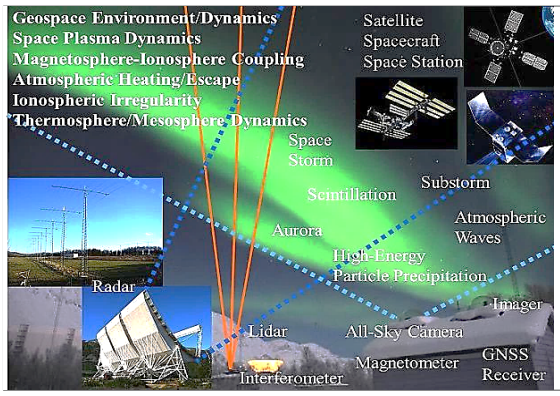
Division for Ionospheric and Magnetospheric Research



- Energy transfer from the solar wind to the magnetosphere and ionosphere
- Magnetosphere-ionosphere-thermosphere coupled system
- Ground-based and network observation
- Space and planetary exploration

The plasma and energy carried by the solar wind to the Earth and other planets exert physical effects on the magnetosphere and ionosphere, known as the geospace. We studied these effects and associated phenomena with international cooperation, primarily through various observational approaches using ground-based instruments, such as EISCAT radars, high frequency (HF)/very high frequency (VHF) radars, global navigation satellite system (GNSS) receivers, high-sensitivity passive/active optical instruments, magnetometers, and instruments onboard satellites/spacecraft, which were developed in our division. We also led the way to future space exploration missions based on our expertise.

Main Activities in FY2021

Measurements of aurora and electromagnetic waves at sub-auroral latitudes (PWING project)

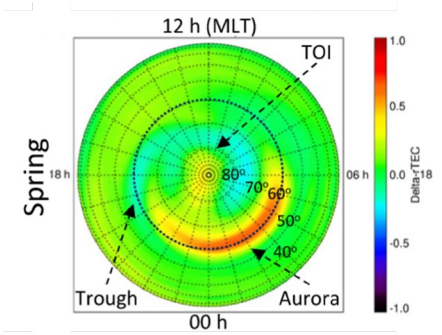
Aurora/airglow imagers and electromagnetic wave receivers have been involved in the PWING project at eight stations around the North Pole, at MLATs of approximately 60° (in Canada, Russia, Alaska, Finland, and Iceland) since 2016. They were used to investigate the plasma and wave dynamics in the inner magnetosphere. Many new results were obtained in FY2021. For example, the plasma and field characteristics in the source region of medium-scale traveling ionospheric disturbances (MSTIDs) in the inner magnetosphere were first revealed based on conjugate measurements by the Arase satellite and at Athabasca, Canada. Other conjugate measurements of isolated proton auroras associated with Pc1 geomagnetic pulsations and an equatorward-detached arc from the auroral oval have been reported using ground airglow/aurora imagers and the Arase Satellite.

Upper atmosphere imaging using the OMTIs

The optical mesosphere thermosphere imagers (OMTIs) consist of five sky-scanning Fabry-Perot interferometers, 21 all-sky charge-coupled device imagers, three tilting photometers, and three airglow temperature photometers, which are used to investigate the dynamics of the mesosphere, thermosphere, and ionosphere. Several new results were obtained from the OMTI measurements in FY2021. For example, we compared the zonal drift speed of equatorial plasma bubbles and zonal wind in the thermosphere over Indonesia and Africa to reveal the F-region dynamo effect on bubble drift. In addition, new observations were made by the PWING project described above at the subauroral latitudes.

Ionospheric disturbances observed by GNSS networks

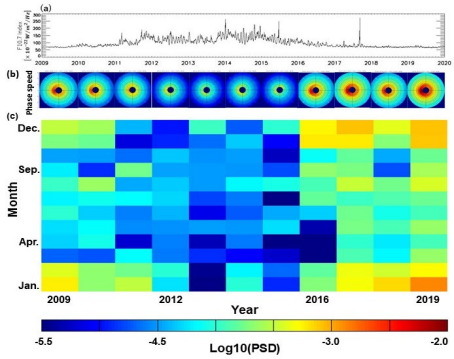
We developed a database that provides global 2-dimensional maps of total electron content (TEC) with high temporal and spatial resolutions for more than 20 years. TEC data have been obtained from more than 9000 GNSS receivers worldwide. Using the TEC database, we statistically studied the ionospheric response to magnetic storms, especially seasonal variations in TEC enhancements related to the tongue of ionization (TOI), auroral oval, and storm-enhanced density (SED) plume, as well as the spatial structure of the mid-latitude trough in the nighttime sector. The geomagnetic activity dependence of equatorial plasma bubbles was also studied.



Polar maps of averaged TEC in the Northern Hemisphere at the epoch time of Dst-index minimum as a function of geomagnetic latitude and local time during the main phase of moderate geomagnetic storms in winter. The TEC is shown as deviation from the geomagnetically quiet condition (Shinbori et al., 2022).

SuperDARN Hokkaido HF radars

Using the SuperDARN Hokkaido HF East and West radars at Rikubetsu, Hokkaido, and other SuperDARN radars, we studied the statistical occurrence characteristics of nighttime medium-scale traveling ionospheric disturbances (MSTIDs) using a 3D-FFT data analysis algorithm. We found that the nighttime MSTIDs occurrence rate was negatively correlated with solar activity. We also statistically studied the ion outflow enhancement associated with the sub-auroral polarization streams using SuperDARN and Arase spacecraft data. Furthermore, we obtained funding for the imaging receiver system at the Hokkaido East Radar. Implementation will begin next fiscal year.



Solar activity (F10.7 index) and seasonal dependence of power spectral density of nighttime MSTIDs. (Hazeyama et al., 2022). (a) F10.7 index. (b) Yearly power spectral density of nighttime MSTID. (c) Monthly averaged PSD. The horizontal axis represents the year and the vertical axis represents the month.

FACTORS initiative as the next space exploration mission realizing *in-situ* observations by formation flight in the space–Earth coupling system

The new space exploration mission, FACTORS, which is next to the ERG (Arase) satellite mission led by our institute, has been promoted for simultaneous *in-situ* observations of the space-Earth coupling physical mechanisms using multi-satellite formation flight. It is planned that satellite separation distances of 1–50 km in the polar orbit at altitudes ranging from 350–3500 km are maintained with two types of formation flight operations using a conventional chemical propulsion method and a newly proposed aerodynamics method with precise satellite attitude controls near the perigee. This fiscal year, we made a detailed design of an on-board propulsion system including a fuel tank, four thrusters, valves, and plumbing. In addition, a new type of data/command-handling circuit system was investigated as a space-qualified application for huge mission data management in space.

Development of a hemispherical FOV electrostatic analyzer suitable for future exploration satellite plans and foil experiments for TOF mass spectrometer

We have developed a hemispherical field-of-view (FOV) double-shell electrostatic energy analyzer that enables the measurement of ion/electron energies and flight directions using one sensor head on a three-axis stabilized satellite. By obtaining the sensor characteristics through numerical simulation and comparing them with the calibration test results, it was confirmed that the performance was close to the numerical calculation results and that the required specifications were satisfied. To establish the design of a time-of-flight (TOF)-type mass spectrometer that analyzes the mass of ions, a

fundamental foil test was conducted to confirm the characteristics of the transmitted particles (angular scattering, energy degradation, particle neutralization, etc.), which are caused by the ultrathin carbon foil widely used in analyzers.

Experiments on floating-mode APD using a beam line, electron guns, and hybrid detector using APD and MCP

We conducted 1) fundamental experiments for the floating-mode avalanche photodiode (APD) accelerating electrons by applying a floating voltage to the APD and 2) development of a hybrid detector combining APD and microchannel plate (MCP). The purpose of the floating mode is to reduce the lowermost energy of electron energy analyzers equipped with APD as detectors. We could detect electrons at 2 keV lower than in previous research. However, the hybrid detector is expected to detect a wide energy band (1 eV –100 keV). We confirmed that the total charge of the electron clouds ejected from the MCP increased as the operation voltage increased.

Promotion of EISCAT and EISCAT_3D projects

We proceeded with the EISCAT project in collaboration with National Institute of Polar Research (NIPR): (1) we performed 11 EISCAT SP experiments with Japanese colleagues; (2) we proceeded with the EISCAT_3D project; and (3) we had a special session for the Master Plan 2020 in JpGU2021. We have also operated a photometer and an MF radar in Tromsø, and a meteor radar in Alta, northern Norway, and collaborated with Japanese and foreign colleagues in studies on turbopause altitude, atmospheric tomography, and sporadic sodium layers in the MLT region. Furthermore, we have been conducting statistical studies of the polar lower thermosphere wind (93–118 km) using EISCAT radar data and of the atmospheric stability of the polar winter upper mesosphere (80–100 km) region using sodium LIDAR data obtained at Tromsø.

Field-aligned low-energy O^+ Ion in the inner magnetosphere

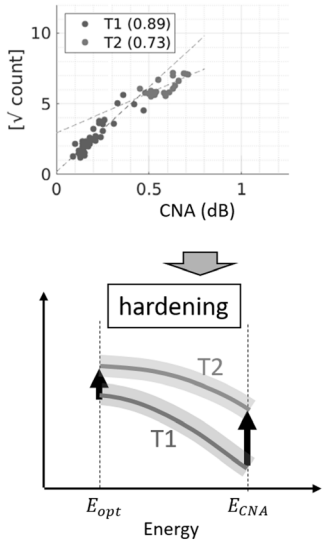
We found that flux enhancements of field-aligned low-energy O^+ ions (FALEO) were simultaneously observed by Arase and Van Allen Probes A and B in the nightside inner magnetosphere during 05–07 UT on September 22, 2018. FALEO has an energy-dispersion signature ranging from a few keV to ~10 eV, only in the direction parallel/antiparallel to the magnetic field. From a numerical simulation to trace the trajectories of test O^+ ions in a model magnetosphere, we revealed that FALEOs originate from ionospheric O^+ ions that are extracted from the upper ionosphere at substorm onset and flow along the magnetic field toward the geomagnetic equator. It was also revealed that 3–9 h after their launch, test O^+ ions less than 400 eV have a spatial distribution in the inner magnetosphere, which is similar to those of the warm plasma cloak and the oxygen torus. Therefore, we conclude that FALEO is a source of these cold ion populations. This result was published in *Journal of Geophysical Research* (Nosé et al., 2022).

Development of a low-cost magnetometer using a MI sensor

The magneto-impedance (MI) effect was discovered approximately 25 years ago, and a microsized magnetic sensor that utilizes this effect has now become commercially available. We made some modifications to the commercially available MI sensors, as they cover the range of the geomagnetic field (±80000 nT). We developed an instrument for ground measurements, including MI sensors, a Raspberry Pi-based data logger, and an A/D converter, which is only ~1/10 of the usual cost of a fluxgate magnetometer. Experimental observations showed that MI sensors can detect geomagnetic variations, such as Sq variations, geomagnetic storms, and geomagnetic pulsations. This instrument can be used for continuous field measurements over several months. We also developed a magnetometer using an MI sensor onboard a sounding rocket that was launched from Alaska on March 5, 2022.

Japan-Russia bilateral project

Several universities and institutes in Japan, including ISEE, Nagoya University have deployed optical and radio wave instruments in northern Scandinavia to collaborate with magnetospheric satellites such as the Arase satellite. We promoted a Japan-Russia bilateral project with the Polar Geophysical Institute (PGI) in Apatity (Murmansk, Russia) to expand the collaborative observation region and encourage cooperation with Magnetosphere-Ionosphere researchers in Russia using the Japan Society for the Promotion of Science budget. The bilateral project extended the ground-based observation network to further eastward of Scandinavia and met with many conjunctions with the Arase Satellite. Thirteen researchers from Japan, including students and 10 researchers from Russia participated in the project. A remote workshop (March 2022) was held, and several papers were published based on discussions during the workshops. For example, latitudinal dependencies of the auroral electron precipitation spectrum were found in high-speed camera and riometer observations during the pulsating auroral patch formation. This finding was published in the *Journal of Geophysical Research Space Physics* (Miyamoto et al., 2021).



(Upper) Relationship between the auroral intensity and mesospheric ionization intensity during a pulsating aurora. There is a difference in the slope of the fitted line before (steeper slope) and after (gentler slope) auroral patch formation. (Lower) Estimated shift in the auroral particle precipitation spectrum to satisfy the slope change.

SDI-3D project

The scanning Doppler imager (SDI) is a ground-based Fabry-Perot Doppler spectrometer operating in an all-sky imaging mode with a separation scanned etalon to resolve Doppler spectra at heights of 90–400 km. A single station can estimate the horizontal wind vector and temperature on the horizontal plane with a diameter of 1000 km. We established an international team in 2018 with researchers from Japan, Scandinavian countries, and the U.S. This team commenced the "SDI-3D" project to deploy three SDIs in the same area as the EISCAT_3D, which might begin operation in 2023. To progress this project, in 2018, an international exchange program (or a cross-appointment system) was concluded between Nagoya University and the University of Oulu (Finland) as the first case in Nagoya University, and a faculty member will stay in Oulu for three months in 2022. The development of the SDI has progressed satisfactorily, based on the budget awarded by the National Science Foundation in the U.S. Stations to deploy the SDIs were decided, with two in Finland and one in Sweden. An etalon system for SDI was delivered from Japan to the U.S.

Data archives

The following data archives are available to the public:

Database	Web site
OMTIs	https://stdb2.isee.nagoya-u.ac.jp/omti/
GPS scintillation	https://stdb2.isee.nagoya-u.ac.jp/QL-S4/
VHF (30.8 MHz) radar	https://stdb2.isee.nagoya-u.ac.jp/vhfr/
SuperDARN Hokkaido radar	https://cicr.isee.nagoya-u.ac.jp/hokkaido/
210-mm magnetic field data	https://stdb2.isee.nagoya-u.ac.jp/mm210/
ISEE magnetometer network	https://stdb2.isee.nagoya-u.ac.jp/magne/
ISEE VLF/ELF data	https://stdb2.isee.nagoya-u.ac.jp/vlf/
EISCAT radar, Sodium lidar, MF/Meteor radar, Optics	https://www.isee.nagoya-u.ac.jp/~eiscat/data/EISCAT.html
Reimei satellite data	http://reimei.stelab.nagoya-u.ac.jp/ (past) http://reimei.isee.nagoya-u.ac.jp/ (present)
Wp geomagnetic index	https://www.isee.nagoya-u.ac.jp/~nose.masahito/s-cubed/