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G1. Ionospheric Irregularities

G1.1. Equatorial Spread F and Plasma Bubble

Variations in ionospheric height associated with the pre-reversal enhancement (PRE) and spread F at two equatorial ionosonde stations separated by 6.34 degree in longitude were studied. The h'F enhancement is localized in longitude when equatorial spread F (ESF) occurs. It is due to the eastward electric field enhancement (Saito and Maruyama, 2007). Ionospheric height variations and plasma irregularity occurrence are affected by meridional wind (Maruyama et al., 2009). The virtual height of the bottom side F-region (h0F) and equatorial spread-F (ESF) onsets at Chumphon were compared with the behaviour of equatorial electrojet (EEJ) ground strength at Phuket during the period from November 2007 to October 2008. The pre-sunset E-region dynamo current and/or electric field are related to the F-region dynamics and ESF onsets around sunset (Uemoto et al., 2010a). The 3-m-scale ionospheric irregularities associated with plasma bubbles were investigated by the Equatorial Atmosphere Radar (EAR), a 630-nm airglow imager, ionosondes, and GPS (Saito et al., 2008a, 2008b). The occurrence of low-latitude ionospheric irregularities was different in different longitude (Li et al., 2010). Middle-latitude plasma bubble was observed in the 10 November 2004 storm-time in Southeast Asia (Li et al., 2009). The Nighttime F-region field-aligned irregularities over Kototabang were observed by VHF radar (Otsuka et al., 2009b). The F-region ionospheric irregularities in the South American sector during the October 2003 "Halloween Storms" were investigated in detail (Sahai et al., 2009a). Large-scale wave structure (LSWS) and equatorial spread F (ESF) were observed at the first time by CERTO radio beacon on the C/NOFS satellite. The LSWS appears in the development of ESF than the post sunset rise (PSSR) of the F layer, and before E region sunset (Thampi et al., 2009a, Tsunoda et al., 2010). The equatorial GPS ionospheric scintillations over Kototabang, Indonesia were associated with atmospheric waves from below (Ogawa et al., 2009a). Medium-scale traveling ionospheric disturbances and plasma bubbles were discovered by an all-sky airglow imager at Yonaguni, Japan (Ogawa et al., 2009c). Decay of 3-m-scale ionospheric irregularities associated with a plasma bubble was observed with the Equatorial Atmosphere Radar (Saito et al., 2008). Oscillations with periods of 3 to 4 days were observed in the meteor radar zonal wind at Cariri (7.4°S, 36.5°W), in the ionospheric minimum virtual height h'F and the maximum critical frequency foF2 at Fortaleza (3.9°S, 38.4°W), and in the TIMED/SABER satellite temperature data in the stratosphere - mesosphere. The oscillation is 3.5–day Ultra Fast Kelvin (UFK) wave, propagating from the stratosphere to the ionosphere (Takahashi et al., 2007). The GPS ionospheric scintillations associated with geomagnetic storm was investigated (Guozhu et al., 2008). The occurrence characteristic of plasma bubble was studied using the ground based GPS receiver networks in the Asian region in 2004 (Nishioka et al., 2008).

G1.2. Sporadic E and Quasi-Periodic Echo

The horizontally drifting sporadic E patch generated from meteor trail plasma was observed for 40 min. The descending rate of the meteor echo was approximately 22 m/s, which was considerably greater than that of the tidal ion layer trapped in a downward-moving wind shear node (Maruyama et al., 2008b). The solar eclipse induced mid latitude plasma irregularities, Quasi Periodic (QP) echoes, were observed at the first time during the partial solar eclipse on 22 July, 2009 by using the middle and upper atmosphere radar (MU radar) at Shigaraki (34.85°N, 136.1°E, 25.0°N geomagnetic laitude) (Thampi et al., 2010). Sporadic E layer was observed with a rocket-borne magnesium ion imager (Kurihara et al., 2010a). The electron temperature (Te), electron density (Ne), and two components of the electric field were measured from the height of 90 km to 150 km by one of the sounding rockets launched during the SEEK-2 campaign. The structure of Es is projected to a higher altitude along the magnetic line of force, thus producing irregular structures of Te, Ne and electric field in higher altitude (Oyama et al., 2008d, 2008e). Gravity wave-driven instability of E layer at mid-latitude was discussed (Shalimov et al., 2009). Polarization electric fields of the Es patches on scales above about 10 km can map efficiently between the E and F regions. The electrical coupling between the dense Es patch and the F region depends on the presence of field aligned closure currents and the orientation of the ambient effective electric field (Shalimov and Yamamoto, 2010). Three-dimensional simulation of the coupled Perkins and Es-layer instabilities in the nighttime midlatitude ionosphere was carried out. The coupling process between E and F regions has a significant effect on the scale of the Es layer perturbation rather than the growth rate of the Es layer instability (Yokoyama et al., 2008, 2009a). Daytime 150-km echoes were observed by Equatorial Atmosphere Radar in Indonesia. The westward and upward/southward irregularity drifts with zonal anisotropy were found to be consistent with daytime background electric fields (Patra et al., 2007, 2008, Yokoyama et al., 2009b). The middle□ and upper□atmosphere (MU) radar (34.85°N, 136.10°E) was operated in the incoherent scatter power□only mode to observe the ionosphere during 17 June 2001. Pronounced 200□ to 300□min. waves in the echo power appeared in the F2 region during 0240–1250 local time on 17 June 2001 (Liu et al., 2007). Simultaneous observations of mean zonal wind at 88 km obtained by the meteor radars at Cariri (7.4°S, 36.5°W) and Ascension Island (7.9°S, 14.4°W) and two medium□frequency radars at Tirunelveli (8.7°N, 77.8°E) and Pamuengpeuk (7.7°S, 107.7°E) were used to investigate the influence of the intraseasonal variations in the lower tropospheric convective activity associated with the Madden□Julian oscillation on the longitudinal behavior of intraseasonal oscillations (ISO) of the zonal winds in the equatorial mesosphere and lower thermosphere (MLT) (Rao et al., 2009).

G2. Ionospheric Disturbances

G2.1. Ionospheric Storm

Variations in the high-latitude ionosphere structure during geomagnetic storm were examined for electron density and temperature by the Cosmos-900 satellite, the ISS-b satellite, the Intercosmos-19 satellite, the DMSP, TIROS and P78 satellites (Karpachev et al., 2007). The forecasting ionospheric variations and storms at Kokubunji (35°N, 139°E) were studied for 24 hours in advance by using a neural network (Nakamura et al., 2007). From studying conditions of intense ionospheric storms at lower midlatitudes in March and April 2001, an eastward disturbance dynamo electric field formed after midnight, the ionospheric layer was uplifted, and the ion drag was reduced (Maruyama and Nakamura, 2007). Ionospheric responses to the major magnetic storm disturbances of October 2003 were investigated using database selected in the Brazilian and Japanese-Asian longitude sectors. Prompt penetrating (PP) dawn-dusk polar cap electric fields produce large F region plasma uplift on the dayside and eveningside, while the associated westward electric field on the nightside produces large downdraft of the F region plasma, and causes development of westward electrojet current (Abdu et al., 2007). Positive ionospheric storms at low latitudes and midlatitudes were studied from a low latitude ionospheric model and observations. The positive ionospheric storms are most likely in the longitudes where the onset of the geomagnetic storms falls in the ionization production dominated morning noon local time sector when the plasma accumulation due to the mechanical effects of the wind largely exceeds the plasma loss due to the chemical effect of the wind. The mechanism agrees with the multi instrument observations made during the super geomagnetic storm of 7–8 November 2004 (Balan et al., 2010). Effects of electric field and neutral wind on positive ionospheric storms were studied (Balan et al., 2009a). The ionospheric response in the Brazilian sector was investigated during the super geomagnetic storm on 20 November 2003 (Becker-Guedes et al., 2007). Intense geomagnetic disturbances with two super storms were observed in two separated longitudinal sectors during the period of 8–10 November 2004 (Sahai et al., 2009b). Prompt Penetration Electric Fields (PPEFs) affected ionospheric structure during great magnetic storm of October 30-31, 2003. For intense southward interplanetary magnetic fields (IMFs), inward plasma sheet convection occurs with the result of magnetospheric ring current formation and an intense magnetic storm. Then, positive phase ionospheric storms occur on the dayside and negative phase ionospheric storms occur on the nightside. The dayside ionospheric storms due to PPEFs are characterized by transport of near equatorial plasma to higher altitudes and latitudes, forming a giant plasma fountain (Tsurutani et al., 2008). Ionospheric response occurred during the geomagnetic storm on 20–22 November 2003 and on 13-17 April 2006 in the West Pacific region (Zhao et al., 2008, 2009).

G2.2. Traveling Ionospheric Disturbances

Large-Scale Traveling Ionospheric Disturbance was observed by SuperDARN Hokkaido HF Radar and GPS Networks. The observation on 15 December 2006 showed a positive correlation between downward ionospheric motion and increasing TEC (Hayashi et al., 2010). Medium-scale traveling ionospheric disturbances (MSTID) and F region field-aligned irregularities were observed with two spaced all-sky airglow imagers and the middle and upper atmosphere radar. The MSTID with the velocity of 80 m/s propagated with the fluctuation amplitudes of 50% from the background intensity and the wavelength of 380 km. The period of the MSTID was similar to the Doppler velocity of the QP echoes. The airglow enhancement (depletion) caused by the MSTID coincided with the southeastward (northwestward) velocity in the QP echo (Otsuka et al., 2007, 2009a, Suzuki et al., 2007a, 2007b, 2008, 2009a, 2009b, Saito et al., 2008). The mesospheric gravity waves over Japan were observed by airglow, lidar, and radar (Suzuki et al., 2010). The daytime MSTIDs over North America were observed at the first time by GPS-TEC and DEMETER satellite (Onishi et al., 2009). The nighttime medium-scale traveling ionospheric disturbances were detected by network GPS receivers in Taiwan (Lee et al., 2008). The medium-scale traveling ionospheric disturbances at middle latitudes were observed by an airglow imager (Shiokawa et al., 2008). The relation between sporadic-E irregularities and medium-scale traveling ionospheric disturbances was investigated with the SuperDARN Hokkaido radar, all-sky imager and GPS network. Daytime radar echoes are due to ground/sea surface (GS) scatter, while nighttime echoes return from 15 m scale F region field aligned irregularities (FAIs). The nighttime MSTIDs are often accompanied by concurrent coherent echoes from FAIs in sporadic E (Es) layers. Some Es echo was connected with the echo areas along the geomagnetic field, indicating the existence of E and F region coupling at night (Ogawa et al., 2009b). The relationship between medium-scale traveling ionospheric disturbance and sporadic E layer in summer night over Japan was investigated (Otsuka et al., 2008). The medium scale traveling ionospheric disturbances (MSTIDs) with amplitude larger than 20 TECU (=10^16el/m2) were observed at mid latitude during the geomagnetic storm on 10 November 2004. This amplitude was more than 10 times larger than that of the average MSTID (Nishioka et al., 2009). A storm-time traveling ionospheric disturbance was compared with AMIE-TIEGCM modeling. In the model, two Joule heating enhancements in the high latitude dayside sector produced two distinct traveling atmospheric waves (TADs), which propagated to Japan in the midnight sector as enhancements in thermospheric temperature and southward wind speed (Shiokawa et al., 2007b). The traveling ionospheric disturbances were observed with the Paratunka OMTI camera and the Hokkaido HF radar (Koustov et al., 2009). The propagation parameters of daytime medium scale traveling ionospheric disturbances (MSTIDs) were investigated using near simultaneous SuperDARN radar data obtained at auroral and middle latitudes. The statistical analysis implies that a portion of MSTIDs with higher horizontal phase velocity are unable to reach the mid latitude due to the enhanced dissipation and the reduction of the ion drag effect (Ishida et al., 2008).

G3. Ionospheric Structure and Models

G3.1. Ionospheric Structure

From simultaneous observations of the electron and neutral density from the CHAMP satellite, rapid thermospheric response within a few minutes was observed (Liu et al., 2007a). Solar activity dependence of the electron density at equatorial and low latitudes was investigated from the CHAMP measurements between 1 August 2000 and 1 August 2006 and compared it with the international reference ionosphere (IRI) model (Liu et al., 2007b, 2007d). The typical diurnal cycle of the mid latitude F region electron density consisted of a midday maximum and a midnight minimum. However, a phase reversal of this diurnal cycle occurred in three distinct regions, East Asian, the Northern Atlantic and the South Pacific (Liu et al., 2010). The 630-nm airglow in the Asian sector was studied by Formosat-2/ISUAL (Adachi et al., 2010). Polar cap patches is generated by shears in the background plasma convection, and the patch motion is investigated statistically by use of airglow imager (Hosokawa et al., 2009a, 2009b, 2009c, 2010a). The penetration electric field from polar region generated super plasma fountain and equatorial ionization anomaly development (Balan et al., 2009b). F3 layer was generated during penetration electric field (Balan et al., 2008a). The F3 layer was observed by the meridional ionosonde network located in Southeast Asia (SEALION). The simultaneous magnetic conjugate observations of the F3 layer showed clear dependences of the F3 layer on the magnetic latitude, which is due to the plasma diffusion effects along the magnetic field lines (Uemoto et al., 2007). Plasma densities measured by the Circum-pan Pacific Magnetometer Network (CPMN) ground magnetometers and the Cluster satellites on the same field line were compared (Maeda et al., 2008). Predawn ionospheric heating observed by HINOTORI satellite was investigated. The observations indicate that the photoelectron flux causing predawn ionospheric heating is attenuated by scattering in the high altitude (>600 km) ionosphere and plasmasphere (Kakinami et al., 2009b). Low-energy (<10 eV) ion outflow of O+ ions was observed in the region of enhanced electron density in the polar cap magnetosphere during geomagnetic storms (Kitamura et al., 2010). Ionosphere was investigated as a coupling system of solar wind, magnetosphere, ionosphere and upper atmosphere (Balan et al., 2008b). Solar activity dependence of the electron density at 400 km at equatorial and low latitudes was investigated by use of CHAMP satellite (Liu et al., 2007e). The total electron content (TEC) enhancement occurred during the low geomagnetic activity observed over Japan. The enhancements of TEC of equatorial origin structures are produced mainly by a disturbance winds dynamo electric field, built up after the main phase of the storms (Kutiev et al., 2007). Ionospheric hole was found behind an ascending Japanese sounding rocket with GPS array over Japan (Furuya et al., 2008), and behind the ballistic missiles from North Korea (Ozaki and Heki, 2010). Highly Energetic Electron Environment in the Inner Magnetosphere is monitored in order to promote Space weather project in Japan (Obara et al., 2009a, 2009b, 2010). Goto et al. (2008) proposed a new lunar ionosphere exploration method using interference patterns of the AKR. This is a new approach to examine the existence of the lunar ionosphere which is not based on the radio occultation technique. A chain of digital beacon receivers established over Japan was used for the tomographic imaging of the ionosphere (Thampi et al., 2009b. Thampi and Yamamoto, 2010, Yamamoto 2008).

G3.2. Ionosphere-Thermosphere Models

A regional reference model of total electron content (TEC) was constructed using data from the GPS Earth Observation Network (GEONET) and the neural network model (Maruyama, 2007, 2010). Empirical models of electron density in low latitude at 600 km altitude obtained by Hinotori satellite and that of Total Electron Content over Taiwan during geomagnetic quiet condition were constructed (Kakinami et al., 2008, 2009a). Simulation was carried out to investigate the increased upward or downward diffusion flux of plasma in the topside ionosphere caused by the electric field penetration during magnetic storm (Jin and Maruyama, 2008). A general circulation model from the ground surface to the upper thermosphere has been developed, and the characteristics of gravity waves in the mesosphere and thermosphere are examined (Miyoshi and Fujiwara, 2008, 2009, Fujiwara and Miyoshi, 2009, 2010). From a whole atmosphere general circulation model and an ionosphere - thermosphere model, it was revealed that the longitudinal structure of the F region zonal electric field (vertical ExB drift) results in the eastward zonal wave number 3 diurnal tide (DE3) that originates from the convective activities in the troposphere and propagates upward. The daytime zonal electric field is a direct result from charge separation induced by the Hall dynamo current, whereas the nighttime zonal electric field is produced under the electrostatic condition (Jin et al., 2008). Solar terminal waves observed by the CHAMP satellite occurred not only in the thermosphere but also in the stratosphere and mesosphere. The terminator wave is excited in the stratosphere and/or troposphere and propagates upward into the upper thermosphere. Specifically, the solar terminator wave is mainly generated by superposition of the upward propagating migrating tides from zonal wave number 4 to zonal wave number 6. The terminator wave is more prominent during solstice than during equinox (Miyoshi et al., 2009). The F2-layer critical frequency (foF2) and peak height (hmF2) measured by the FM/CW ionosonde at Thailand equatorial latitude station Chumphon from January 2004 to December 2006 were analyzed based on the diurnal, seasonal variation, and compared with IRI-2001 model (Wichaipanich et al., 2009). Convectively generated atmospheric gravity waves that propagate into the equatorial stratosphere were investigated using a cloud resolving model (Horinouchi 2008). The global distribution, sources, and propagation of atmospheric waves in the equatorial upper troposphere and lower stratosphere were investigated using an atmospheric general circulation model with T106L60 resolution (120 km horizontal and 550 m vertical resolution). The quasibiennial oscillation (QBO) with a period of ~1.5–2 years was simulated well without gravity wave drag parameterization (Kawatani et al., 2009).

G3.3. Ionospheric Electric Field and Current

Penetration of the magnetospheric electric field to the equatorial ionosphere was examined for the geomagnetic storm on 6 November 2001, by analyzing the difference in magnitude of the geomagnetic storm recorded at the dayside geomagnetic equator, Yap (−0.3° GML) and low latitude, Okinawa (14.47° GML). The penetrated electric field caused the DP2 currents at the equator, i.e., eastward currents during the main phase of the storm, while the overshielding currents, i.e., westward currents dominated during the recovery phase. The electric field associated with the DP2 currents contributed to the development of the ring current during the main phase (Kikuchi et al., 2008). The relation between equatorial ionization anomaly of the total electron content and equatorial electrojet of ground-based geomagnetic field strength was investigated (Chen et al., 2008). Low-latitude ionospheric electric and magnetic field disturbances were associated with solar wind pressure enhancements (Huang et al., 2008). Characteristics of the Equatorial Electrojet current in Central South America was investigated (Rastogi et al., 2008). Auroral electrojets were investigated with solar wind parameters during the extremely large magnetic storm of November 20-21, 2003 (Solovyev et al., 2008). A new index was presented in order to monitor the temporal and the long-term variations of the Equatorial Electrojet from MAGnetic Data Acquisition System / Circum-pan Pacific Magnetmeter Network Data (MAGDAS/CPMN) real-time data (Uozumi et al., 2008). Characteristics of counter-Sq SFE (Solar Flare Effects) at the Dip equator (SFE*) by CPMN stations were investigated, and ionospheric electric field was inferred during SFE (Yamazaki et al., 2009a). Sq current system and Sq vortex were studied from 210° magnetic meridian (MM) of the Circum pan Pacific Magnetometer Network (CPMN) covering both the Northern Hemisphere and Southern Hemisphere (Yamazaki et al., 2009b). Interhemispheric trans-equatorial field-aligned currents deduced from MAGDAS at equatorial zone were measured (Bolaji et al., 2010). The Sq-EEJ relationship based on extended magnetometer networks in the East Asian region was analyzed (Yamazaki et al., 2010). Pedersen current was carried by the electrons in the auroral D-region, observed by the EISCAT VHF radar in Tromsø, Norway when an intense pulsating aurora (PA) occurred. It is important in the closure of FAC associated with the patch of PA (Hosokawa and Ogawa, 2010). Kasaba et al. (2010) developed three types of stiff and extendible electromagnetic sensors in rigid monopole antenna, loop antenna, and Yagi-Uda antenna for future space missions. One of them, rigid monopole antennas, coupled with an inflatable actuator system, was successfully used in the JAXA S-520-23 sounding rocket experiment in September 2007. The sheath capacitance measurements from impedance probes onboard the S-520-23 sounding rockets allow for estimation of the electron temperature and the electron density of Maxwellian plasma (Suzuki et al., 2010). The Jicamarca Radio Observatory, magnetometer observations from the Pacific sector and ionosonde data from Brazil were used to study equatorial ionospheric electric fields during the November 2004 geomagnetic storm. The very large eastward and westward daytime electrojet current perturbations appeared with lifetimes of about an hour in the Pacific equatorial region during the November 7 main phase of the storm. The largest daytime prompt penetration electric fields (about 3 mV/m) were observed over Jicamarca. The large equatorial electrojet current and drift perturbations were present in the Pacific and Brazilian equatorial regions (Fejer et al., 2007).

G4. Coupling with Atmosphere/Lithosphere

G4.1. Neutral Atmosphere-Ionosphere System

A global picture of thermospheric neutral density and the climatology of the equatorial mass anomaly (EMA) in the thermosphere using 4 years of CHAMP measurements were revealed. There are strong variations of the EMA with season and solar flux level. The EMA structure is most prominent around equinox, with a crest to trough ratio about 1.05 for F10.7 = 150. The density crest attains maximum 1–2 hours earlier and reaches higher values in the summer hemisphere than in the winter hemisphere (Liu et al., 2007c). From an ionosonde network in the Southeast Asian area, thermospheric neutral winds were inferred and compared with the HWM93 empirical thermospheric wind model (Maruyama et al., 2007, 2008a). A solar terminator wave in thermospheric wind and density was found by Liu et al., 2009a. Ionosphere-thermosphere coupling was investigated with DE2 satellite. The fast zonal neutral wind occurs inside the zonal plasma drift velocity anomaly (PDA) in the evening hours, and such latitudinal structures in the zonal wind and plasma drifts are associated with equatorial ionization anomaly (EIA). This is a strong manifestation of the ionosphere - thermosphere coupling processes over the low latitude (Watanabe and Kondo, 2010). Fast thermospheric wind jet at the Earth’s dip equator was observed by both CHAMP and DM2 satellites (Liu et al., 2009c). The lower thermospheric wind was investigated from a long run data set obtained by the EISCAT UHF radar at Tromsø (69.6°N, 19.2°E) over ~23 days, from September 6 to 29, 2005. The 5–6 day oscillations in the lower thermosphere were found, where there were planetary wave activities in the lower thermosphere (Nozawa et al., 2010). Lower-thermospheric wind fluctuations were measured with a Fabry Perot Interferometer (FPI) during pulsating aurora at Tromso (Oyama et al., 2010). Nighttime mesospheric and thermospheric waves were observed by optical mesosphere thermosphere imagers at middle and low latitudes (Shiokawa et al., 2009a). An intense gravity wave near the mesopause region was observed by a Fabry-Perot interferometer and an airglow imager (Shiokawa et al., 2007a). Airglow temperature photometer with cooled-CCD detectors was developed (Shiokawa et al., 2007c). The upper atmosphere and plasma imager / the telescope of visible light (UPI/TVIS) were installed in the Kaguya spacecraft (Taguchi et al., 2009). OI 630.0 nm dayglow variations were obtained over low latitudes during onset of a substorm (Chakrabarty et al., 2010). Ionospheric electron density enhancement occurred during Lithium releases from sounding rocket during WIND campaign. It is due to photo ionization of Lithium atom (Uemoto et al., 2010b). The gravity waves and the vertical eddy diffusivity across the tropopause was obtained by MU radar and the Equatorial Atmospheric Radar (EAR) (Alexander and Tsuda, 2007, Alexander et al., 2007a, 2007b, Alexander and Tsuda, 2008). COSMIC satellite temperature data were used to derive the 2006/07 winter mean stratospheric Northern Hemisphere potential energy Ep from gravity waves (Alexander et al., 2008, 2009). Long-term mean vertical winds were downward in the middle troposphere and upward above the jet-stream wind maximum, which was obtained by VHF/UHF radars (Chen et al., 2008). Semidiurnal tides were obtained from the Extended Canadian Middle Atmosphere Model (CMAM) and the results were compared with TIMED Doppler Interferometer (TIDI) and meteor radar observations (Du et al., 2007). The seasonal variation of short-period (<2 h) gravity wave activity was investigated in the troposphere and lower stratosphere using the wind observations made with VHF radar at Gadanki (13.5°N, 79.2°E), India (Dutta et al., 2008). As part of the Maui-Mesosphere and Lower Thermosphere program, data from the Utah State University Mesospheric Temperature Mapper (MTM) and the University of Illinois Meteor Wind Radar (MWR) were used to investigate wave-driven dynamical interactions in the upper mesosphere at low latitudes. On 29 June 2003, short-period (~20 min) gravity waves (GWs) were imaged in the MTM in the near-infrared OH and O2 airglow emissions for most of the night from 0700 to 1500 UT. The GWs were observed to disappear rapidly in the O2 data (peak altitude: ~94 km) around 1400 UT but remained evident in the lower altitudes OH data (~87 km) for a further 30 min (Ejiri et al., 2009, Yue et al., 2009). The Middle and Upper atmosphere Radar (MUR) was upgraded in March 2004 for radar imaging capability with 5 frequencies across a 1 MHz bandwidth and 25 digital receivers (Hassenpflug et al., 2008). The horizontal structures of GWs were obtained directly by using multiple profiles based on the GPS RO data from the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC)/FORMOSAT-3 mission (Horinouchi and Tsuda, 2009). During the 9-day continuous campaign in September 2003, the Colorado State University sodium lidar observed significant short-term tidal variability in both diurnal and semidiurnal tides above 85 km on days 265–268 (Li et al., 2009). The horizontal wind data acquired by MF radar at Tirunelveli (8.7°N, 77.8°E) for the period January 1993 to July 2006 were used to study long-term variability of equatorial mesosphere and lower thermosphere (MLT) winds (Sridharan et al., 2007).

G4.2. Effect of Thunderstorm and Meteorological Phenomenon

Neutral winds, ambipolar diffusion coefficients, and neutral temperatures were observed by the Nippon/Norway Tromsø Meteor Radar (NTMR) and ion temperatures observed by the European Incoherent Scatter (EISCAT) UHF radar at Tromsø (69.6°N, 19.2°E), during a major stratospheric sudden warming (SSW) that occurred in January 2009. The zonal winds at 80–100 km height reversed approximately 10 days earlier than the zonal wind reversal in the stratosphere and the neutral temperature at 90 km decreased simultaneously with the zonal wind reversal at the same altitude. The SSW is strongly linked to thermal structure and dynamics in the high latitude mesosphere, lower thermosphere, and ionosphere (Kurihara et al., 2010b). From plasma drift and magnetic field measurements during the 2001–2009 December solstices, the longitudinal dependence of equatorial ionospheric electrodynamic perturbations during sudden stratospheric warming was investigated. The large electrodynamic perturbations during stratospheric warming periods are due to strongly enhanced semidiurnal lunar wave effects (Fejer et al., 2010). The seasonal variation in the longitudinal structure of the equatorial ionosphere agreed well with that of the nonmigrating diurnal tides DE3, supporting a close coupling between the ionosphere and the mesosphere - lower thermosphere possibly via the DE3 tidal modulation of the E layer dynamo (Liu and Watanabe, 2008). Wave-4 pattern of the equatorial mass density anomaly was found by CHAMP satellite. It is due to the direct penetration of the DE3 to F-regions heights (Liu et al., 2009b). Ground-based detection of sprites and their parent lightning flashes over Africa were carried out during the 2006 AMMA (African Monsoon Multidisciplinary Analysis) campaign (Williams et al., 2009). Global distribution of intense lightning discharges and their seasonal variations were studied (Sato et al., 2008). Optical energy of sprites and its charge moment of parent lightning discharge were obtained by ISUAL/AP (Takahashi et al., 2010). Atmospheric monitoring system of JEM-EUSO mission is being developed (Mitev et al., 2007).

G4.3. Earthquake Effect on the Ionosphere

GPS TEC anomaly was investigated statistically for M>5.9 earthquakes in Indonesia during 1993-2002 (Saroso et al., 2008). The temporal precursor of the GPS TEC around the epicenter was significantly reduced during the afternoon period on day 5 before the M9.3 earthquake, which occurred in Sumatra Andaman, Indonesia on 26 December 2004 (Liu et al., 2010a). During the 2005 Sumatora earthquakes, the ionospheric and geomagnetic disturbances occurred (Hasbi et al., 2009), and ULF geomagnetic anomalous were observed (Saroso et al., 2009). The ULF wave may be used for the phenomena associated with earthquake (Yumoto et al., 2009). The ground-based receivers of the global positioning system (GPS) in the Taiwan area detected coseismic ionospheric disturbances (CIDs) in the total electron content (TEC) triggered by the Chi-Chi earthquake of Mw 7.6 at 17:47 UT on 20 September 1999 (Liu et al., 2010b, Nishitani et al., 2009). The reduction of electron temperature occurred in low latitude ionosphere at 600 km altitude before and after large earthquakes (Oyama et al., 2008a). The plan of Micro/mini satellites for earthquake studies was proposed (Oyama et al., 2008b). Ionospheric electron content anomalies were detected by a FORMOSAT-3/COSMIC empirical model before and after the Wenchuan earthquake in 12 May 2008 (Liu et al., 2009, Kakinami et al., 2010, Jhuang et al., 2010). The FORMOSAT-3/COSMIC results showed that the ionospheric F2 peak electron density, NmF2, and height, hmF2, significantly decreases approximately 40% and descends about 50–80 km, respectively, when the GPS TEC anomalously reduces. The dependence of waveform of near-field coseismic ionospheric disturbance was discussed (Astafyeva and Heki, 2009, Astafyeva et al., 2009).

G5. Polar Atmosphere-Ionosphere

Temperature enhancements and vertical winds in the lower thermosphere associated with auroral heating were observed during the Dynamics and Energetics of the Lower Thermosphere in Aurora (DELTA) campaign. N2 rotational temperature was measured with a rocket-borne instrument launched from the Andøya Rocket Range, neutral winds were measured from auroral emissions at 557.7 nm with a Fabry Perot Interferometer (FPI) at Skibotn and the KEOPS, and ionospheric parameters were measured with the European Incoherent Scatter (EISCAT) UHF radar at Tromsø (Kurihara et al., 2009). Polar cap tongue of ionization during magnetic storm was investigated. The polar cap tongue of ionization was caused by a combination of temporal variations in the global-scale plasma circulation system (Hosokawa et al., 2010b). Longitudinal development of a substorm brightening arc was observed (Shiokawa et al., 2009b, Yogo et al., 2007) and the Rayleigh-Taylor type instability mechanism was discussed (Shiokawa et al., 2010). Simultaneous ground and satellite observations of an isolated proton arc were carried out at subauroral latitudes. The observed isolated proton arc at subauroral latitudes was caused by the EMIC (electromagnetic ion cyclotron) waves, which were generated near the plasmapause and resonantly scattered the ring current protons into the loss cone (Sakaguchi et al., 2007). The GPS total electron content variations were associated with a polar cap arc (Jayachandran et al., 2009). QSAT the satellite for polar plasma observation was planed (Tsuruda et al., 2009). The IMF dependence of high-latitude thermospheric wind was studied (Forster et al., 2008, Luhr et al., 2007). The energy transport from the exterior cusp into the ionosphere was investigated using coordinated ground-based (EISCAT and MIRACLE) and satellite (Cluster) observations. The particles seen at about 9 Re in the exterior cusp carry an earthward energy flux that corresponds to the observed heating of the F-region. The estimated earthward Poynting flux is more than enough to account for the Joule heating in the E-region (Yordanova et al., 2007). Using the European incoherent scatter (EISCAT) Svalbard radar located in Longyearbyen (78.2°N, 16.0°E) and with the EISCAT UHF radar located in Tromsø (69.6°N, 19.2°E), the data obtained for six consecutive days from 1000 UT on 1 July 1999 to 1000 UT on 7 July 1999 were investigated the ion drag on the lower thermospheric wind dynamics in the summer polar region (Tsuda et al., 2007, 2009). Lower-thermospheric winds at high latitudes during moderately-disturbed geomagnetic conditions were studied using data obtained with the European Incoherent Scatter (EISCAT) Kiruna-Sodankylä-Tromsø (KST) ultrahigh frequency (UHF) radar system on 9–10 September 2004. The meridional neutral-wind speed suddenly changed its direction from equatorward to poleward when the heating event began, and then returned equatorward coinciding with a decrease in the heating event. The pressure gradient caused the lower-thermospheric wind to accelerate obliquely upward over Tromsø in the poleward direction (Oyama et al., 2008c). The relationship between bulk ion upflows and suprathermal ions was investigated using data simultaneously obtained from the European Incoherent Scatter (EISCAT) Svalbard radar (ESR) and the Reimei satellite. The plasma waves such as broadband extremely low frequency (BBELF) wavefields associated with precipitation are connected to the bulk ion upflows in the cusp and effectively cause the heating of suprathermal ions (Ogawa et al., 2008). The F region strong sunward ion flow embedded in the duskside cell of expanding polar cap ion convection and coincidental increase in the ion temperature were observed from about 73° to 69° in geomagnetic latitude between 16:00 and 16:48 MLT on 19 August, 2006 from an experiment using the European Incoherent Scatter (EISCAT) radars at Tromsø, Sodankylä and Longyearbyen together with the CUTLASS HF radars (Maeda et al., 2009). Hydrogen ion (H+) and oxygen ion (O+) upflow were observed in the topside polar ionosphere by the EISCAT Svalbard Radar and the Reimei satellite. The H+ upflow occurred equatorward of the cusp above 500 km altitude. Within the cusp the H+ density was very low, and the upflow was dominated by the O+ ions, but on closed field lines the H+ became the larger contributor to the upward flux above about 550 km altitude (Ogawa et al., 2009). The upward ion flux was generally higher when solar activity was high. The solar activity influences long-term variations of the ion upflow occurrence (Ogawa et al., 2010). Neutral winds and plasma motions were obtained by coordinated Fabry Perot imager and VHF radar observations at Syowa Station, Antarctica. There was discrepancy between the neutral winds and the plasma Doppler velocities, which is consistent with the linear theory of E region irregularities including the radar Doppler velocity by E × B drift and neutral wind (Sakanoi et al., 2009).

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