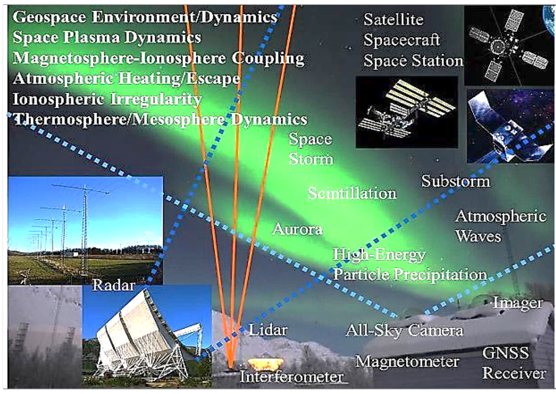
Division for Ionospheric and Magnetospheric Research



- 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 European Incoherent Scatter (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 FY2022

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

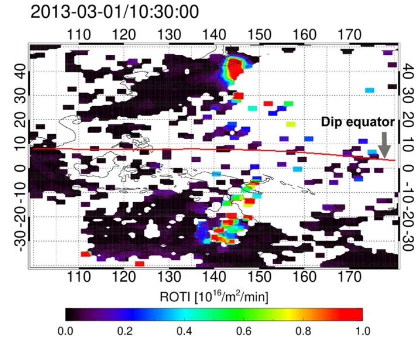
Since 2016, the PWING project has operated aurora/airglow imagers and electromagnetic wave receivers at eight stations around the North Pole at MLATs of approximately 60° (Canada, Russia, Alaska, Finland, and Iceland). They were used to investigate plasma and wave dynamics in the inner magnetosphere. The PWING project will be concluded at the end of FY2022, but the operation of the instruments will continue under the new PBASE program that was initiated in the second half of FY2022. Several new results have been obtained for FY2022. We determined the instantaneous longitudinal extent of Pc1 geomagnetic pulsations based on a statistical study of 1-year geomagnetic field measurements at seven ground stations at subauroral latitudes. A new report was made on spot-like ozone depletion in the upper stratosphere due to energetic particle accretion associated with Pc1 geomagnetic pulsations. Eight cases of simultaneous observations of nighttime medium-scale propagating ionospheric disturbances (MSTIDs) with the Arase satellite in the inner magnetosphere elucidated the conditions under which the electric field and density variations of the MSTIDs propagate into the magnetosphere. Several new results have been obtained predominantly through simultaneous satellite- and ground-based observations.

Upper atmosphere imaging using the OMTIs

We continued to operate the optical mesosphere thermosphere imagers (OMTIs) comprising of five sky-scanning Fabry-Perot interferometers, 21 all-sky charge-coupled device imagers, three tilting photometers, and three airglow-temperature photometers. OMTIs were used to investigate the dynamics of the mesosphere, thermosphere, and ionosphere. Several new results were obtained from OMTI measurements in FY2022. We succeeded in observing a low-latitude aurora at Rikubetsu, Hokkaido, Japan, for the first time in eight years. We elucidated the propagation characteristics of mesospheric atmospheric gravity waves and MSTIDs by using data from Darwin, Australia and Sata, Japan over a 10-year period.

Ionospheric disturbances observed by GNSS networks

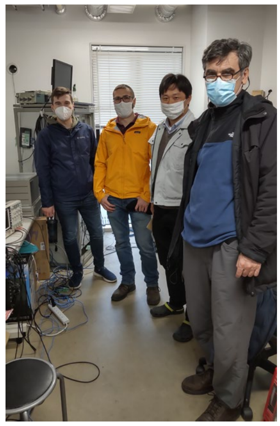
We developed a database providing global 2-dimensional total electron content (TEC) maps with high temporal and spatial resolutions including more than 20 years of data. We found that equatorial plasma bubbles extending to mid-latitudes have geomagnetic conjugate structures between both the Northern and Southern hemispheres during the main phase of a magnetic storm, and that the plasma bubbles disappeared earlier in the Northern hemisphere than in the Southern hemisphere. A comparison with Super Dual Auroral Radar Network (SuperDARN) radar data during geomagnetic storms on May 27 and 28, 2017 revealed that plasma density irregularities associated with plasma bubbles extending to mid-latitudes were observed by the radar.



Distribution of Rate of TEC Index (ROTI) during a magnetic storm. ROTI enhancement corresponding to plasma bubbles had a geomagnetic conjugate structure between Northern and Southern hemispheres (Sori et al., 2022).

SuperDARN Hokkaido HF radars

Using SuperDARN Hokkaido HF East and West radars in Rikubetsu, Hokkaido, we studied the ionospheric disturbances caused by the Tonga volcanic eruption. We compared them with GNSS TEC data to demonstrate that disturbances were observed in the Northern Hemisphere earlier than the arrival of pressure waves. This result was interpreted as the projection of a dynamic electric field onto the opposite hemisphere. We also studied the statistical characteristics of diverse Pc5 pulsation parameters and suggested that Pc5 waves observed at geomagnetic latitudes of 45–55° were global waves generated by solar wind disturbances. Additionally, we developed a full-spec imaging receiver system for implementation at the Hokkaido East Radar. Five international researchers visited the institute to perform joint research on diverse topics using SuperDARN and other ground-based satellite observation.



Group photo of the international technical exchange program activity between Canadian and Japanese scientists / engineers on the development of the SuperDARN imaging system

Promotion of EISCAT and EISCAT_3D projects

We proceeded with the EISCAT project in collaboration with the NIPR: (1) we performed 10 EISCAT SP experiments for Japanese colleagues, (2) we proceeded with the EISCAT_3D project, and (3) we held a special session for the Master Plan 2020 in JpGU2022. We also operated a photometer, an MF radar in Tromsø, and a meteor radar in Alta, Northern Norway, and collaborated with Japanese and international colleagues on mesoscale wind dynamics and sporadic sodium layers in the MLT region. By using all-sky digital camera images, we have created the “Tromsø AI” that can alert us when an auroral display shows up above Tromsø (69.6ºN, 19.2ºE).

Atmospheric stabilities in the polar upper mesosphere above Tromsø

We have studied atmospheric stabilities of the polar winter upper mesosphere region (80–100 km) using temperature and wind data of 6-min and 1-km resolutions obtained with the sodium lidar at Tromsø. The probability of convective (dynamic) instability varied from approximately 1% (4%) to 24% (20%), with a mean value of 9% (10%). The probability of convective instability demonstrates a dependence on the geomagnetic activity (local K-index) between 94 and 100 km, suggesting an auroral influence on atmospheric stability. The probability of dynamic instability demonstrates a solar cycle dependence, including a dependence on the 12 h wave amplitude. The probability of convective instability at Tromsø appears to be higher than that at middle/low latitudes, whereas the probability of dynamic instability is similar to that at middle/low latitudes.

SDI-3D project

The Scanning Doppler Imager (SDI) is a ground-based Fabry-Perot Doppler spectrometer operating in the all-sky imaging mode with a separation-scanned etalon to resolve the Doppler spectra at heights of 90–400 km. A single station can estimate the horizontal wind vector and temperature on a horizontal plane with a 1000 km diameter. We established an international team in 2018 with researchers from Japan, Scandinavian countries, and the US. 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. In 2018, an international exchange program (or cross-appointment system) was established between Nagoya University and the University of Oulu (Finland). This was the first time for Nagoya University, and resulted in a faculty member staying at Oulu for three months in 2022. The development of SDIs has progressed satisfactorily to deploy them at three locations (two in Finland and one in Sweden) based on a budget awarded by the National Science Foundation from the US. As a preliminary work toward simultaneous observations with EISCAT_3D and SDIs, measurements from optical instruments (Fabry-Perot interferometer and all-sky imager), Dynasonde, and Swarm satellites were evaluated. This study presented a delay of approximately 10 min in the thermospheric wind reversal to ionospheric ion velocity reversal in the vicinity of an ionospheric trough (Oyama et al., 2022).

FACTORS mission for *in-situ* plasma observations by formation flight in the space–Earth coupling system

To realize simultaneous *in situ* observations of space-Earth coupling physical mechanisms using multi-satellite formation flight, a new space exploration mission, FACTORS, after the ERG (Arase) satellite mission has been proposed in the next small satellite mission category of ISAS/JAXA. Although the separation distance (1–50 km) between two satellites in polar orbit at 350–3500 km altitudes was planned to be controlled by new types of formation flight operations, our proposal has not been approved because the total cost of the mission and the new formation flight techniques would not meet ISAS/JAXA requirements. Countermeasures and further improvements toward mission reconstruction still need to be considered.

Experiments to lower the detectable energy of electrons using floating mode APD

We attempted to detect electrons with energies of less than several keV using the electrostatic acceleration of a floating-mode avalanche photodiode (APD). We succeeded in detecting down to 10-eV electrons due to 5-keV acceleration. We also performed experiments to install the APD at the electrostatic energy analyzer exit and detect electrons passing through the analyzer using a floating-mode APD. We verified that the floating-mode APD could detect down to 10-eV electrons while retaining the characteristics of the analyzer in terms of the energies and angles of the incident electrons.

Development of ion mass analyzing technology in combination with an electrostatic analyzer

We performed ion mass spectrometry experiments using an APD in combination with an electrostatic analyzer. In this experiment, we detected H^+, He^{2+}, He^+, and N^+ (as a substitute for O^+) from 5 to 80 keV/q. We found that we were able to distinguish between H^+ and He^{2+} at incident energies above 10 keV/q and between H^+ and N^+ at incident energies above 20 keV. Additionally, an experiment to accelerate ions by floating the entire APD at a -5 kV potential was also performed, and 5 keV H^+ was successfully detected by using the floating mode.

Magnetic field variations in pulsating auroras observed by the LAMP sounding rocket

We observed magnetic field variations in association with pulsating auroras using a magneto-impedance sensor magnetometer (MIM) carried by the Loss through Auroral Microburst Pulsations (LAMP) sounding rocket that was launched at 11:27:30 UT on March 5, 2022, from the Poker Flat Research Range, Alaska. At 200–250 km altitude, the MIM detected clear enhancements in the magnetic field by 15–25 nT. From simultaneous observations with the ground all-sky camera, we found that the LAMP footprint at an altitude of 100 km was located near the center of a pulsating auroral patch. These observations were compared with the results of a simple model computation, wherein local electron precipitation into the thin-layer ionosphere caused an elliptical auroral patch. We conclude that a pulsating auroral patch is fundamentally associated with a one-pair field-aligned current comprising downward (upward) currents at the poleward (equatorward) edge of the patch.

Development and deployment of a low-cost magnetometer using MI sensor

We made some modifications to commercially available magneto-impedance (MI) sensors, as they cover the geomagnetic field (±80,000 nT) range. We developed an instrument for ground measurements, including MI sensors, a Raspberry Pi-based data logger, and an A/D converter, which cost only approximately 1/10 of the usual cost of a fluxgate magnetometer. Experimental field observations over a few months demonstrated that the MI sensors could detect geomagnetic variations, such as Sq variations, geomagnetic storms, and geomagnetic pulsations. We named this instrument MIM-Pi and installed it at Kawatabi, Miyagi, Shirakami, and Aomori in the autumn of 2022 for continuous observations. In the future, we plan to deploy MIM-Pi in the Kanto-Tohoku region and construct a dense network of geomagnetic field observations. Network data will be used to estimate the plasma mass density in the inner magnetosphere. The operating principles of the MI sensor and its pilot observational results were published in *Journal of Geophysical Research*).

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/