Challenge of PSTEP (Project for Solar-Terrestrial Environment Prediction)

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Although solar activity may significantly impact the global environment as well as socio-economic systems, the mechanisms for solar eruptions and the subsequent processes have not yet been fully understood. Thus, modern society is at a risk from severe space weather disturbances. Project for Solar-Terrestrial Environment Prediction (PSTEP) was launched in order to improve this situation through synergy between the basic science research and the forecast operation. PSTEP is a nation-wide research collaboration supported by a Grant-in-Aid for Scientific Research on Innovative Areas from MEXT/Japan. By this project, we seek to answer some of the fundamental questions concerning the solar-terrestrial environmental system, and aim to contribute to building a next-generation space weather forecast system to prepare for severe space weather disasters. PSTEP is organized by four research groups and proposal-based research units with the participation of more than 90 scientists. In this presentation, we will talk about the key aims and strategies of PSTEP.

Keywords: space weather, space climate, prediction

Analysis of Needs-Seeds Matching for Using Space Weather Information

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NICT has been investigating the needs of space weather (SWx) information with asking users by paper and face to face meeting on 2013 and 2014, in addition to arranging "space weather users forum" for ten years since 2005.
"Project for Solar-Terrestrial Environment Prediction" (PSTEP) was accepted on the Grant-in Aid for Scientific Research on Innovative Areas (2015-2019), MEXT, Japan. One of the main theme of PSTEP is o provide useful products ot users with developing with cutting-edge results from academic work. It is essential to build a communication framework among the scientists, adata providers, and users for achieving this goal.
As our first action, we have been analyzing gap analysis between needs and seeds of SWx information.
Especially, the aviation is one of the most advanced fields for using SWx information to the operation. We will discuss the matching using these examples.

Keywords: space weather, user investigation, aviation

Solar Flare Prediction with Vector Magnetogram and Chromospheric Brightening using Machine-learning

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

Keywords: Space Weather Forecast, Solar Flare, Statistical Analysis, Machine-Learning, Photospheric vector Magnetic field, Chromosphere

Solar Flare Prediction Studies Using Universal Time Series Predictor UFCORIN

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We have been studying space weather forecast using time-series prediction engine UFCORIN(Universal Forecast Constructor by Optimized Regression of INputs.) In our studies (Muranushi et al. 2015), we have compared 6'160 different prediction strategies that uses subset of wavelet features of SDO/HMI images as well as GOES past light curves.
Use of TSS (True Skill Statistics) as the indicator of flare forecast performance has been widespread since it is proposed by Bloomfield et. al(2012). However, we found that variation of bare TSS values over different cross-validation (CV) data sets is too large, so that we cannot measure significant difference between different forecast strategies. We found by using the z-value, or standard deviation of TSS, we can distinguish such strategies that show forecast performance consistently better than the average. We suggest the use of z-value as a method of finding good forecast strategies from thousands of candidates.
In our studies, the laregest TSS for X,M, and C class flare forecast, were 0.75 ± 0.07, 0.48 ± 0.02, and 0.56 ± 0.04, respectively.
Based on (Muranushi et al. 2015), we have been operating real-time flare forecast server since August 2015. The system have been making forecast every 12 minutes, except for some down times. We would also like to report on the latest state of this experience.

Keywords: Space Weather Forecast, Flare Forecast

Realtime Solar X-ray Flux Forecast using Deep Learning

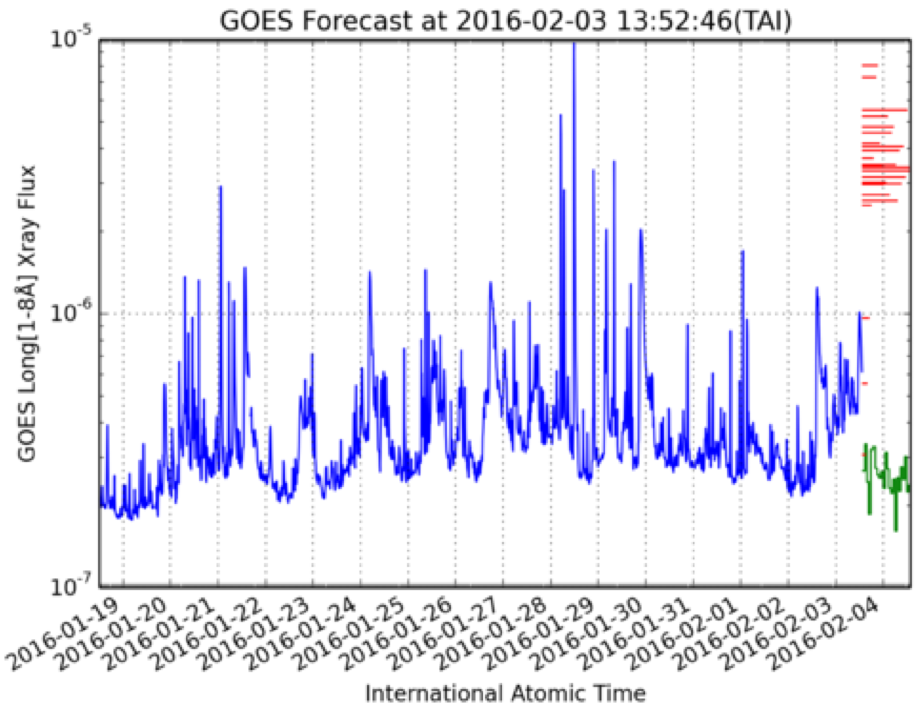
We present the 24-hour forecast of GOES X-ray flux, based on realtime GOES data and HMI-720s Near-Real-Time data.

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

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

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

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



Radiation Protection of Humans in Space and Aviation: Current States and Future Needs on the Warning System for Aviation Exposure to SEP (WASAVIES)

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

Keywords: SEP, Radiation Exposure, Space Weather

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

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

NASA Heliophysics and the Science of Space Weather

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

Scientific research in support of space weather goals

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

Keywords: Space weather, Space research, Heliophysics

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

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

Keywords: Space weather, Geomagnetically induced currents

Empirical estimation of GICs from the geomagnetic data in Japan

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

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

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

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

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

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

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

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Keywords: geomagnetically induced current, transformer station, transfer function

Polar cap potential saturation during the Bastille day storm using global MHD simulation

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

Keywords: global MHD simulation, polar cap potential, extreme event

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

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

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

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

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

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

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

Solar Corona and Space Weather

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

Keywords: Sun, Coronal activity, Space weather

Generation mechanism of large-scale magnetic field revealed with high-resolution solar dynamo calculation

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

Keywords: Sun, Thermal convection, Dynamo

Modeling the thermosphere ionosphere system and space weather impacts

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

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

Effects of energetic particle precipitation and solar irradiance on ozone

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

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

International joint study of EEP effects on the atmospheric minor components during pulsating aurora

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

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Keywords: pulsating aurora, atmospheric minor component

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

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

Keywords: Geomagnetically Induced Currents, Space Weather Modeling

Substorm simulation: Current system and auroral structure

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

Keywords: Substorm, Aurora, Geomagnetically Induced Current (GIC)

Identification of ionospheric plasma density changes due to solar flares and energetic particle precipitation using the SuperDARN radar data

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

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

Keywords: SuperDARN radars, ionospheric plasma density change, solar flare / energetic particle precipitation

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

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

Keywords: machine learning, total electron content, TEC forecast

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

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

References:

Amm, O., and A. Viljanen, Earth Planets Space, 51, 431-440, 1999.
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Keywords: Polar and auroral ionosphere (Ionospheric irregularities, Ionospheric currents, Energetic particles), Radio science (Radio wave propagation, Space and satellite communication), Space weather (Impacts on technological systems)

Ionospheric data assimilation with TIE-GCM and GPS-TEC during geomagnetic storm period

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

Keywords: Ionospheric data assimilation, geomagnetic storm

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

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The origins of upper atmospheric variations do not only come from the solar activities and rotation, but also from the Earth’s lower atmosphere. In order to now-cast and forecast the upper atmospheric disturbances and variations, we have developed a whole atmosphere-ionosphere coupled model called GAIA. The model incorporates the Japanese meteorological reanalysis (JRA) into its lower atmospheric part as well as the daily F10.7 index, in order to reproduce the effects of realistic forcing both from the lower atmosphere and solar irradiance. We have validated the model through the comparison of its long-term run with observations of ionosphere and ionosphere, and found out that further development of the model is necessary for higher accuracy.
In this talk, we will show the results from several updates of the model, such as improvement of ionospheric dynamics and energetics, and increase of model resolution. We have developed the interface of GAIA to data assimilation system and will show future plan.

Keywords: ionosphere, thermosphere, simulation, modeling, data assimilation

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

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

Keywords: Data assimilation, Forecast, Auroral activity index

New solar radio telescope of NICT and its space weather forecasting

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The solar corona contains many eruptive phenomena such as flares. Non-thermal electrons accelerated in the coronal eruptive phenomena emit radio waves. As a result, many types of solar radio bursts are observed. The radio emission propagates faster than the particles. Hence, the monitoring observation of the solar radio bursts is one of the efficient tools to forecast the arrival of the space weather phenomena such as coronal mass ejections (CMEs) and solar energetic particles (SEPs). National Institute of Information and Communications Technology (NICT) have been observed the solar radio burst since 1980's at Hiraiso. The current solar radio observation instruments named HiRAS have been used to monitor the solar radio burst for more than 20 years. Recently, we developed a new solar radio telescope to improve the observation quality and achieve the better space weather forecasting. The new telescope was constructed in the Yamagawa radio observation facility of NICT at Kagoshima prefecture. This telescope has an 8m parabola dish. The feed system of this telescope consists of two wideband log-periodic antennas. These two antennas are tuned for different frequency bands and the entire observation frequency band of this telescope is between 0.07 GHz and 9.0 GHz. The apparent diameter of the Sun is about 0.5 degree. The higher band of the feed system is de-focused to cover the entire solar disc on the field of view. The received signal is divided in the receiver system and fed to the digital fast Fourier transform (FFT) spectrometers made of the field-programmable gate array (FPGA). We developed two types of digital spectrometers. The one has 2 GHz bandwidth and 4096 FFT points. The other one has 1 GHz bandwidth and 32768 FFT points. These spectrometers have no dead time and spectra are accumulated inside the FPGA processors. The accumulated spectra are recorded every 8ms. The observation system has a total of 10 digital spectrometers. The entire system can simultaneously observe the right and left handed circular polarizations of the solar radio emission between 0.07 and 9.0 GHz with 8ms time resolution. This wide observation frequency band is very efficient to capture the various types of solar radio bursts. Therefore, the new observation system will improve the detection accuracy of the space weather phenomena. In addition, the high time resolution of this instrument has a significant benefit to detect the various fine spectral structures of the radio bursts that are thought to be generated by the micro plasma processes in the corona. Hence, the new system will also be sued to understand the coronal plasma physics such as the particle acceleration processes of the solar flares.

Keywords: Sun, solar rasio burst, space weather forecasting, solar energetic particle, radio observation

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

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

Keywords: Solar corona, Solar prominence/filament, MHD wavess

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

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

Keywords: CME, solar wind, MHD

A dynamical model of the heliosphere with the adaptive mesh refinement

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

Keywords: heliosphere, solar wind, MHD

A humid climate of the last stage of the Little Ice Age in central Japan reconstructed using oxygen isotopes from tree-ring

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

Keywords: Little Ice Age, Monsoon, tree-ring, oxygen isotopes

Relationship between typhoon occurrence and solar activity

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

Keywords: typhoon, solar activity, 27-day, thunderstorm, WPWP

