COMMISSION G: Ionospheric Radio and Propagation (including ionospheric communications and remote sensing of ionised media) (November 2020 – May 2023)

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1. Summary

URSI Commission G aims to discuss radio and its propagation in the ionosphere. In addition to these essential purposes, this commission is to study the ionospheric communications and remote sensing of the ionized media, too. The last purpose includes general research of the ionosphere and/or the upper atmosphere. We should note that measurement techniques and instruments take important part of our research in the commission G.

The ionosphere that overlaps with the upper atmosphere is the transition region from the Earth's atmosphere to the space. It is a region that is largely affected from both the top and bottom, and complex interactions occur. Recently, studies of the other planets are getting more important in our research community. Researchers from Japan contribute the vast research area of the USRI Commission G in wide spectrum. Level of the research is also very high. We have various measurement instruments on the ground, sounding rocket, and satellites. Region of the studies spreads from Japan, Asia to the world as well. We have big efforts on modeling (large-scale computer simulation) and database. Comprehensive analyses of multiple data are also actively conducted.

This report compiles contributions from our committee members. We summarized the research activities from major institutions in Japan. They include variety of studies with major measurement instruments, observation network, related model/database projects, and future plans that are closely related to the Commission G.

2. Activity Report

2.1. National Institute for Polar Research (NIPR)

NIPR continues to promote national and international collaborative research using the PANSY and EISCAT radars. For the PANSY project, research results on gravity waves in the Antarctic troposphere and lower stratosphere and polar mesospheric echoes have been published. For the EISCAT project, several research results related to pulsating auroras, etc. have been published. A summary paper on the Interhemispheric Coupling Study by Observations and Modelling (ICSOM) has also been published.

The advanced radar research promotion center (ARRC) was established in NIPR in April 2022 to promote further joint usage and collaborative research with advanced radars such as the EISCAT Svalbard Radar (ESR), PANSY, and the forthcoming EISCAT_3D radar system. Its website is https://www.arrc.nipr.ac.jp/. The first open call for proposals for the joint use of the PANSY radar was launched in December 2022. Six applications were accepted, and the selected proposals will be implemented in FY2023.

2.2. Institute for Space-Earth Environmental Research (ISEE), Nagoya University

Many ground-satellite conjugate measurements of phenomena at subauroral latitudes have been reported in 2020-2023 such as (1) plasma and field observations in the magnetospheric source region of four stable auroral red (SAR) arc, (2) spatiotemporal development of global distribution of magnetospheric ELF/VLF waves, (3) magnetic conjugacy of Pc1 waves and isolated proton precipitation at subauroral latitudes, (4) multi-event study of characteristics and propagation of

naturally occurring ELF/VLF waves, (5) simultaneous observation of two isolated proton auroras at subauroral latitudes, (6) first simultaneous observation of a nighttime medium-scale traveling ionospheric disturbance, (7) multi-wavelength imaging observations of STEVE. We further reported (1) a review of medium-scale traveling ionospheric disturbances (MSTIDs), (2) statistical results of the MSTID activity and propagation direction of MSTIDs, (3) statistical study of MSTIDs over Taiwan, (4) the occurrence features and causes of storm-time plasma bubbles in the equatorial to mid-latitude ionosphere, (5) relationship between the locations of the midlatitude trough minimum in the ionosphere and plasmapause in the inner magnetosphere, (6) calculation TEC variations by inputting the temporal variation of the solar flare spectrum for the X9.3 flare into the GAIA model and compared it with the observed TEC, (7) an unseasonal equatorial plasma bubble (EPB) event over South-East Asia, (8) a general review of equatorial plasma bubbles and scintillation features including their physical mechanisms and controlling factors responsible for their occurrence, and unresolved issues related to their day-to-day and short-term variability, (9) the polarization electric field and associated density variations of a night time MSTID in the magnetosphere. Furthermore, J.-P. St-Maurice and Nishitani (2020) proposed a new generation mechanism of the near range echoes observed by the SuperDARN radars.

2.3. Research Institute for Sustainable Humanosphere (RISH), Kyoto University

We are operating two large atmospheric radars in Japan and in Indonesia. They are described as follows. The MU radar is the 46.5-MHz atmospheric radar located in Shigaraki, Shiga, Japan. The radar can measure atmospheric winds from near the surface to about 20km, and is also useful to measure coherent and incoherent scatters from the ionosphere. Multi-beam capability with the active-phased array antenna is the most power feature of the system, and the various interesting observations were conducted so far. (MU radar and EAR web: http://www.rish.kyoto-u.ac.jp/mu+ear/english/index.html)
MU radar web: http://www.rish.kyoto-u.ac.jp/mu/en/

Equatorial Atmosphere Radar (EAR) is a big atmospheric radar located in West Sumatra, Indonesia. The EAR was established in June 2001, and has continued long-term observations since June 2001. Research Institute for Sustainable Humanosphere (RISH), Kyoto University and National Institute of Aeronautics and Space (LAPAN) of Indonesia jointly operate the facility that is open to scientists from both countries and from the world. The EAR data are basically opened.
EAR web: http://www.rish.kyoto-u.ac.jp/ear/index-e.html

Our recent research activities are study of atmospheric turbulence by using multiple measurement instruments, the MU radar, EAR, radiosonde, UAV etc. This is to fill gap that existed for long time between the turbulence theory and observations. For the study of the ionosphere radio propagation techniques are used. One is the dual-band beacon experiment at 401MHz/965MHz from the COSMIC-2 satellites to the ground-based receiver in Thailand, Vietnam, and Indonesia. Another way is 3D tomography analysis of the total-electron content (TEC) measurement from GNSS receivers of GEONET. Numerical model studies were conducted to connect between global and local models. The analysis technique largely advanced by including data from the ionosonde network. There were much effort on the radio remote sensing techniques. One is advanced study for radar clutter rejection. We also conducted theoretical simulations of the atmospheric radar echo itself. Development of new wind measurement technique by using radar imaging technique is underway.

2.4. National Institute for Information and Communications Technology (NICT)

We have been operating regular ionosonde observations in Japan and in the Antarctica since 1950's to monitor ionospheric conditions as a part of space weather. The observations have been also used for various research topics such as short-wave fadeout during extreme space weather event (Tao et al., 2000). GEONET is the GPS receiver network over Japan that is operated by Geospatial Information Authority of Japan. GEONET is also used for ionospheric monitoring and research. Two-dimensional total electron content (TEC) maps over Japan have been provided routinely by NICT (https://aer-nc-web.nict.go.jp/GPS/DRAWING-TEC/). Several prominent research topics related to GEONET are statistical analysis of long-term estimation of extreme TEC in Japan (Nishioka et al., 2021) and solar

activity dependence of medium-scale traveling ionospheric disturbances (Perwitasari et al., 2022). SEALION is an ionospheric observation network in Southeast Asia to monitor and study the occurrence and growth of equatorial ionospheric disturbances, especially plasma bubbles. The network has been setup by NICT since 2003 and has been operated to date by NICT with an international effort by seven institutes in five Southeast Asian countries. In January 2020, a new VHF radar was installed in Chumphon, Thailand, close to the magnetic equator (SEALION data web: https://aer-nc-web.nict.go.jp/sealion/). Many studies on the equatorial ionosphere have been carried out recently (e.g., Thammavongsy et a., 2020, Meenakshi et al., 2021, Tulasi et al., 2020 and so on). Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy (GAIA) is a global physics model of the Earth's whole atmospheric regions from the troposphere to the topside thermosphere as well as the ionosphere. The model has been developed under the collaboration between Kyushu University, Seikei University and NICT since 2007. Some of the recent studies using GAIA can be found in the ionospheric research (Shinagawa et al., 2021, Watanabe et al., 2021 and so on). The real-time and prediction system using GAIA has also been developed (Tao et al., 2020). A regional ionospheric model has also been developed and used for the studies of sporadic E layers (e.g., Andoh et al., 2023).

2.5. Electronic Navigation Research Institute (ENRI)

Electronic Navigation Research Institute (ENRI) is studying ionospheric impacts on GNSS. Ionospheric effects on GNSS and mitigation are important topics for practical use of GNSS such as air navigation. Spatial variation in the ionospheric total electron contents (TEC), ionospheric scintillation in GNSS signals are characterized to support such GNSS-based aeronautical navigation system. Realtime ionospheric monitoring over Japan is realized and continuously operated by ENRI. The realtime monitoring includes TEC perturbation, TEC variation (rate of TEC index: ROTI), absolute TEC, and three-dimensional electron density profiles reconstructed by using realtime GNSS network data. Anomalous long-distance propagation of VHF aeronautical navigation signals (108-118 MHz) by the sporadic E (Es) layer, which is a potential source of radio interference, is continuously observed by a ground-based receiver network developed by University of Electro-Communications and other groups. Observation of signals of Instrument Landing System (ILS) Localizer (LOC) by an aviation receiver has been started to assess the impact of anomalous propagation on an airborne receiver.

2.6. University of Electro-Communications

Studies of mid and low latitude ionosphere using various radio and optical observations have been conducted. One of the targets is sporadic E which is a thin layer of enhanced electron density in the mid-latitude E region ionosphere. Spatial structure and its dynamical characteristics were investigated by using monitoring observations of aeronautical navigation radios at VHF frequencies. By combining such VHF radio observations with GPS TEC measurements, the spatial structure of sporadic E during daytime was visualized to show a front-like structure extending in the zonal direction and move in the meridional direction. The dynamical characteristics of sporadic E was also examined by using a HF Doppler sounding system in Japan. The HF Doppler observation of sporadic E during nighttime indicated that the structure moves southwestward in tandem with the Medium-Scale Traveling Ionospheric Disturbances (MSTIDs) in the F region altitutde, confirming the coupling of the E and F region ionosphere during summer nighttime. Data from the HF Doppler sounder were also used to show the vertical motion of the mid-latitude ionosphere trigger by the penetrating electric field from the magnetosphere. Now the system of the HF Doppler sounder is being upgraded and most of the receiving system is based on the software defined radio. In the close future, we plan to add a FM-CW ranging capability to the HF Doppler sounding system and derive the altitude of reflection.

2.7 Chiba University

Chiba University, in collaboration with other universities and institutes, has been conducting studies on ionospheric disturbances using HF (High Frequency) and LF (Low Frequency)/VLF (Very Low Frequency) bands of radio waves. For research using HF-band radio waves, our focus has been on studying ionospheric disturbances associated with natural disasters such as earthquakes, volcanic

eruptions, and typhoons using HF Doppler observation. The University of Electro-Communications has been an active partner in this research, and due to nearly two decades of observation, an update to the system was necessary. Our laboratory has played a central role in developing new receivers using software-defined radios (SDRs) to replace conventional ones. Currently, all stations except one have been upgraded to new digital receivers. Since SDR receivers are now becoming smaller and less expensive, even relatively small ones can perform observation effectively. Therefore, we are also developing an inexpensive SDR receiver for the HF Doppler observation. As part of the HF-START project, conducted in collaboration with the National Institute of Information and Communications Technology, we have opened a web page to the public. However, the current webpage only provides information on propagation paths. A new scheme for deriving the attenuation of radio waves in the ionosphere is being developed to provide information on received strength. In addition to HF observations, we are involved in international collaborative observations with Tohoku University and Hokkaido University, known as AVON (Asia VLF Network Observation)/OCTAVE (Observation of CondiTion of ionized Atmosphere by VLF Experiment), using LF/VLF observations. Through these observation networks, we have successfully clarified D-region ionospheric variations associated with earthquakes. Moreover, we have revealed the D-region oscillations caused by ULF-modulated energetic electron precipitation in the sub-auroral zone, horizontal inhomogeneity of the D-region during solar flares, and the relationship between the D-region variation and SSW (Sudden Stratospheric Warming).

2.8. Tohoku University

Members (staffs and graduate school students) of Tohoku University, and their collaborators carried out research activities for the Earth's ionosphere and magnetosphere using the data from the ground (EISCAT radar etc.) and spacecrafts (Arase, VAP, etc.). We also performed planetary atmospheric studies by modeling, and probe data particularly for Mars using the data taken by MGS, MAVEN, and ExoMars/TGO. In addition, we participate as Co-I for the future planetary spacecraft missions, such as, JUICE, MMX. We have also operated our auroral all sky imagers at Arctic Longyearbyen and Antarctic Syowa station as collaborations with NIPR since 2022. We are also conduction ground-based telescopes dedicated to planetary atmospheric observation at the Haleakala summit of Hawaii.

Tohoku University organized the symposium on planetary science was held in Sendai in February every year during this period. The goal of this symposium is to extend present research, and also to create new researches, fields for the future, through reviews and discussions on planetary sciences of not only solar-planetary plasmas/atmospheres but also interaction with the surface of planetary bodies and environment of exoplanets. (See the website at http://pparc.tohoku.ac.jp/sympo/sps/.)

The publication list is in the following. We have three research group in Tohoku University, and our web pages are https://pparc.gp.tohoku.ac.jp/, https://pat.gp.tohoku.ac.jp/, https://pat.gp.tohoku.ac.jp/.

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