COMMISSION G: IONOSPHERIC RADIO AND PROPAGATION

Edited by Takashi Maruyama

G1. Ionospheric Observation Techniques

G1.1. Application of GPS to Ionospheric studies

A dense GPS receiver network, GPS Earth Observation Network (GEONET), in which about 1200 receivers cover Japan's islands, has a large capability in imaging ionospheric total electron content (TEC) with high time and spatial resolution. New algorithms of TEC and instrumental biases derivation based on the GEONET data were developed by Ma and Maruyama [2003] and Ma et al. [2005a]. Ping et al. [2002] and Otsuka et al. [2002a] developed TEC regional mapping techniques. Electron density structure in the vertical plane was calculated by a tomography technique [Ma et al., 2005b]. By using these and also previously developed techniques, ionospheric disturbances such like traveling ionospheric disturbances (TIDs) and storms were extensively studied in conjunction with other techniques as described in sections G1.2 and G2.3. Balan et al. [2002] compared GPS derived TEC and numerical model results. Another application of GPS signals to ionospheric studies is the so-called occultation measurements, in which a low earth orbit satellite receives the GPS signals. Hocke and Igarashi [2002], Hocke et al. [2002b], and Pavelyev et al. [2003] studied electron density structure by analyzing occultation data.

G1.2. Multiple Instruments and Campaigns

Alaska Project

National Institute of Information and Communications Technology (NICT) is conducting Alaska Project in collaboration with Geophysical Institute, University of Alaska Fairbanks, USA. The project aims to observe Arctic atmosphere environment in Alaska, and was first formed in 1992, under the Japan-US Science Technology Cooperation Agreement. Murayama et al. [2002] review an overview of the project and its results. For the project, NICT developed advanced radio/optical remote-sensing technologies and constructed the observation system of the Arctic middle atmosphere. Major instruments involved in the project are a Fabry-Perot interferometer [Ishii et al., 2002], all-sky imagers [Kubota et al., 2002; Yamamoto et al., 2002], an imaging riometer [Mori et al., 2002], and SALMON (system for Alaska middle atmosphere observation data network) [Oyama et al., 2002].

FRONT

Nighttime TIDs and F-region ionospheric irregularities were simultaneously observed in an observation campaign named FRONT (F-region Radio and Optical measurement of the Nighttime TID). Saito et al. [2002] led the first FRONT campaign in May 1998. They employed the MU radar, a GPS receiver network (GEONET), and a network of 630-nm all-sky imagers. The observations were quite successful in finding a close relationship between the wavelike structures of F-region field-aligned irregularities (FAIs) and medium-scale TIDs (MS-TIDs). There was the FRONT 2 campaign in August 1999 by adding another 630-nm all-sky imager in Okinawa [Shiokawa et al., 2002a]. In May-June 2003, FRONT 3 was carried out with simultaneous observations of all-sky imagers in Japan and Australia. Shiokawa et al. [2005b] discovered clear geomagnetic conjugate structures of the MS-TIDs between Japan and Australia.

WAVE2000

Iwagami et al. [2002] conducted WAVE2000 (Waves in Airglow Structures Experiment over Kagoshima in 2000), a coordinated rocket-born and ground-based observation campaign for investigating a formation process of wavelike airglow structures. They used a sounding rocket and a network of OH (hydroxyl) and O (atomic oxygen) 558-nm imagers. From the rocket observations they obtained a height distribution of the atomic oxygen. They also conducted a foil chaff experiment to measure neutral winds [Koizumi et al., 2003; 2004]. The successive campaign, WAVE2004, were conducted in January 2004.

Coupling Processes in the Equatorial Atmosphere (CPEA)

A large VHF radar, Equatorial Atmosphere Radar (EAR), was installed in 2001 right on the equator in West Sumatra, Indonesia (0.20°S, 100.32°E) [Fukao et al., 2003a]. “Coupling Processes in the Equatorial Atmosphere (CPEA)” is a research program funded by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) as a Grant-in-Aid for Scientific Research on Priority Areas in the period from September 2001 to March 2007. CPEA studies dynamical coupling processes in the equatorial atmosphere by conducting various observations in the Indonesian equatorial region. EAR is the core facility for the program. As the geomagnetic latitude of the EAR site is 10.36°N, it is a suitable location for investigating the low latitude ionosphere in the southern hemisphere [e.g., Fukao et al., 2003b].

SEEK-2

SEEK-2 (Sporadic-E Experiment over Kyushu 2) is an observation campaign conducted in August 2002 to study spatial structure of FAI and sporadic-E (Es) layer by means of two sounding rockets and a ground-based observation network of radars and optical instruments. We found that the quasi-periodic (QP) structures seen in RTI plots are the reflection from FAIs associated with horizontal structures of the Es layers. Candidate mechanisms of the structuring are gravity waves and Kelvin-Helmholtz Instability. Polarization electric field was induced from the Es layer with QP echoes, mapped upward along the geomagnetic field line, and played an important role in determining structures of the whole ionospheric E-region. These results will be soon reported by papers in a special issue [e.g., Yamamoto et al., Ann. Geophys., in press, 2005].

On-going experiment and future plans

FERIX (F-region and E-region Coupling Study) is an on-going experiment to study electrodynamical coupling processes between ionospheric F- and E-regions. In June-August 2004, the MU radar observed the F-region FAIs and a portable radar observed the E-region FAIs. Both scattering volumes were connected with the same geomagnetic field line. The results showed clear correlation between FAIs in the both regions. In 2005 similar experiment continues with the MU radar and GEONET. Coordinated rocket-ground experiment in summer 2007 is proposed, which aims to study seeding mechanisms of MS-TIDs. Lithium-release from the rocket will be conducted to measure the neutral winds in the F-region. Mesosphere-Thermosphere-Ionosphere (MTI) satellite working group is planning a small-satellite mission to study MLT and F-regions at low- and midlatitudes by observing airglow emissions from the Earth's upper atmosphere. The project was formally proposed to JAXA in January 2005.

G1.3. Other Techniques

There were developments of radio/optical techniques to measure the ionosphere and MLT regions. Maruyama [2002] developed a technique to estimate in-situ electron density in the topside ionosphere from the cosmic radio-noise intensity measurements by the satellite. During the Leonid meteor shower in November 2001, Maruyama et al. [2003] ran the ionosondes in a rapid-run mode and found meteor-induced Es patches. Nakamura et al. [2002] conducted meteor echo observations with the MU radar, and showed that it is possible to measure spatial changes in the wind velocity field by dividing the echoing region into four azimuth sectors. Radar echoes from the mesosphere are not fully understood. Kubo et al. [2002] carefully analyzed the MU radar data and constructed an empirical model for the mesospheric VHF radio wave scattering. Shiokawa et al. [2003c] developed a two-channel Fabry-Perot interferometer with thermoelectric-cooled CCD detectors. The system is able to measure neutral winds in the mesopause region at 558 nm and in the thermosphere at 630 nm, automatically operated in the MU radar site in Shigaraki, Japan. Nakazawa et al. [2004] investigated "SEKKI" that means "red atmosphere" appearing in Japanese historical literature in the 12-19th centuries. From careful discussions they reached a conclusion that the SEKKI phenomena are giant low-latitude auroras.

G2. Ionospheric Structure and Disturbances

G2.1. Polar Ionosphere

Many studies using European Incoherent SCATter (EISCAT) radar has been published in this period. Fujii et al. [2002] determined the characteristics of field-aligned ion motions in the E and F region ionosphere. Maeda et al. [2002] investigated ion and neutral temperature profiles in the E-region between 105 and 115 km, and compared the results with precipitating particles observed with the DMSP satellite. Nozawa et al. [2002] had a comparative study of the neutral wind in the polar upper mesosphere/lower thermosphere using two radars, EISCAT UHF radar and Tromso MF radar. Nozawa et al. [2003a] examined characteristics of the quasi 2-day waves in the polar mesosphere using the same set of instruments. Nozawa et al. [2003b] compared the quasi 2-day wave observed at Tromso and Poker Flat MF radars. Fujiwara et al. [2004] estimated turbulent and electromagnetic energy dissipation rates in the altitude range of 98-116km using data obtained by the EISCAT radar.

Super Dual Auroral Radar Network (SuperDARN) is an international collaborative project based on the network of coherent HF radars in the Northern and Southern polar regions. Hosokawa et al. [2001, 2002b] identified the dusk scatter event (DUSE) from 39 months of the observational database. Hosokawa et al. [2002a, 2003] performed a statistical analysis of the occurrence distribution of Doppler spectral width around the day-side high-latitude ionosphere using data from the conjugate radar pair, the CUTLASS Iceland-East radar in the Northern Hemisphere and the SENSU Syowa-East radar in the Southern Hemisphere. Hosokawa et al. [2004a] performed a case study of a favorable conjunction of an overpass of the Oersted satellite with the field-of-view of the SuperDARN Syowa-East radar during an interval of the southward IMF B_z. Hosokawa [2004b, 2005] and Ogawa et al. [2002a] discussed peculiar backscatter returns which are suspected as Polar Mesosphere Summer Echoes (PMSE). Nishitani et al. [2003] observed a strong asymmetry of the convection between the Northern and Southern hemispheres with the HF radar and DMSP satellite. Nishitani et al. [2004] reported a presence of ionospheric echoes with high Doppler velocity (>450 m/s) and very low spectral width (<60 m/s), observed by the CUTLASS and Syowa-East and -South SuperDARN radars. Ogawa et al. [2002b,c, 2003a,b] analyzed Syowa Station HF radar under disturbed geomagnetic conditions for studying how echoing region changes due to HF wave refraction caused by ionospheric disturbance. Ogawa et al. [2004] improved this study to discuss PMSE observed in both the hemispheres using HF, MF and VHF radars. Motoba et al. [2003] presented a case study of quasi-periodic pressure pulses detected by the ACE satellite and discussed the condition using the SuperDARN convection patterns.

Ishii et al. [2002, 2003, 2004] studied thermosphere-ionosphere coupling (TI coupling), especially vertical winds in the thermosphere on the vicinity of aurora using Fabry-Perot interferometers. Oyama et al. [2001a,b] discussed possibilities that these TI coupling is a source of gravity waves. Oyama et al. [2003, 2004, 2005] discussed TI coupling from the observed ion motion with IS radars in the polar region. Kubota et al. [2003] discovered a new type of auroras which do not change their shapes for several hours with high-sensitive all-sky imagers, and the phenomenon was named “co-rotating patches”. Lummerzheim et al. [2003] also used the instruments for understanding the mechanism of proton auroras. Mori et al. [2004] studied characteristics of precipitating electrons with the energy range of 40-80 keV using a 16x16 imaging riometer.

Sakanoi et al. [2004] investigated the generation mechanisms of flickering auroras with a high-speed imaging photometer system. Shiokawa et al. [2005a] reported that a total of 20 low-latitude aurora events in Japan were identified during the high solar activity period of 1999-2004 from routine observations by means of highly sensitive all-sky cameras and tilting-filter photometers.

G2.2. Midlatitude Ionospheric Structure

Many types of variations in the Sq field such as seasonal, year-to-year, and day-to-day variations are known to exist. Takeda [2002a,b] studied seasonal and year-to-year variations of geomagnetic Sq field using the global equivalent current system. It was found that the Sq current intensity in the solar minimum period is about half that in the solar maximum period and its year-to-year variation is relatively smooth. Takeda et al. [2003] examined relationships of the geomagnetic Sq field to the electric field, conductivity, and currents in the ionosphere.

F2 layer electron density strongly depends upon the solar EUV flux, thermospheric concentration, temperature, and wind. Zhang et al. [2002, 2003] explored a method for inferring solar EUV flux, atmospheric composition and wind using ionospheric electron density profile measurements. Incoherent scatter radar data from Millstone Hill and Shigaraki were assimilated into a theoretical model, which was used to derive EUV flux and [O]/[N_2] from electron density profiles.

Kawamura et al. [2002] studied the annual and semiannual variations of the midlatitude ionosphere under low solar activity using MU radar and a plasmasphere-ionosphere model. The study showed that the variations of the daytime midlatitude ionosphere near and above the ionospheric peak depend more on the neutral wind than on the thermospheric composition.

G2.3. Midlatitude Ionospheric disturbances

Ionospheric storms

Signatures of upper atmospheric disturbances during a major magnetic storm were studied by the MU radar, MF radar, optical imager, and GPS-derived TEC [Balan et al., 2004]. Kutiev et al. [2005] analyzed TEC data for 2000-2002, and found that TEC behavior during the storms is similar to that of foF2. While, Maruyama et al. [2004] found that positive TEC and negative foF2 disturbances could simultaneously occur in some time intervals of storms. Tsurutani et al. [2004] also analyzed global characteristics of ionospheric uplift and TEC changes during a large magnetic storm. Pavlov et al. [2004a] compared the electron density measured by the MU radar and modeled electron density during a magnetic storm.

Traveling ionospheric disturbances

Airglow images over Japan were analyzed and characteristics of MS-TIDs were discussed [Shiokawa et al., 2003a,b]. Further observations of MS-TIDs at the magnetic conjugated points in Japan and Australia revealed the simultaneous appearance of MS-TIDs at the both stations, which led that electromagnetic processes were more important for the generation of MS-TIDs [Otsuka et al., 2004a; Shiokawa et al., 2005b]. GPS derived TEC regional mapping is also a powerful tool for the study of TIDs. Saito et al. [2002] studied MS-TIDs in conjunction with the MU radar, and they found collocation of TID and 3-m scale irregularities. Airglow images and TEC of MS-TIDs were compared; Ogawa et al. [2002a] interpreted the observations by the assists of model calculations and Shiokawa et al. [2002a] found a latitudinal limitation of MS-TID activity.

Neutral wind fields associated with an equatorward traveling large scale TIDs (LS-TIDs) were investigated by using multiple instrumental technique [Shiokawa et al., 2002b, 2003d]. While, Tsugawa et al. [2003, 2004] clarified temporal and spatial characteristics of LS-TIDs based on the TEC data obtained by GEONET during the periods of geomagnetic disturbance.

Otsuka et al. [2003] investigated another type of ionospheric disturbances called midnight brightness wave, which propagated north-northeastward, using airglow images, Fabry-Perot interferometer (FPI), the MU radar, and the ionosonde network. Sahai et al. [2001] observed mesoscale-enhanced airglow bands moving to the southwest direction.

Sporadic E and irregularities

Ogawa et al. [2002d] conducted simultaneous observation of E-region FAIs with the MU radar and Es layers with ionosondes. They found that quasi-periodic (QP) structures of the FAIs were enhanced when f_oEs-f_bEs increased, which means that the FAI generation is closely related to localized density gradients within the Es layers. With the MU radar, Hysell et al. [2002a] carried out imaging observations of E-region FAIs, and found fine structures of QP echoes. Kagan et al. [2004] studied the Doppler shift of FAI radar echoes, and determined contribution from the neutral winds and electric fields. An observation campaign, SEEK-2 (Sporadic-E Experiment over Kyushu 2), was conducted in August 2002 with two sounding rockets and ground-based radio/optical instruments. The results will be soon published [e.g., Yamamoto et al., Ann. Geophys., in press, 2005].

Spatial structures of Es layers and polarization electric fields are important to know generation mechanism of the QP structures of the FAIs. Hysell et al. [2002b] simulated three-dimensional clouds of enhanced plasma density with a background electric field imposed by the F-region dynamo. If the clouds are smaller than about 1 km, the polarization electric field can be large enough for the FAI onset. Yokoyama et al. [2003] conducted two-dimensional simulation with rod-like enhancements of plasma density and found that polarization electric fields are induced by the neutral winds as well as by the background electric field. They showed that the induced polarization electric field maps upward along the magnetic field line, and form secondary plasma structures up to 120 km altitudes. Yokoyama et al. [2004a] found that Pedersen conductivity of the F-region strongly affects the polarization mechanism in the E-region by the 3-D numerical simulations. Cosgrove et al. [2004] studied the electrodynamical coupling processes and showed that the Perkins instability in the midlatitude F-region would be enhanced by the coexisting E-region instability with the same horizontal alignment.

G2.4. Equatorial Ionosphere

Plasma bubbles and ionospheric instability were studied by the Equatorial Atmosphere Radar (EAR), airglow imager, and ionosondes. The 47-MHz EAR located in West Sumatra, Indonesia has a capability of observing FAIs in multiple directions, in which radar beams perpendicularly intersect the magnetic field lines. Range-time-intensity (RTI) plots of radar backscattering for each beam revealed true spatial structure and evolution of plasma bubbles. Onsets of plasma bubbles near sunset [Yokoyama et al, 2004b] and sunrise [Fukao et al., 2003a] terminators and spatial structure of evening bubbles [Fukao et al., 2004] were diagnosed. Otsuka et al. [2004b] compared the radar backscattering with all-sky airglow images and found coexistence of small scale irregularities and airglow depletions. Optical imaging technique was used for the study of plasma bubbles not only in the equatorial region but also in the main islands of Japan. Temporal and spatial evolution of high altitude plasma bubbles was observed at the magnetic conjugate points in Japan and Australia by Shiokawa et al. [2004] and Otsuka et al. [2002b]. Ogawa et al. [2005] compared the magnetic conjugated lower midlatitude plasma bubbles observed by ground and IMAGE-satellite based airglow depletions. Maruyama et al. [2002] analyzed h’F variations near the magnetic equator and at a low latitude, both in the Philippines, in connection with onsets of spread F.

G2.5. Ionosphere-Neutral Atmosphere Coupling

Dynamical behavior of the MLT region is very important to understand physics in the ionosphere. The all-sky imager of OH band (720-910 nm) and OI (557.7 nm) nightglow is a powerful instrument to study gravity waves in the MLT region. Ejiri et al. [2002] conducted dual-site imaging observations and determined the true altitude of the nightglow layers. Statistical studies of the gravity waves were carried out for Japan by Ejiri et al. [2003] and for Indonesia by Nakamura et al. [2003]. Hocke et al. [2002a] analyzed the radio occultation data from the GPS/MET experiment, and determined global distribution of gravity waves and Es layers. They found that both phenomena are enhanced over the Southern Andes, an indication of an orographic effect of the Andes to the ionospheric structure through atmospheric waves. By simulations, Yokoyama et al. [2004c] found that gravity waves generated in the troposphere can modulate Es layers and induce a polarization electric field with reasonable intensities.

Global behavior of planetary waves with periodicities of 4-10 days was studied with a network of MF and meteor radars [Isoda et al., 2002; Lieberman et al., 2003]. Tsuda et al. [2002] studied long-term variations of the equatorial atmospheric waves, i.e., Kelvin waves, by means of MF radars in the equatorial Pacific. Long-period wind data set from the meteor radar in Jakarta were utilized to detect the lunar semidiurnal tide at heights from 70 to 120 km [Stening et al., 2003]. The data from 46 MF and meteor radars and space-based HRDI data were accumulated, and a new model for the prevailing wind in the MLT region was constructed [Portnyagin, et al., 2004].

G3. Ionospheric Modeling

G3.1. Earth's Ionosphere

Numerical modeling is a useful tool for studying ionospheric disturbances. Pavlov et al. [2004a,b] used a model of the low- and midlatitude ionosphere and plasmasphere to study the ionosphere during magnetic storms. Mechanisms causing the morning and evening peaks in the electron temperature were discussed. Zhang et al. [2004] used a one-dimensional high-latitude ionospheric model to study the conductivities in auroral regions where electrojets exist. Shinagawa et al. [2003] developed a nonhydrostatic thermosphere-ionosphere model to study high-latitude disturbances. Thermospheric winds near a moving auroral arc were simulated. Miyoshi and Fujiwara [2003] developed a new general circulation model (GCM), which contains the region from the ground surface to the exobase. The results showed that day-to-day variations of the migrating diurnal tide are evident from the upper troposphere to the thermosphere. Kamide et al. [2003] described the Global Environment Data Analysis System (GEDAS) developed at the Solar-Terrestrial Environment Laboratory, Nagoya University. The system is intended to study the geospace environment combining various kinds of real-time data and numerical models.

G3.2. Planetary Ionosphere

A two-dimensional global hybrid model was developed by Terada et al. [2002, 2004] to study kinetic processes associated with the solar wind interaction with the Venus ionosphere. The entire solar wind-Venus ionosphere region was included kinetically by applying boundary fitted coordinates to the particle-in-cell code. It was found that the Kelvin-Helmholtz instability occurred at the Venus ionopause plays an important role in the ion escape from the planet. Recent progress in modeling the planetary ionospheres was reviewed by Shinagawa [2004] and Kallio and Shinagawa [2004].

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