists of a small color CCD camera (WAT-221S2) from Watec Co. Ltd., Japan, paired with a fish-eye lens (YV2.2X1.4A-SA2, Fujinon Co. Ltd.). Color images are captured every minute with an exposure time of 4.3 seconds, using a USB video encoder (PCA-DAV2), and saved as JPEG files at a resolution of 640 × 480 pixels. The CCD camera is controlled by a Raspberry Pi3 equipped with a GPS receiver and operates when the Sun is well below the horizon. The entire system is powered by solar cells and batteries, shared with the fluxgate magnetometer system operative at the same observatory. The primary objective of this observation is to detect proton aurorae at the low-latitude edge of the sub-auroral region, a phenomenon associated with EMIC waves in the magnetosphere. Since the start of the observations in 2018, however, signatures of aurora have not yet captured near the central part (zenith) of the field-of-view.

On the night of May 11, 2024, i.e., the second local night during the Mother's day magnetic storm, the camera was operational for approximately 7.5 hours, from 06:32 to 14:00 UT. When the camera began recording, a less structured magenta aurora already covered nearly the entire sky. This phase of magenta aurora persisted for about 30 minutes, until around 07:10 UT. Subsequently, the camera observed multiple instances of image saturation caused by intense auroral displays, likely indicating auroral breakups in the lower sub-auroral region. Concurrently, the fluxgate magnetometer observed significant fluctuations, with amplitudes estimated to be at least 500 nT. The actual fluctuations likely exceeded this value, but they were beyond the detectable range of the instrument. Several sharp decreases and increases were detected in the local magnetic north component, which likely corresponded to the explosive brightening of the aurora captured in the optical data.

In this presentation, we will first provide an overview of the morphological features of this storm time aurora by showing the color keogram, with particular emphasis on the transition of the color of aurora. Additionally, we will present space-based optical data from the DMSP/SSUSI instrument, comparing these with the ground-based observations from New Zealand. Finally, we will discuss the factors driving the change of the color of aurora from magenta to a mix of green and red, in close relation to the development of the magnetic storm.

S002-P09
ポスター１：11/24　PM1/PM2（13:15-18:15）

2023-2024 年に日本で 7 回観測された低緯度オーロラの特徴

#塩川 和夫 [1), 大塚 雄一 [2), 西谷 望 [3), 南條 壮汰 [4), 片岡 龍峰 [5)
([1] 名大宇地研, ([2] 名大・宇地研, ([3] 名大 ISEE, ([4]Swedish Institute of Space Physics（IRF), ([5] 極地研

Characteristics of low-latitude red/green/blue auroras observed seven times in Japan in 2023-2024

#Kazuo Shiokawa[1)], Yuichi Otsuka[2)], Nozomu Nishitani[3)], Sota Nanjo[4)], Ryuho Kataoka[5)]
([1]Institute for Space-Earth Environmental Research, Nagoya University, ([2]Institute for Space-Earth Environmental Research, Nagoya University, ([3]Institute for Space-Earth Environmental Research, Nagoya University, ([4]Swedish Institute of Space Physics（IRF), ([5]National Institute of Polar Research

The glowing solar activity in cycle 25 has been causing characteristic low latitude auroras observed in Japan seven times in 2023-2024. This number is much larger than that in the previous cycle 24 (only two times in 2009-2020). These low-latitude auroras were observed on 27 February, 24 April, 5 November and 1 December in 2023 and 11 May, 28 June, and 12 August in 2024 at Moshiri (44.37N, 142.27E, MLAT=35.6) and Rikubetsu (43.46N, 143.77E, MLAT=34.7), Japan. These observatories are operated by the Institute for Space-Earth Environmental Research (ISEE), Nagoya University. The 11 May 2024 event was also observed at the Shigaraki MU Observatory, Kyoto University (34.85N, 136.11E, MLAT=25.4), Japan. All of them were characterized by red 630-nm emissions, while two of them were also accompanied by rather strong 557.7-nm (green) emission (stronger than 630-nm emission) on 27 February 2023 and 427.8 nm (blue) emissions on 11 May 2024. The blue emission on 11 May 2024 was also identified in color cameras by amateur astronomers, showing longitudinal structures with scale sizes of several hundred kilometers, appearing associated with a storm-time substorm. The blue low-latitude auroral emission has been considered as a manifestation of precipitation of energetic neutral atoms from the ring current. However, visible longitudinal structures pose a question on this consideration. In the presentation we will summarize the characteristics of these seven low-latitude auroras observed in Cycle 25, and compare and discuss them with the low-latitude auroras previously observed in Japan by ISEE, Nagoya University.

サイクル 25 の太陽活動極大期における 2023 年から 2024 年にかけて、名古屋大学宇宙地球環境研究所では 7 回、低緯度オーロラを日本の北海道で観測してきた。この回数は、サイクル 24（2009～2020 年）における 2 回をすでに大きく超えており、今太陽周期が、前の周期と比べて大きく異なっていることを表している。これらの低緯度オーロラは、2023 年は 2 月 27 日、4 月 24 日、11 月 5 日、12 月 1 日、2024 年は 5 月 11 日と 6 月 28 日、8 月 12 日に、北海道の母子里観測所（北緯 44.37 度、東経 142.27 度、磁気緯度 35.6 度）と陸別観測所（北緯 43.46 度、東経 143.77 度、磁気緯度 34.7 度）で観測された。2024 年 5 月 11 日は滋賀県の京都大学生存圏研究所の信楽 MU 観測所（34.85N, 136.11E,MLAT=25.4）でも観測された。いずれも 630nm の赤色発光であったが、2023 年 2 月 27 日には 557.7nm（緑色）、2024 年 5 月 11 日には 427.8nm（青色）の強い発光も観測された。2024 年 5 月 11 日の青色発光は、アマチュア天文家によるカラーカメラでも確認され、嵐の時のサブストームと思われる数百 km の経度構造を示している。低緯度の青いオーロラ発光は、リングカレントからの高エネルギー中性原子の降り込みによると考えられてきた。しかし、目に見える経度方向の構造は、この考察に疑問を投げかけている。講演では、サイクル 25 に観測されたこれら 7 回の低緯度オーロラの特徴をまとめ、これまでに名古屋大学宇宙地球環境研究所が日本で観測してきたオーロラとの比較・考察を行う。

S002-P10
ポスター１：11/24　PM1/PM2 （13:15-18:15）

2024 年 5 月の磁気嵐中に日本で観測された全電子数増大及び電子密度擾乱

#大塚 雄一 [1), 塩川 和夫 [1), 新堀 淳樹 [1), 山本 衛 [2), 横山 竜宏 [2), 西村 耕司 [2), 西岡 未知 [3), Perwitasari Septi[3)
[(1] 名古屋大学宇宙地球環境研究所, [(2] 京都大学生存圏研究所, [(3] 情報通信研究機構

Total Electron Content Enhancement and Irregularities Over Japan During a Magnetic Storm on May 2024

#Yuichi Otsuka[1)], Kazuo Shiokawa[1)], Atsuki Shinbori[1)], Mamoru Yamamoto[2)], Tatsuhiro Yokoyama[2)], Koji Nishimura[2)], Michi Nishioka[3)], SEPTI PERWITASARI[3)]
[(1]Institute for Space-Earth Environmental Research, Nagoya University, [(2]Research Institute for Sustainable Humanosphere, Kyoto University, [(3]National Institute of Information and Communications Technology

In May 2024, a super geomagnetic storm with a SYM-H minimum value of -512 nT occurred. This study analyzes global Total Electron Content (TEC) obtained from Global Navigation Satellite System (GNSS) receivers, thermospheric neutral wind from a Fabry-Perot interferometer (FPI) in Darwin, Australia, and plasma drift velocity observed by the MU radar in Shigaraki, Japan. The GNSS-TEC map shows that TEC enhancement with an amplitude of approximately 20 TECU appeared around (40^oN, 150^oE) at approximately 12 UT (21 JST) on May 11, 2024 and extended northwestward. This feature is similar to Storm-Enhanced Density (SED). After 13 UT (22 JST), ionospheric irregularities, indicated by the Rate Of TEC change Index (ROTI), were observed at the poleward edge of the TEC enhancement. The ROTI enhanced region also extended northwestward. Simultaneously, ROTI enhancement also appeared over Australia in the southern hemisphere, suggesting a geomagnetic conjugate structure of the ROTI enhancement. Zonal winds observed by the FPI in Darwin were approximately 80 m/s westward on average from 13 to 20 UT on May 11. The zonal plasma drift velocity observed by the MU radar in Japan was approximately 70 m/s westward at 13 UT (22 JST). We found that TEC depletions are embedded within the TEC enhancement and coincide with ROTI enhancement, indicating the presence of plasma bubbles. These results suggest that the westward extension of the TEC enhancement and the plasma density irregularities could be caused by westward ExB plasma drift driven by westward disturbance winds. From the temporal variation of the ROTI enhancement on the global map, we find that the ROTI enhancement is initiated around the magnetic equator at a longitude of 180° E around 8 UT (local post-sunset) and moves westward, extending poleward. These results suggest that plasma bubbles generated at the magnetic equator during local post-sunset extend to higher latitudes and that both the plasma bubbles and the surrounding dense plasma move westward due to ExB plasma drift caused by the westward disturbance winds.

S002-P11
ポスター１：11/24　PM1/PM2 （13:15-18:15）

#北島 慎之典 1), 渡邉 恭子 1), 陣 英克 2), 垰 千尋 2), 増田 智 3), 西岡 未知 2)
(1 防衛大, (2 情報通信研究機構, (3 名大

Evaluation of electron density variation using PHITS and GAIA models during solar flares in May 2024

#Shinnosuke Kitajima[1)], Kyoko Watanabe[1)], Hidekatsu Jin[2)], Chihiro Tao[2)], Satoshi Masuda[3)], Michi Nishioka[2)]
(1National Defense Academy of Japan, (2National Institute of Information and Communications Technology, (3Nagoya University

High-frequency (HF) radio communication is an important method often used in disaster response and air traffic control because of its capability for long-distance communication using reflections in the ionosphere. However, a rapid increase in X-ray emissions due to solar flares causes a rapid increase in the electron density in the lower ionosphere, and often making HF radio unusable. In May 2024, more than 10 X-class flares occurred, causing various space weather phenomena, including global occurrences of communication failures known as HF radio shortwave fadeouts (SWFs). SWFs were recorded in Japan more than 10 times during this period. In order to know the occurrence of these SWFs and their magnitude, it is necessary to estimate the fluctuations in electron density in the ionosphere accurately.

In this study, we use the GAIA model (Jin et al., 2011) and PHITS code (Sato et al., 2024) to estimate the electron density variation during solar flare. The GAIA is one of the effective numerical simulation models for the whole global atmosphere, providing electron density variations throughout the ionosphere in solar flare emissions. However, it still does not account for photochemical reactions in the ionosphere below 100 km. Therefore, we use PHITS, which is a particle transport and collision simulation code using the Monte Carlo method, to reproduce electron density variations in the lower ionosphere due to flare X-ray emission, and then to compensate for the electron density in the lower ionosphere.

The occurrence and magnitude of SWF can be known from the minimum frequency in the ionogram (f_{min}). From the ionogram of the ionosonde operated by NICT, we found that a strong SWF occurred in Japan on 11 May 2024 from 1:00 to 3:00 (UT) associated with the X5.8 class flare. In particular, a blackout was recorded at the ionosonde in Kokubunji for about an hour starting at 1:20 (UT). In this presentation, we will report an assessment of the electron density variability on 11 May 2024 by comparing the electron density determined using the PHITS and GAIA models with data observed by ionosondes in Japan. Additionally, we also discuss the SWFs caused by other flares that occurred in May 2024.

S002-P12
ポスター１：11/24　PM1/PM2（13:15-18:15）

LF 帯標準電波を用いた 2024 年 5 月 11 日に発生した X5.89 クラス太陽フレア発生時における D 領域電離圏振動

#久保田 朱音 [1], 大矢 浩代 [1], 土屋 史紀 [2], 中田 裕之 [1]
([1] 千葉大, ([2] 東北大・理・惑星プラズマ大気

Oscillation in the D-region ionosphere during a X5.89 class solar flare of 11 May, 2024 using LF transmitter signals

#Akane Kubota[1], Hiroyo Ohya[1], Fuminori Tsuchiya[2], Hiroyuki Nakata[1]
([1]Graduate School of Science and Engineering, Chiba University, ([2]Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University

When solar flares occur, X-rays increase and then electron density in the ionosphere (60-1000 km altitude) increases. This can cause problems with satellite attitude control, satellite communication problems, and reduced GPS positioning accuracy. To validate these effects, it is necessary to more accurately quantify the increase in ionospheric plasma density caused by solar flares, although this has not yet been precisely clarified. Previous studies for VLF (very low frequency, 3-30 kHz)/LF (low frequency, 30-300 kHz) transmitter waves have shown that the amount of reflected height decrease in the D-region ionosphere tends to differ with respect to the solar zenith angle at the midpoint of the path depending on the class of solar flares, and that electron density variation due to solar flares is estimated to be smaller for north-south and east-to-west propagation (Nakayama et al., 2024). Thus, the response of the D-region ionosphere to solar flares remains unclear. In this study, we investigate the D-region ionospheric variations using the LF transmitter signals for a solar flare of the X5.89- class that occurred at 01:10 UT on May 11, 2024 and was the largest solar flare among the consecutive solar flares that occurred in May 2024. The LF transmitter signals used in this study were OCTAVE/AVON data operated by this research group in the Asian region. The LF waves were transmitted from JJY60 (60.0 kHz) in Japan and BPC (68.5 kHz) in China, and received at Pontianak (PTK) in Indonesia. During the X5.89- class solar flares, the LF phases oscillated, which was rare phenomenon. Normally, when a solar flare occurs, the time variation is similar to that of the X-ray flux, although a periodic variations in LF phases were observed during the flare. Based on wavelet analysis of these oscillations, the periods were 549 s for the phase of the JJY60-PTK path and 349 s for the phase of the BPC-PTK path, respectively. The geomagnetic data observed at Kakioka and Kagoshima at this time were compared, although no relationship was found. In this session, detailed results will be reported.

太陽フレアが発生すると、X 線が増加し、電離圏（高度 60-1000 km) の電子密度が増加する。これは人工衛星の姿勢制御等のトラブルや衛星通信障害、GPS 測位精度低下などの要因となる。これらの影響をより適切に評価するため、太陽フレアによって引き起こされる電離圏のプラズマ密度の増加をより正確に定量化する必要があるが、まだ正確には明らかになっていない。先行研究では、太陽フレアの規模により、VLF (very low frequency, 3-30 kHz)/LF(low frequency, 30-300 kHz) 帯標準電波の電離圏での反射高度低下量はパスの中点の太陽天頂角に対して異なる傾向が見られることや、南北伝搬や東→西伝搬の場合、太陽フレアによる電子密度変動量が少なく推定されることが報告されている。(Nakayama et al., 2024) このように、太陽フレアに対する D 領域電離圏の応答が明らかになっていない。そこで本研究では、2024 年 5 月 11 日 01:10 UT に発生し、連続発生した太陽フレアの中でも最大規模となる X5.89 クラスの太陽フレアについて LF 帯標準電波を用いて D 領域電離圏変動を調べた。本研究で使用した LF 帯標準電波はアジア域で本研究グループが運用している OCTAVE/AVON 観測ネットワークで運用されているものである。日本に位置する JJY60（60.0 kHz）および中国に位置する BPC（68.5 kHz）から送信し、インドネシアのポンティアナにある PTK で受信された標準電波データを用いた。その結果、X5.89 クラスの太陽フレア時に、通常の変化と異なる位相の振動が見られた。通常は太陽フレアが発生すると、X 線フラックスと同様の時間変化をするが、今回観測した結果では、フレア発生後に周期的な変動が見られた。この変動をウェーブレット解析した結果、JJY60-PTK パスの位相では 549 s、BPC-PTK パスの位相では 349 s の周期であることが分かった。この時の柿岡と鹿児島で観測された地磁気データと比較したが関連性は見られなかった。セッションでは、詳細な結果を報告する。

#田中 友啓 [1)], 小川 泰信 [1,2)], 田中 良昌 [1,2,3)], 門倉 昭 [2,3)], 吹澤 瑞貴 [2)], 村瀬 清華 [2)], 細川 敬祐 [4)], 大山 伸一郎 [2,5)], Kero Antti[6)]
[(1] 総研大, [(2] 極地研, [(3]ROIS-DS, [(4] 電通大, [(5] 名大 ISEE, [(6] オウル大 SGO

Frequency dependence of CNA due to various sources observed by spectral riometers during the May 2024 storm

#Tomotaka Tanaka[1)], Yasunobu Ogawa[1,2)], Yoshimasa Tanaka[1,2,3)], Akira Kadokura[2,3)], Mizuki Fukizawa[2)], Kiyoka Murase[2)], Keisuke Hosokawa[4)], Shin ichiro Oyama[2,5)], Antti Kero[6)]
[(1]The Graduate University for Advanced Studies, SOKENDAI, [(2]National Institute of Polar Research, [(3]Joint Support-Center for Data Science Research, ROIS, [(4]The University of Electro-Communications, [(5]Institute for Space-Earth Environmental Research, Nagoya University, [(6]Department of Physical Sciences, University of Oulu, SGO

A spectral riometer measures cosmic noise absorption (CNA) in the frequency between 20-55 MHz and is expected to have an ability to estimate the altitude profile of the electron density especially in the lower ionosphere. In the May 2024 solar magnetic storm event, spectral riometers in the arctic region; in Kilpisjärvi (KIL, 69.07° N 20.75° E) and in Oulujarvi (OUJ, 64.52° N, 27.23° E) etc., observed a number of CNA enhancements. During this event, the CNA enhancements were caused by three different sources: solar X-rays, solar energetic protons, and energetic electrons from the magnetosphere, known as major sources of ionization in the atmosphere. These three types of events may have different altitude profiles of ionization. The CNA is expected to be proportional to the − 2 power of the observed frequency when the electron density enhancement occurs at higher altitudes (>70 km), while the CNA would be proportional to between − 1 and − 2 power of the frequency when the enhancement occurs at altitude lower than 70 km. Therefore, we will investigate the frequency dependence of these three types of the CNA events. At around noon on May 11, for example, an intermittent strong CNA was observed by the riometers, when an X-class solar flare occurred at 13:30 UT, and an increase of energetic proton (>10 MeV) flux was also measured by the GOES satellite. Note that the solar zenith at noon on the day at that location was 52.6 degrees. In the presentation, we will show how the frequency dependence of the CNA spectra differs between the three types of ionization agent, and then discuss the mechanism behind such dependencies.

S002-P14
ポスター１：11/24　PM1/PM2 （13:15-18:15）

高エネルギー粒子降下による南極昭和基地上空での中間圏オゾン濃度変動

#鈴木 ひかる [1], 土屋 史紀 [1], 水野 亮 [2], 村田 功 [1], 笠羽 康正 [1], 長浜 智生 [2], 後藤 宏文 [2]
([1] 東北大学, ([2] 名古屋大学宇宙地球環境研究所

Variations in the ozone concentration in the mesosphere at Syowa station associated with energetic particles precipitation

#Hikaru Suzuki[1], Fuminori Tsuchiya[1], Akira Mizuno[2], Isao Murata[1], Yasumasa Kasaba[1], Tomoo Nagahama[2], Hirohumi Goto[2]
([1]Tohoku university, ([2]ISEE, Nagoya university

We report variations in ozone concentration in the mesosphere above Syowa station, Antarctica, caused by energetic particle precipitation (EPP) associated with a major magnetic storm that occurred from May 10th to 11th, 2024. The goal of this study is to clarify the decrease in O3 concentration in the mesosphere associated with EPP during night.

In polar regions, EPP are associated with solar proton events and magnetic storms. The higher the energy of these particles, the lower the altitude of the precipitate. If an electron has an energy of approximately 300 keV or higher, it precipitates at an altitude below 70 km. The ionization of atmospheric molecules induced by the EPP produces nitrogen oxide(NOx) and hydrogen oxide in the mesosphere, which could cause O3 destruction. In addition to the direct effect of EPP, EPP may have an indirect effect on O_3 in the lower atmosphere through the transport effects. NOx produced in the lower thermosphere can reach the upper stratosphere via polar winter descent, where it can participate in catalytic reactions that destroy O_3. Since O_3 is a significant component distributed across a wide range of altitudes and has a crucial impact on climate, it is necessary to investigate the effects of EPP.

We used a millimeter-wave spectroradiometer installed by Nagoya University at Syowa station in Antarctica. Long-term observations of the spectral lines of nitric oxide (NO) and O_3 began in 2012. In 2022, simultaneous observations of two O3 emission lines in the 250 GHz band carbon monoxide (CO) emission lines in the 230 GHz band, and six NO emission lines in the 250 GHz band were started. The spectrum observed by the millimeter-wave spectroradiometer on the ground is an integration of the O3 radiation over altitudes from the surface to the lower thermosphere. We retrieved the altitude distribution of the O3 volume mixing ratio (VMR) from the radiation spectra to quantitatively estimate the O3 concentration in the mesosphere. The observed spectra used for the retrieval are integrated over one hour. When the optical depth varies significantly with time due to weather conditions, the data are excluded from the analysis. Thus, up to 24 O_3VMR profile data are obtained per hour per observation day. The retrieval tool uses the O3 height distribution obtained by the MLS satellite as an a-priori distribution and estimates the vertical distribution of O3VMR from the model spectrum that best matches the observed spectrum, using the NASA-JPL molecular spectroscopy catalog and the meteorological vertical profile data from MERRA2. Since the altitude distribution of O3 is affected by sunlight, a-priori distributions for daytime and nighttime are switched at times of sunset and sunrise.

We have analyzed the data from May 1st to 23rd. From May 10th to 11th, an increase in the flux of protons with energies above 100 MeV was confirmed from GOES satellite data. No clear increase was observed in the EPP flux data over Syowa station from the POES satellite. The riometer installed at Syowa station confirmed an increase in precipitating electrons between 17:00 UT and 18:30 UT on May 10th. We found a decrease in the mesospheric (60 – 70 km) O_3 column amount during the night from May 10th to 11th. The decrease in the average O_3 column amount during that night with the previous night was approximately 0.035 D.U., which represents the largest change in the daily mesospheric O_3 column amount during the analysis period. When examining the hourly changes in the mesospheric O_3 concentration profiles from 15:00 on May 10th (LT18:00 at Syowa station) to 3:00 on May 11th (LT6:00), a decrease was observed from around LT19:00 to LT22:00. This was followed by an increase LT22:00 to LT23:00 and another decrease from LT23:00 to LT06:00. This pattern differs from the typical diurnal variation in O_3 column amounts. In addition to the major magnetic storm from May 10th to 11th, moderate magnetic storms ranging from -50 to -100nT occurred in May 2024, leading to increased proton and electron precipitation. In this presentation, we will report variations in the O_3 concentration in the mesosphere over Syowa station associated with EPP during May 2024.

2024 年 5 月 10 日から 11 日に発生した巨大磁気嵐に伴う高エネルギー粒子降込み (EPP) による南極昭和基地上空中間圏でのオゾン (O_3) 濃度変動の解析結果を報告する。本研究は、EPP に伴う中間圏の夜間 O_3 濃度減少を観測により検証することを目標としている。

地球極域では、太陽フレアやコロナ質量放出に伴う太陽高エネルギー粒子の発生や、磁気嵐に伴う磁気圏内の高エネルギー電子の散乱などによって、EPP が起こる。これらの粒子は、エネルギーが高いほど低い高度まで降下する。電子の場合、約 300keV 以上のエネルギーを持つと中間圏の高度である 70km 以下まで降下する。EPP が引き起こす大気分子のイオン化反応の結果、窒素酸化物 (NOx) や水素酸化物が生成され、それらが触媒として働き、中間圏 O3 を破壊すると言われている。このような EPP の O_3 に対する直接的な影響に加え、中層大気の輸送効果によって間接的に下層大

気の O_3 に影響を与える可能性もある。具体的には、下部熱圏などの高高度で生成された NOx が、極域の冬の大気下降輸送によって上部成層圏に到達し、O_3 を破壊する触媒反応などである。O_3 は、広い高度領域にわたり分布する成分であり、気候や大気輸送に影響を与える非常に重要な物質であるため、EPP による影響を調べる必要がある。

使用した観測装置は、名古屋大学が南極昭和基地に設置しているミリ波分光放射計である。2012 年から一酸化窒素 (NO) と O3 の線スペクトルの長期観測を開始され、2022 年からは 230GHz 帯の一酸化炭素 (CO) 輝線、250GHz 帯の 2 本の O3 輝線、6 本の NO 輝線の同時観測が可能となった。この装置が観測するスペクトルは、地表から熱圏下部の高度にわたる O3 放射の積分である。このため、リトリーバルと呼ばれる、放射スペクトルから高度分布の導出する処理を行い、中間圏での O3 体積混合比 (VMR) を定量的に推定する。リトリーバルでは、初期値に MLS 衛星が得た O3 高度分布を与え、NASA-JPL の分子分光カタログと MERRA 2 の気象場鉛直プロファイルデータを用いて、観測スペクトルと最も合致するモデルスペクトルから O3VMR プロファイルを推定する。O3 の高度分布は日照 (太陽紫外線) の影響を受けるため、初期値は、日の出から日の入りまでの時間帯では昼用、日の入りから日の出までの時間帯では夜用に切り替える。リトリーバルに用いる分光スペクトルは 1 時間積分値であり、天候によって光学的厚さの時間変動が大きい日時の観測は解析対象から除外する。したがって、観測 1 日あたり、1 時間ごとに最大 24 個の O_3VMR プロファイルデータが得られる。

現在までに 5 月 1 日~23 日のデータについて解析を実施した。5 月 10 日から 11 日にかけて、GOES 衛星のプロトンフラックスデータから、100MeV 以上のプロトンのフラックス増加が確認できた。POES 衛星の昭和基地上空の電子フラックスデータには、明確な増加は確認できなかった。しかし、昭和基地に設置されたリオメーターで電子フラックスの空間分布を確認したところ、5 月 10 日 17 時から 18 時半にかけて降下電子の増大が確認できた。5 月 10 日から 11 日の中間圏 (60~70km)O_3 カラム量の一晩平均と、前日の O_3 カラム量の一晩平均を比較すると、0.035D.U. 程度の減少が見られた。これは解析期間中の 1 日あたりの中間圏 O_3 カラム量の変化量としては、最大の変化量である。5 月 10 日 15 時 (昭和基地の LT18 時) から 5 月 11 日 3 時 (LT6 時) の 1 時間ごとの中間圏 O_3 濃度プロファイル変化を確認すると、LT19 時から LT22 時にかけて減少が見られた。その後、LT22 時から LT23 時にかけて増加し、20 時 (LT23 時) から 3 時 (LT6 時) にかけて再度減少していることが確認された。この変化は、典型的な O_3 カラム量の日変動とは異なる傾向であるため、さらに詳しい解析を進める予定である。2024 年 5 月は地磁気活動が非常に活発で、巨大磁気嵐が起きた 10 日から 11 日以外にも、-50 から-100nT 程度の中規模磁気嵐が頻繁に発生しており、それに伴うプロトンや電子の降込みが見られる。本講演では、それらの期間を含む 2024 年 5 月 1 か月間の解析結果を報告する。

S002-P15
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#福島 光太郎 [1)]
[(1]JAXA 宇宙研

XRISM in Storms: Observations and Operations in the Maximum of 25 Solar Cycle and Possible Effects on the X-ray Data Analysis

#Kotaro Fukushima[1)]
[(1]Japan Aerospace Exploration Agency/Institude of Space and Astronautical Science

X-ray Imaging and Spectroscopy Mission (XRISM, pronounced as crism), which was launched in September 2023, is an X-ray astronomy satellite equipped with a microcalorimeter detector called Resolve with an energy resolution of 5 eV@6 keV in orbit and a CCD camera called Xtend that offers a wide field of view (FoV) ˜38' x 38'. After the commissioning phase to confirm the performance of these instruments, XRISM began regular operation; and until August 2024, it has observed targets selected by the XRISM project team. From this September, XRISM will begin scientific observations based on proposals by general observers as a public observatory open to the world. As XRISM aims to elucidate the structural and chemical evolution and energy transport of the universe, it is scheduled to observe various objects such as galaxy clusters and black holes.

Simultaneously, the 25th solar cycle is nearing its peak, resulting in a surge of vigorous solar activity characterised by significant solar flares and coronal mass ejections. Previous X-ray observatories like Suzaku have demonstrated the detectability of X-ray emission from solar wind charge exchange (SWCX, e.g., Fujimoto et al., 2007; Ezoe et al., 2011; Ishi et al., 2019). Emissions that take place within the Earth's magnetosphere contribute to foreground emission in the observations of various objects, both inside and outside the Galaxy. In fact, during the huge geomagnetic storm that occurred in May 2024, the Xtend detector observed the CX spectrum with a high photon statistic thanks to its large FoV. On the other hand, one would analyse a wide area in the FoV to derive gas temperature and density of diffuse emissions from, e.g., galaxy clusters stated above. Thus, it is even more important to estimate the intensity of foreground components accurately, such as SWCX emission, and understand their properties. Moreover, the adverse effects of serious magnetic disturbances driven by solar activity on satellite operation, such as the reduction in the orbital altitude, have been recognised as an issue. Then, the XRISM science operations team is also showing interest in space weather forecasting. In this presentation, we will discuss the XRISM satellite during the upcoming solar maximum from the perspectives of impacts on scientific observations and satellite operations, referring to examples of space storms that occurred during XRISM observations.

2023 年 9 月に打ち上げられた XRISM 衛星は、軌道上で 5 eV@6 keV のエネルギー分解能を実現したマイクロカロリメータ検出器 Resolve と、38' x 38' もの広い視野をもつ CCD カメラ Xtend を搭載した X 線天文衛星である。観測機器等の性能確認をおこなう初期運用期間の後、定常運用を開始し、2024 年 8 月現在にいたるまで XRISM プロジェクトチーム内で選定した天体の観測の実施してきた。当年 9 月からは、いよいよ世界に開かれた公開天文台として公募による科学観測を開始する。XRISM 衛星が掲げる宇宙の構造的・化学的進化やエネルギー輸送の解明を目指して、銀河団やブラックホールなど多様な天体の観測が予定されている。

時期を同じくして、第 25 太陽活動周期は極大期をむかえつつあり、大規模な太陽フレアや質量放出が頻発するなど、太陽は活発さを増してきている。「すざく」衛星など過去の X 線天文衛星では、太陽風電荷交換反応による X 線放射が検出されうることが示された (e.g., Fujimoto et al, 2007, Ezoe et al. 2011, Ishi et al. 2019)。このような地球磁気圏内部で起こる X 線放射は、銀河系の内外を問わず様々な天体の X 線観測において前景放射として存在するものである。実際、2024 年 5 月に発生した巨大磁気嵐の際には、その視野の広さによって Xtend 検出器で高統計の電荷交換反応スペクトルが観測されている。一方で、とくに前述した銀河団など広がった放射をもつ天体においては、視野中の広い領域を X 線データ解析の対象としてガス温度や密度を求めるため、電荷交換反応など前景放射の強度評価や性質の正確な理解がいっそう重要となる。また、太陽活動で駆動される大規模な磁気擾乱に伴う衛星の軌道降下など、衛星運用そのものへの影響も課題として認識され始めており、運用チームでは宇宙天気予報への注目が高まっている。本講演では、XRISM 衛星の観測中に発生した宇宙嵐の事例を参照しながら、科学観測への影響と衛星運用への影響の両側面から太陽極大における XRISM 衛星について議論する。