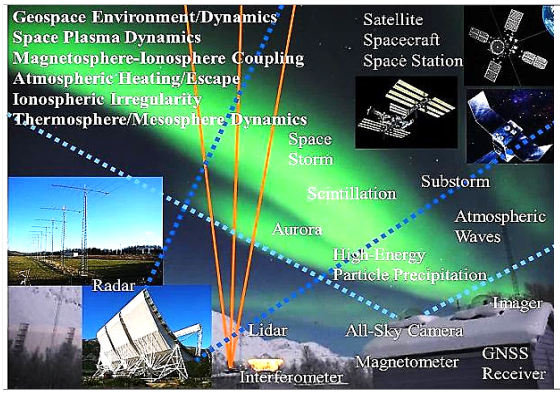
# Division for Ionospheric and Magnetospheric Research




- 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 FY2020

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

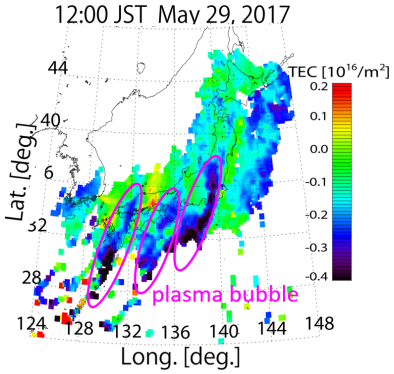
Aurora/airglow imagers and electromagnetic wave receivers have been involved in the PWING project at eight stations around the North Pole, at MLATs of approximately 60° (in Canada, Russia, Alaska, Finland, and Iceland) since 2016. They were used to investigate the plasma and wave dynamics in the inner magnetosphere. New results were obtained in FY2020. For example, the plasma and field characteristics of discrete and diffuse auroras in the inner magnetosphere were revealed based on a conjugate measurement by the Arase satellite and at Nain, Canada. This observation also showed that the field-aligned potential difference that creates discrete auroral arcs extended at altitudes more than 30000 km. Another four conjugate ground–satellite measurements revealed that the source mechanism of the stable auroral red arcs was mainly Coulomb collisions between ring current ions and plasmaspheric electrons.

### 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. New results were obtained from OMTI measurements in FY2020. For example, we reported the first multi-wavelength images of STEVE auroras at sub-auroral latitudes. The images showed that the STEVE auroras contain ordinary auroral green and red emissions, and background continuum emissions in almost the same arc shape in the images.

## Ionospheric disturbances using GNSS receiver network

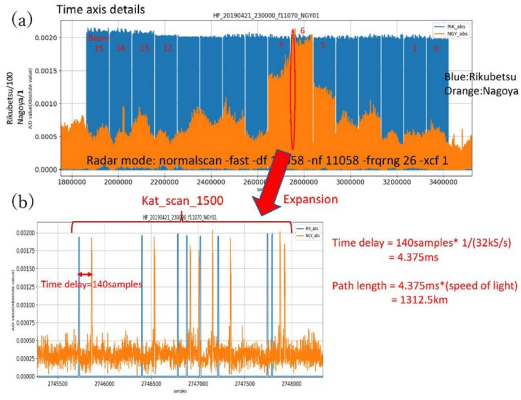
We developed a database that provides global 2-dimensional maps of the total electron content (TEC) with high temporal and spatial resolutions. The TEC data were obtained from more than 9000 GNSS receivers worldwide. Using the TEC database, we studied the generation mechanism of storm-enhanced density (SED) and found that the major cause of the midlatitude broad SED is the upward motion of the ionosphere by the enhanced convection electric field. The TEC maps also revealed that plasma bubbles over Japan survived until the afternoon during the recovery phase of a geomagnetic storm, although plasma bubbles usually disappeared at sunrise.




Map of TEC over Japan during a geomagnetic storm. Plasma bubbles can be seen as TEC depletions.

## 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 sub-auroral polarization streams, and found that the sub-auroral polarization stream occurrence rate depends not only on the season, magnetic latitude/local time, and geomagnetic activity, but also on the geographical longitude. In addition, we installed a 4-ch subset imaging receiver system at the Hokkaido East radar site and obtained some initial scientific results. The results of the operation of the HF radar remote receiver at Nagoya University's main campus were accepted for publication.




Sample plots of the SuperDARN Hokkaido East radar remote receiver data (Nagoya University main campus).

## Promotion of FACTORS 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 for terrestrial radiation belt exploration, is being promoted for simultaneous multi-point *in-situ* observations by multi-satellite formation flight in the near-Earth space and terrestrial upper atmosphere. During this fiscal year, to maintain satellite distances of 1–50 km in the polar orbit at altitudes ranging from 400 to 4000 km, we numerically simulated two types of formation flight operations using the conventional thruster method with propellant and a newly proposed aerodynamics method with precise satellite attitude controls near the perigee. The results indicated that the aerodynamics method was more applicable because the required high-level accuracy could be achieved better with a small and stable atmospheric reaction, rather than the thruster operation, whose main purpose is large orbital control.

## Improvement of charged particle beamline system used in a calibration experiment of analyzers mounted on space exploration satellites

In the clean room of our institute, we modified the charged particle beamline system required for the calibration experiment in the development processes of particle analyzers for future space exploration. The filament from which the electron emissions produce the ions and electrons in the neutral gas source was changed from a tungsten to a high-emission type of iridium filament coated by $Y_2O_3$, and thus the beamline could be operated with lower power (1.7 A/1.65 V/2.8 W) than before (4.71 A/2.55 V/12 W). The ion beam mass discrimination profile of the 90-degree course line was also improved by adjusting the electromagnet position and changing the magnetic field strength.

## Floating-mode APD experiments using 10s-keV electrons and $^{241}$Am

To lower the lowest limit of the energy range of electron energy analyses using avalanche photodiodes (APDs) as alternative space-qualified detectors of microchannel plates, we applied a floating voltage to the APD to accelerate electrons by the electric field generated around it, and then analyzed the electron energies. First, we performed experimental tests to confirm the basic features of APD with alpha particles and gamma rays radiated by $^{241}$Am; thus, we removed the noise originating from the floating voltage with a low-pass filter and analyzed the energies of the accelerated electrons. The next step was to perform energy analyses of electrons whose original energies were much less than 5 keV before the APD acceleration after significantly reducing the background noise level by modifying the electrical circuit.

## Promotion of EISCAT and EISCAT_3D projects

We proceeded with the EISCAT project in collaboration with National Institute of Polar Research (NIPR) and undertook the following: (1) Seven EISCAT Special Program experiments for Japanese colleagues; (2) EISCAT_3D project; and (3) a special session for the Master Plan 2020 in JpGU2020. We have also operated a photometer, an MF radar, and a meteor radar in northern Scandinavia, and have collaborated with Japanese and foreign colleagues in studies on atmospheric stability, gravity waves, sporadic sodium layers, and vertical winds. We conducted statistical studies of the lower thermosphere wind and the atmospheric stability of the polar winter mesopause region.

## Oxygen density enhancement and EMIC waves in the inner magnetosphere

The $O^+$ density is sometimes enhanced in a limited range of altitudes in the deep inner magnetosphere and is referred to as the oxygen torus. We investigated the longitudinal structure of the oxygen torus using simultaneous observations from the Arase and Van Allen Probes satellites. We found that the oxygen torus was localized to the dawn sector, indicating a crescent-shaped torus. It was newly found that an EMIC wave in the $H^+$ band coincided with the oxygen torus. The linearized dispersion relation of EMIC waves showed that the growth rate was higher in the oxygen torus than in the adjacent regions in the plasma trough and plasmasphere. We concluded that the oxygen torus in the inner magnetosphere might play an important role in the excitation of EMIC waves. These results were published in Earth Planets and Space (Nosé et al., 2020).

## Development of a low-cost magnetometer using a MI sensor

The magneto-impedance (MI) effect was discovered approximately 25 years ago, and a micro-sized 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 (±70000 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 the MI sensors could detect geomagnetic variations such as Sq variations, geomagnetic storms, and geomagnetic pulsations. This instrument could be used for continuous field measurements over a few months. We are also developing an onboard instrument for future sounding rockets.

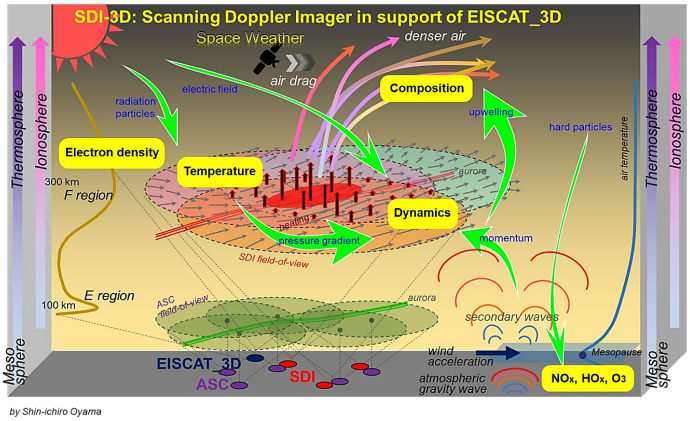
## Japan-Russia bilateral project

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. Remote workshops (September 2020 and March 2021) were held, and we published several papers based on discussions during the workshops. For example, we studied the ionospheric trough and auroral activity, which appeared during an interval between two high-speed solar wind events, analyzing measurements from all-sky cameras deployed in Scandinavia and Russia, and satellites crossing over the cameras. An auroral arc emerged for only 7 min immediately after the substorm onset, but in the ionospheric trough, which appeared at higher latitudes than usual. This finding on a possible moment of the stable auroral red (SAR) arc birth was published in the *Journal of Geophysical Research Space Physics* (Oyama et al., 2020).

## 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 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. 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 stayed in Oulu for one month in 2020. A proposal submitted to the National Science Foundation in the USA was awarded in 2020, and the development of optical and radio wave instruments, including three SDIs, began. We officially participated in administrative-level meetings with the Memorandum of Understanding, integrating the ground-based observation network in Finland, Norway, and Sweden.




Schematic drawing of the SDI-3D project. The three SDIs will begin operation in fall 2023 and perform collaborative experiments with the EISCAT_3D radar, optical instruments and radio wave receivers that are deployed in the same area. This project aims at wide and high-resolution measurements of the ionosphere and thermosphere in association with intensive inputs of energy and particles into the polar region during periods of geomagnetic activity.

## 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)<br>http://reimei.isee.nagoya-u.ac.jp/ (present) |
| Wp geomagnetic index | https://www.isee.nagoya-u.ac.jp/~nose.masahito/s-cubed/ |