Study of the Coupled Solar-Earth System with Large Atmospheric Radars, Ground-based Observation Network and Satellite Data: Project Overview

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The solar energy can mainly be divided into two categories: the solar radiation and the solar wind. The former maximizes at the equator, generating various disturbances over a wide height range and causing vertical coupling processes of the atmosphere between the troposphere and middle and upper atmospheres by upward propagating atmospheric waves. The energy and material flows that occur in all height regions of the equatorial atmosphere are named as "Equatorial Fountain." These processes from the bottom also cause various space weather effects, such as satellite communication and GNSS positioning. While, the electromagnetic energy and high-energy plasma particles in the solar wind converge into the polar region through geomagnetic fields. These energy/particle inflow results in auroral Joule heating and ion drag of the atmosphere particularly during geomagnetic storms and substorms. The ion outflow from the polar ionosphere controls ambient plasma constituents in the magnetosphere and may cause long-term variation of the atmosphere.
We promote to clarify these coupling processes in the solar-terrestrial system from the bottom and from above through high-resolution observations at key latitudes in the equator and in the polar region. We propose to establish a large radar with active phased array antenna, called the Equatorial Middle and Upper atmosphere radar, in west Sumatra, Indonesia. We will also participate in construction of the EISCAT_3D radar in northern Scandinavia. These radars will enhance the existing international radar network. We will also employ a data collected with a global observation network of ground-based radio and optical remote sensing measurements as well as novel satellite measurements.

Keywords: Atmospheric radar , Solar-terrestrial coupling processes , ground-based observation network , IUGONET

Status of Equatorial MU radar project in 2017

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Research Institute for Sustainable Humanosphere, Kyoto University (RISH) has been studying the atmosphere and ionosphere by using radars. The first big facility was the MU (Middle and Upper atmosphere) radar installed in Shiga, Japan in 1984. This is one of the most powerful and multi-functional radar, and is successful of revealing importance of atmospheric waves for the dynamical vertical coupling processes. The next big radar was the Equatorial Atmosphere Radar (EAR) installed at Kototabang, West Sumatra, Indonesia in 2001. The EAR was operated under close collaboration with LAPAN (Indonesia National Institute for Aeronautics and Space), and conducted the long-term continuous observations of the equatorial atmosphere/ionosphere. The EAR, however, had a limited sensitivity to the MU radar as the total output power is just 1/10 to the MU radar. Our new project is to establish "Equatorial MU (EMU) Radar" just next to the EAR site in Indonesia. The EMU will have an active phased array antenna with the 163 m diameter and 1055 cross-element Yagis. Total output power of the EMU will be more than 500 kW. The EMU is the "MU radar class" facility, and can detect turbulent echoes from the mesosphere (60-80 km). In the ionosphere incoherent-scatter observations of plasma density, drift, and temperature would be possible. Multi-channel receivers will realizes radar-imaging observations. The EMU is one of the key element in the project "Study of coupling processes in the solar-terrestrial system" that is one of the important project in the Master Plan 2014 of the Science Council of Japan (SCJ). Last year we applied the project again to SCJ Masterplan 2017, and was awarded as an important project (total 28 projects were selected this time). We conduected EAR 15th year anniversary and international symposium in August 4, 2017 in Jakarta, Indonesia, which was a good opprtunity for us to show the EMU radar plan to Indonesian government and also to Japan Embassy in Indonesia.

Keywords: Equatorial Atmosphere, Equatorial Ionosphere, Atmospheric radar, Indonesia

Solar Radar

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The prospects of probing the solar corona, solar prominences, and coronal mass ejections (CMEs) from the ground using a large radar will be examined. Solar radar would utilize direct reflection (i.e. soundings) from the solar plasma supplemented by coherent scatter from Langmuir waves in coronal arcs and CMEs. Active sounding could provide unambiguous information about the range, bearing, and speed of the targets. Such information would be crucial for initial-value and assimilative space-weather models providing operational space-weather forecasts.

Challenges posed by solar-radar are significant but manageable, and many of the design choices are clearcut. For solar studies, the radar wavelength must be longer than the plasma Debye length. This places a premium on low radar frequencies which overrides the penalty of increased sky and solar noise. However, the radar frequency should not fall below the maximum usable frequency (MUF) since that would invite radar clutter from sky waves. The ideal frequency is therefore between 40--50 MHz. The most important parameter is the transmitter power-aperture product which limits the flux that can be delivered to the Sun. To optimize this flux, the antenna for transmission should be a steerable aperture or filled array with about a 1-degree half-power beamwidth. Steerability is required to keep the radar beam trained on the Sun, facilitating long incoherent integration times. The receive array meanwhile must be large enough that most of the noise it receives comes from the solar disk itself and not from the galactic background. However, we must consider that the main source of noise will be type III radio bursts. The noise temperature at VHF frequencies from solar radio bursts can be several orders of magnitude greater than that of the quiet sun, and system performance will depend on discriminating solar echoes from radio bursts. Adaptive beamforming will ultimately be critical for operational solar-radar space-weather applications. It is in this way that a large, modular receiving arrays become important.

All things considered, a facility comparable in size and power to the existing NSF Geospace Facilities but operating in the VHF band and possessing spaced-receiver capabilities should be able to detect solar echoes. Several attempts have been made already to detect solar echoes. The historical record is mixed, and the plausibility of the concept remains somewhat ambiguous. Recent and ongoing attempts to receive solar echoes at The Jicamarca Radio Observatory near Lima, Peru, will be discussed.

Keywords: space weather, radar, solar corona

Shigaraki UAV-Radar Experiments (ShUREX): Measuring Turbulence in the Lower Troposphere

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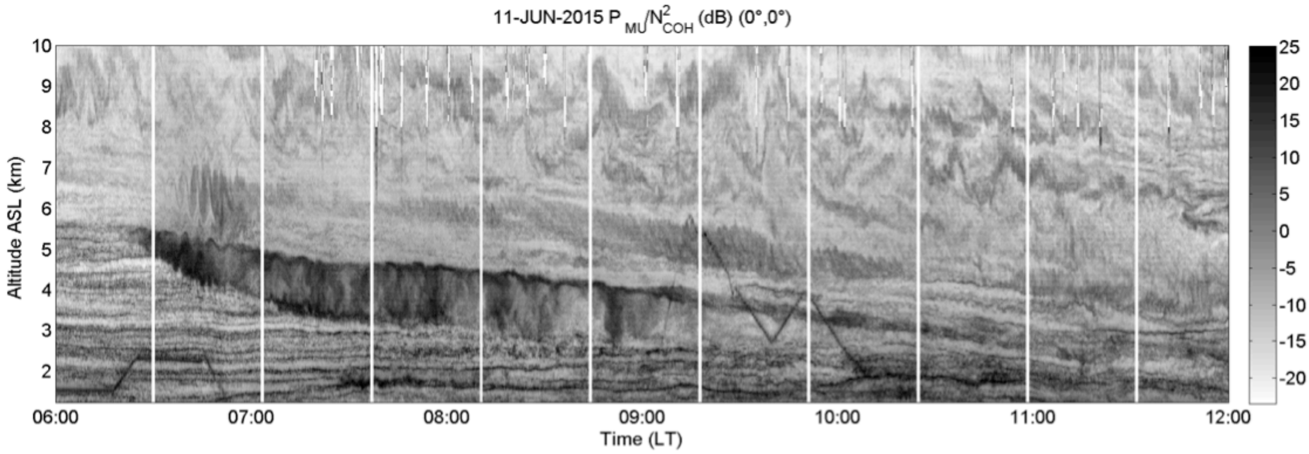
The Shigaraki UAV-Radar Experiment (ShUREX) is an international (US-Japan-France) observational field campaign, aimed at measuring and obtaining a better understanding of turbulent mixing and atmospheric structures in the lower troposphere. During the two campaigns in 2015 and 2016, the unmanned aerial vehicle (UAV) DataHawk (developed at the University of Colorado, Boulder, and equipped with high frequency response cold wire and pitot tube, as well as an IMET sonde) was flown near and over the VHF-band Middle and Upper Atmosphere (MU) radar to obtain measurements in the atmospheric column in the immediate vicinity of the radar. The radar was operated in range imaging mode to provide high vertical resolution of 20 m so that fine scale structures could be resolved. Simultaneous and continuous operation of the radar permitted the UAV to be commanded to sample interesting structures, guided in near real time by the radar images. ShUREX 2015 campaign was quite successful in achieving the goals set forth at the outset. It unambiguously demonstrated the utility of a small, inexpensive UAV, such as DataHawk, in probing the lower atmosphere and of the synergistic use of VHF radars and UAVs. We were able to sample interesting atmospheric structures such as sheets and layers (SL), MCT and convective boundary layer (CBL), guided in real time by the radar images. Salient results have been obtained and are described in greater detail in related publications. However, the less than optimal frequency response (100 Hz), combined with the high noise level of the coldwire and pitot turbulence 100 Hz sensors, prevented the use of the spectra above a certain frequency, leading to rather narrow inertial subranges in the turbulence spectra. In addition, the vibrations induced by the motor contaminated the turbulence spectra during ascent (and occasionally during descent when the throttle was high) and the discrete frequency spikes in the data had to be removed before deducing epsilon, CT2 and Cn2. ShUREX 2016 campaign carried out in May-June 2016 used higher frequency response sensors (800 Hz) with much lower noise floor, which yielded broader inertial subranges without contamination by motor vibrations. This enabled more accurate and reliable derivation of the TKE dissipation rate and turbulence structure parameters such as CT2 and Cn2. We will present some of these results in this talk. ShUREX 2015 and 2016 campaigns have demonstrated the presence of fine scale structures in the moist troposphere hitherto unknown or unappreciated by the atmospheric community. They also enabled simultaneous sampling of turbulent atmospheric structures such as MCT by in-situ turbulence sensors flown on a UAV and the radar. As productive as these campaigns have been, they do suffer from the deficiency that we were unable to map the complete evolution of structures such as MCT, SL and CBL. We were unable to catch a KHI event. We will attempt to sample these structures more comprehensively, concentrating on CBL and SL structures in ShUREX 2017 during June 2017.

Keywords: MU radar, turbulence, Lower troposphere, Unmanned Aerial Vehicle


11-JUN-2015 P MU/N2COH (dB) (0°,0°)
Altitude ASL (km)
Time (LT)
06:00
07:00
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HF simulator: A door to space weather users

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Utilization of radio wave enhances convenience, safety level and quality of life for decades. Various space weathers, which affect the Earth via the coupling processes in the Sun-Earth system, cause unreachability, intensity fluctuation, abnormal route propagation, propagation delay, etc. of radio wave. Space weather is thus significant to radio wave users, especially the user who deals with the critical radio application. High frequency (HF) radio communication is an important means of aeronautical communications especially for airplanes oceanic en-route and in polar routes, even though satellite communications are getting popular. Reasons are, for example, satellite communication is expensive, GEO satellites are not visible from polar region, etc. For sky wave mode, HF radio waves are reflected back to the Earth by the ionosphere layer. Integrity and availability of HF waves are unavoidably associated with 3D structure of plasma frequency in the Earth’ s ionosphere. This paper presents a problem of existing radio propagation model and the challenge on developing the radio propagation simulator that is dedicated to space weather users. The future plan for users will be reported.

Keywords: Radio propagation, HF, Space weather, Ionosphere

EISCAT_3D: Current Status on Japan's Contribution

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The European Incoherent Scatter(EISCAT) Scientific Association with associate members from Sweden, Norway, Finland, UK, China and Japan, is planning to construct the next generation near-earth space and upper atmosphere radar system in northern Feno-Scandinavia, called EISCAT_3D. The technical design work is being almost finalized and the project has now entered the new phase of production engineering. The Swedish Research Council, the Academy of Finland, the Research Council of Norway and the European Commission have secured funds for the development, construction and operation of EISCAT_3D, which covers approximately more than 70% of the total costs of establishing the first stage of the system. EISCAT 3D is the major upgrade of the existing EISCAT mainlamd radars, with a multi-static phased array system composed of one central active (transmit-receive) site and 4 receive-only sites to provide us 50-100 times higher temporal resolution than the present system. The construction of EISCAT 3D is planned to implement by 4-staged approach, starting from the core site with half transmitting power about 5MW at Skibotn (Norway) and 2 receiving sites at Kaiseniemi (Sweden) and Karesuvanto (Finland) at the 1st stage. The Japanese EISCAT group has been pursuing the opportunity to contribute in-kind to the construction of EISCAT_3D by supplying power amplifiers for the radar transmitters as a joint venture with the EISCAT_3D Project Office in cooperation with Japanese industry. The EISCAT_3D program in Japan has been successfully granted as as one of 27 high-priority programs of Master Plan 2014 and 10 new Roadmap 2014 programs, as a part of ’ Study of Coupling Processes in the Solar-Terrestrial System’ (PI: Prof. Tsuda, Kyoto Univ.). This program is recently selected as one of 28 high-priority programs of the Master Plan 2017 update as well. Supported by these high evaluations, National Institute of Polar Research has been submitting a funding proposal to the Ministry (MEXT) for EISCAT_3D, collaborating with the Institute for Space-Earth Environmental Research, Nagoya University. Since last year, manufacturing of high energy-efficient transmitter power amplifiers has started for the engineering verification test at the EISCAT Tromso site using the development study budget from MEXT. In this paper, we will overview the current status and outlook on Japan’ s national contribution to the EISCAT_3D project.

Keywords: incoherent scatter radar, arctic, geospace

Magnetosphere-ionosphere-thermosphere-middle atmosphere coupling in the polar region

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Recently, many coupling processes between the magnetosphere, ionosphere, thermosphere, and lower atmosphere have been shown from observations and numerical simulations. In particular, it is known that some meteorological phenomena would have impacts on the thermosphere and ionosphere; for example, typhoon and sudden stratospheric warming events. The coupling between neutrals and plasmas is wellknown and important processes to understand various ionospheric and thermospheric variations. When we understand all the coupling processes between the regions, we would come close to realizing the predictions of the ionospheric and thermospheric weathers.

In the present study, we focus our attention on the polar ionosphere and thermosphere where various coupling processes would exist. Among the coupling processes, chemical ones caused by the precipitating particles in the polar region seem to be far from complete understandings for us. We have made observations of the dayside polar cap ionosphere using the EISCAT radar system to monitor ionospheric disturbances due to the particle and energy inputs from the magnetosphere. The polar cap ionospheric disturbances in the higher latitude have been observed at almost all the time even during geomagnetically quiet periods. We will show some fundamental features of the polar cap ionosphere revealed from the EISCAT observations. In addition, we have performed modelling studies to understand physics and chemistry of the polar ionosphere and thermosphere. In the present study, we will introduce our attempt to estimate productions of ions, NOx, and HOx in the altitude of 50-500 km due to precipitating particles.

The results from the EISCAT observations and modelling studies will be included in our whole atmosphere and ionosphere GCM, GAIA, in the future.

Keywords: thermosphere, ionosphere, middle atmosphere, aurora, magnetosphere

Gradient drift instability in the trailing edge of polar patches

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Polar patches, which are regions of high electron density in the polar cap F region ionosphere, are frequently observed during southward interplanetary magnetic field (IMF) conditions. Recently, finger-like structures along the trailing edges of polar patches have been detected by using all-sky airglow imagers. The observed its growth rate and spatial scale is approximately 300 s (~$3x10^{-3}$ s^{-1}) and 100 km, respectively. Previous studies indicated that the gradient drift instability (GDI) plays an important role for the generation of the finger-like structure. However there are few studies that evaluate this hypothesis quantitatively based on observational and theoretical approaches. In this study, we derived the linear growth rate of GDI for cases of polar patches observed by the EISCAT Svalbard radar (ESR). We also performed a two-dimensional numerical simulation of polar cap patches to obtain linear growth rate for a typical polar cap patch. The estimated linear growth rates are 10-3 s-1 for polar patches observed by ESR. The numerical simulation showed that the linear growth rate is approximately 10^{-3} s^{-1}. This good agreement indicates that GDI is regarded as the dominant mechanism of the generation of the finger-like structure.
The linear growth rate used in above calculations depends only on the electron density gradient and electric field but does not depend on wave number. As a result, it cannot explain the appearance of the finger-like structure which has a particular scale size, namely ~100km. We found the difference in predominant finger scales which were seen in the numerical simulation calculated with changing the Pedersen conductivity. This result implies that the ion-neutral collision frequency strongly contributes to generation of predominant finger scale. Therefore, we developed the linear growth rate involving the finger scale calculated with the ion collision frequency. The growth rate suggested that the growth of large scale structure (<1000 km) is suppressed in the lower F region.
In this presentation, we will show these simulation results and observation results.

Keywords: Polar Patch, gradient drift instability

Studying ionospheric plasma processes with the Swarm satellites and ground-based receivers

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The three ESA Swarm satellites have been orbit since November 2013 collecting, among other data, particularly high precision measurements of the magnetic field and observations of electron density and temperature as well as ion drift. Owing to their polar orbits high latitude processes can be studied as well as phenomena at equatorial and mid-latitudes. Studies have been particularly effective when combined with ground-based radars and receivers. I'll present an overview of what has been achieved at both high and equatorial latitudes.

Keywords: Ionosphere, F region, Irregularities

Ionosphere in low frequency Synthetic Aperture Radar images

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Space borne Synthetic Aperture Radar (SAR) images the Earth’s surface through the ionosphere. The images in L-band SAR are known to be distorted by the ionospheric propagation effects associated with ionospheric irregularities both in high and low latitude. We present recent experiments to study ionosphere using space borne radar images, ground radars and GNSS measurements. In high latitude, during evenings of geomagnetic disturbances, the enhancement of ionospheric electron densities associated with auroral activity is detected by ground observations. The simultaneous acquisitions of SAR show distortions of the ground images where streak-like structures are present. In low latitudes, on the other hand, the post-sunset drifts of plasma instabilities monitored by ground radars are seen as stripe structures in SAR images. We develop methods to identify ionospheric parameters from SAR measurements and propose it as a new complementary method for ground radars.

Keywords: Ionosphere, SAR, GNSS

Climatology of plasmaspheric total electron content obtained from Jason-1 satellite

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We used more than 40 million Total Electron Content (TEC) measurements obtained from the GPS TRSR (TurboRogue Space Receiver) receiver onboard the Jason-1 satellite in order to investigate the global morphology of the plasmaspheric TEC (pTEC) including the variations with local time, latitude, longitude, season, solar cycle, and geomagnetic activity. The pTEC corresponds to the total electron content between Jason-1 (1336 km) and GPS (20,200 km) satellite altitudes. The pTEC data were collected during the seven-year period from January 2002 to December 2008. It was found that pTEC increases by about 10 - 30 % from low to high solar flux conditions with the largest variations occurring at low latitudes for equinox. During low solar flux condition, pTEC is largely independent of geomagnetic activity. However, it slightly decreases with increasing geomagnetic activity at low latitudes during high solar flux. The seasonal variations such as the annual and semiannual anomalies in the ionosphere also exist in the low-latitude plasmasphere. In particular, the American sector (around 300°E) shows strong annual asymmetry in the plasmaspheric density, being larger in December than in June solstice.

Keywords: Plasmasphere, Total electron content (TEC), JASON satellite

SuperMAG: Global Specifications of Ionospheric Currents based on Ground Magnetic Field Observations, and Beyond

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The ionospheric current is one of the most important components for specifying the electrodynamic coupling between the magnetosphere and ionosphere. Whereas local (equivalent) currents may be deduced from local magnetic field observations, global distributions of ionospheric currents can be obtained only by collecting, processing, and analyzing data from various networks, which is always a challenge. SuperMAG is a worldwide collaboration of organizations and national agencies that currently operate more than 300 ground based magnetometers, and it provides easy access to validated ground magnetic field perturbations in the same coordinate system, identical time resolution and with a common baseline removal approach [Gjerloev et al., 2012, DOI: 10.1029/2012JA017683] through its website (http://supermag.jhuapl.edu/). In this paper we present its (i) basic products and functions such as generalized geomagnetic indices, polar plots, and personalized movie creation, (ii) recent additions such as global ULF maps and global equivalent currents at uniform grids, and (iii) future expansions for more comprehensive global specifications including Birkeland currents and ionospheric convection.

Keywords: SuperMAG, Ground Magnetometer Networks, Ionospheric Currents, Magnetosphere-Ionosphere Coupling, ULF Waves

Ground network observation of the Optical Mesosphere Thermosphere Imagers and the PWING project

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The Institute for Space-Earth Environment Research (ISEE) of Nagoya University operates the Optical Mesosphere Thermosphere Imagers (OMTIs) since 1997. The OMTIs consist of more than fifteen all-sky cooled-CCD imagers, five Fabry-Perot interferometers, three airglow temperature photometers, and three meridian-scanning photometers. These instruments are in automatic operation at various locations from high to equatorial latitudes in Canada, Russia, Norway, Finland, Japan, Thailand, Indonesia, Nigeria, and Australia. They measure two-dimensional airglow images in the mesopause region and in the thermosphere, wind and temperatures in the lower thermosphere, and airglow rotational temperatures in the mesopause region. Recently we also started to deploy OMTI airglow imagers as well as 64-Hz induction magnetometers, 40-kHz VLF receivers, and 64-Hz riometers at 8 stations at magnetic latitudes of ~60 degree around the north pole to cover longitudinal variation of aurora and electromagnetic disturbances in the inner magnetosphere under the PWING project (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations, http://www.isee.nagoya-u.ac.jp/dimr/PWING/PWING_web_e.htm), which will last for 5 years from April 2016, as a Grant-in-Aid for Specially Promoted Research of the Japan Society for the Promotion of Science (JSPS). In the presentation, we introduce current status and some recent results obtained by these multi-instrument ground networks around the world.

Keywords: PWING Project, Optical Mesosphere Thermosphere Imagers , inner magnetosphere, thermosphere, ionosphere, mesosphere

Recent Development of ICWSE/MAGDAS project for Study of Coupling Processes in the Solar-Terrestrial System

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For study of coupling processes in the Solar-Terrestrial System, International Center for Space weather Science and Education (ICSWSE), Kyushu University has developed a real time magnetic data acquisition system (the MAGDAS project) around the world. The number of observational sites is increasing every year with the collaboration of host countries. Now at this time, the MAGDAS Project has installed 77 real time magnetometers –so it is the largest magnetometer array in the world. The history of global observation at Kyushu Univ is over 30 years and number of developed observational sites is over 140.By using MAGDAS data, ICSWSE produces many type of space weather index, such as EE-index (for monitoring long tern and shot term variation of equatorial electrojet), Pc5 index (for monitoring solar-wind velocity and high energy electron flux), Sq-index (for monitoring global change of ionospheric low and middle latitudinal current system), and Pc3 index (for monitoring of plasma density variation at low latitudes). In this talk, we will introduce recent development of MGADAS/ICSWSE Indexes project and topics for open policy for MAGDAS data will be also discussed.

Keywords: Space Weather, Master Plan, MAGDAS

A new millimeter-wave spectrometer in Tromsø, Norway for coordinated observations with Syowa

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Energetic particle precipitations (EPPs) related to solar activity induce changes of chemical composition around mesosphere and lower thermosphere in the polar regions. We have been carrying out ground-based millimeter-wave monitoring of nitric oxide (NO) emission at 250.796 GHz and ozone at 235.709 GHz since January 2012 at Syowa Station and revealed so far that NO partial column density in upper mesosphere and lower thermosphere above Syowa shows two types of temporal variations; one is seasonal variation increasing in polar winter mainly due to photochemistry, and the other is short-term (several days) sporadic enhancement related to EPPs (Isono et al. JGR, 2014). However, during the midnight sun period, the photo-dissociation and EPP induced ionization/dissociation occur simultaneously, and this makes difficult to distinguish and evaluate the pure contribution of the EPP effects on the chemical composition change. Thus, we planned to implement coordinated observations from both the polar regions and installed a new millimeter-wave spectrometer at the EISCAT Tromsø facility in Norway. The basic feature of the millimeter-wave spectrometer is almost the same as the one operating at Syowa, i.e., equipped with a low-noise superconductive SIS receiver and a digital FFT data processor. Though the instrument is not yet fully operational at present, we succeeded detecting a clear ozone spectrum of S/N ~ 12 with 30-second integration as a result of test observation. In near future, the SIS receiver will be upgraded to multi-frequency SIS receiver system that enables us to observer several molecular lines simultaneously.
In this presentation, we will present the summary of the observational results at Antarctic Syowa, current status of the instruments in Arctic Tromsø, and future plan of the research.

Keywords: Polar Region, Energetic Particle Precipitation, Millimeter-wave Spectroscopy

Current status of the IUGONET project

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The earth's atmosphere in a height range of more than 80 km is called the upper atmosphere, and the atmospheric layer is influenced by both the solar activity and the atmospheric waves propagating from the lower atmosphere. Therefore, in order to understand the physical mechanism of the short-term and long-term variations in the upper atmosphere, we need to perform the integrated analysis of various kinds of ground-based and satellite observation data taken by different instruments. Since these observation data were separately being managed by each institute, it was difficult for users to effectively find and analyze them for promotion of an interdisciplinary study. In order to solve this problem, the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) project has been initiated in 2009, consisting of five institutes (Tohoku University, National Institute of Polar Research, Nagoya University, Kyoto University, and Kyushu University). In this project, we created a metadata for various kinds of ground-based observation data such as solar image, geomagnetic field, optical image, neutral wind, and several metrological data, and built a metadata database to share them on the Internet. We also developed an integrated data analysis tool, which is called the IUGONET Data Analysis Software (UDAS) written in an Interactive Data Language (IDL). This analysis tool is a plugin software for Space Physics Environment Data Analysis Software (SPEDAS) to analyze and visualize various kinds of ground-based and satellite observation data. However, since there are several major problems on usability of the IUGONET metadata database (for example, no Quick Look (QL) images, no description of how to use the UDAS for each dataset, and high operation cost etc.), we replaced the old IUGONET metadata database by the IUGONET Type-A to solve these problems on October 1st, 2016, and we opened it for users on November 1. In the IUGONET Type-A, we rearranged a dataset category of each instrument or project displayed on the top window so that users can easily search and find the data and related information they want to know. Since this web service has a function to display the QL images/plots related to the selected dataset on the top widow, users can easily learn the characteristics of different types of the IUGONET ground-based observation data and find several interesting phenomena observed in the upper atmosphere by looking at the QL images/plots. Moreover, the time range of all the QL plots created by the UDAS/SPEADS tool becomes 7 days, so users can investigate the characteristics of upper atmospheric phenomena aligned to every date and time on the basis of different type of observation data taken by various kinds of instrument distributed all over the world. In order for students and young scientists to learn how to use these IUGONET data and products, we hold tutorial seminars several times a year in Japan and sometimes foreign countries. It is expected that the two main IUGONET products (IUGONET Type-A and UDAS/SPEDAS) promote an interdisciplinary study on coupling processes of solar-terrestrial system and space climatology and contribute to an open science and cultivation of human resources to promote it.

Keywords: IUGONET, Upper atmosphere, IUGONET Type-A, Open Science, IUGONET Data Analysis Software (UDAS), Interdisciplinary study

Observations of Total Electron Content Using Multi-frequency and Multi-constellation Global Navigation Satellite System Receivers

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Total Electron Content (TEC), which is total number of electrons along a ray path from the satellite to receiver, has been obtained from dual-frequency radio signals of the Global Positioning System (GPS). It is widely used to monitor the plasma density in the ionosphere. Recently, multi-frequency and multi-constellation GNSS (Global Navigation Satellite System) receivers have been developed and GNSS signals at three frequency bands from not only GPS but also GLONASS, Galileo, BeiDou and so on can be received simultaneously. Using tri-frequency signals, TEC is estimated from three pairs of the signals so that accuracy of the TEC estimation could be improved. Benefit of the multi-constellation is improvement for spatial distribution of visible satellites. In order to obtain absolute TEC by subtracting instrumental biases inherent in satellites and receivers, spatial uniformity of TEC is assumed. In the method of Otsuka et al. [EPS, 2002], it is assumed that the hourly average of vertical TEC is uniform within an area covered by a receiver; this area corresponds to a surrounding of approximately 1,000 km. This assumption is not valid at equatorial region, where spatial gradient of TEC is large so that the estimation of the absolute TEC is degraded. Recently, we have improved this method by considering spatial gradient of hourly-averaged vertical TEC, and have applied improved method to the GPS-TEC data at mid- and low-latitudes. By using the improved methods, residuals of the least-square fitting procedure are reduced to 15% at mid-latitudes and 43% at low-latitudes compared to those in the original method. By using multi-constellation data, we expect that accuracy of the absolute TEC estimation could be further improved because of high spatial resolution of TEC data.

Keywords: GNSS, ionosphere, TEC, GPS, GLONASS, Galileo

