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IONOSPHERIC OBSERVATION USING KOREAN SATELLITES

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ABSTRACT

We report the results of the ionospheric measurement obtained from the instruments on board the Korea Multi-Purpose Satellite - 1 (KOMPSAT-1). We observed a deep electron density trough in the nighttime equatorial ionosphere during the great magnetic storm on 15 July 2000. We attribute the phenomena to the up-lifted F-layer caused by the enhanced eastward electric field, while the spacecraft passed underneath the layer. We also present the results of our statistical study on the equatorial plasma bubble formation. We confirm the previous results regarding its seasonal and longitudinal dependence. In addition, we obtain new statistical results of the bubble temperature variations. The whole data set of measurement for more than a year is compared with the International Reference Ionosphere (IRI). It is seen that the features of the electron density and temperature along the magnetic equator are more prominent in the KOMPSAT-1 observations than in the IRI model.

Key words : ionosphere: equatorial ionosphere—ionosphere: satellite observation

I. INTRODUCTION

Ionospheric physics has a long history of observation and modeling. For example, large databases from satellite observations have been analyzed statistically to obtain seasonal, diurnal, and longitudinal features of the global ionospheric variations (Huang et al. 2001). New results of these studies are often implemented into the revised model of the International Reference Ionosphere (IRI) (Rich & Sultan 2000).

Ionosphere is a region of many interesting plasma physics phenomena. Especially in the equatorial ionosphere, dramatic changes are seen following sunset as a result of the eastward electric field that is attributed to the F region dynamo. For example, the so called Appleton anomaly, regions of high F layer electron density maximizing about 15° in latitude north and south of the dip equator, is seen more prominent due to the enhanced plasma transport to the regions. Another notable feature is the equatorial plasma bubble that consists of F region irregularities within a region of reduced electron density. Irregularities are also seen below the F layer maximum, a phenomenon known as bottom side spread F.

In this paper, we would like to introduce some of the results obtained from the Korea Multipurpose Satellite-1 (KOMPSAT-1). KOMPSAT-1 is a remote sensing satellite, launched on December 21, 1999, with a sun-synchronous polar orbit. The altitude is 685 km and its orbital inclination angle is 98°. As a secondary payload, the Ionospheric Measurement Sensor (IMS) is located in front in the ram direction, being free from the wake effect. As seen in Figure 1, IMS consists of a Langmuir Probe (LP) and an Electron Temperature Probe (ETP) (Lee et al. 2000). LP measures electron density and temperature with a time resolution of 4 s, and ETP measures the electron temperature and floating potential with a 1 s time resolution. The results from these two instruments are verified against each other to confirm the reliability of the data. With the fixed descending node at 22:50 LT of the spacecraft, IMS observed the nighttime upper ionosphere over more than a year from June 28, 2000 to August 1, 2001 with a nominal 30 % duty cycle until the instrument suffered an unexpected power failure (Lee et al. 2002).

II. RESULTS

Here we report some of the results obtained from IMS. First, we describe the deep electron density trough in the nighttime equatorial ionosphere during the Bastile event on 15 July 2000. Second, we present the results of our statistical study on the equatorial plasma bubble formation. And last, we compare the KOMPSAT-1 measurement of the nighttime upper ionosphere with the IRI model.

(a) Observation of the Bastile event

The Bastile Day storm was one of the largest magnetic storms observed during the last solar maximum. Following a coronal mass ejection on July 14, 2000, an enhancement of AE exceeding 1000 nT was recorded at 10:00 UT on July 15, 2000 and it continued to rise while the Dst index showed a sudden decrease to -130 nT around 21:00 UT followed by a minimum value of -300 nT at 22:00 UT.

Figure 2 shows the Dst and Kp variations during the period from July 5 to August 19, 2000. In addi-

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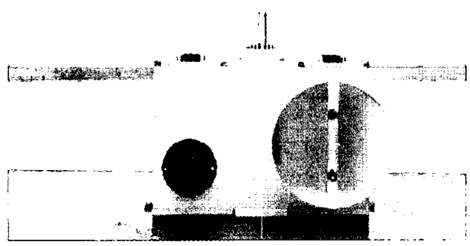

Fig. 1.— Ionospheric Measurement Sensor on board the KOMPSAT-1. On top of the electronic box resides the Langmuir Probe and the two half-disks on the right are the Electron Temperature Probe. The High Energy Particle Detector is also seen on the left.

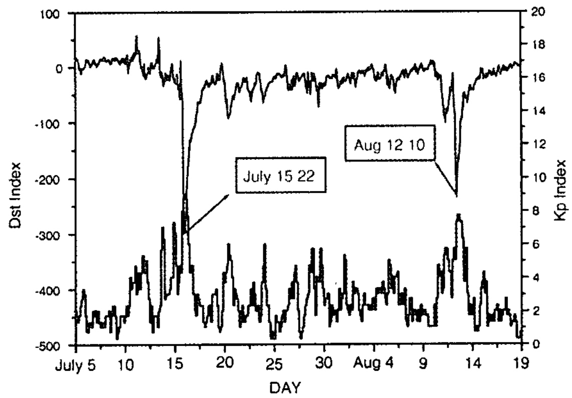

Fig. 2.— The variations of geomagnetic indices Dst (top) and Kp (bottom) from July 5 through August 19, 2000. Two strong magnetic storms are seen on July 15 and on August 10. KOMPSAT-1 observed very disturbed nighttime ionosphere during both of the storms.

tion to the magnetic storm associated with the Bastile event on July 15, in which the Dst index reached as low as -300 and Kp as high as 9°, another big storm is seen on August 12. KOMPSAT-1 observed very disturbed ionospheres during these storms. We will concentrate on the July 15 storm in this discussion. First, we note that a rather high level of magnetic activity preceded the magnetic storm of July 15, as the Kp index in Figure 2 shows multiple peaks even before the onset of the magnetic storm. Indeed, KOMPSAT-1 measurement revealed somewhat disturbed equatorial ionosphere around 06:35 UT on July 15 when the storm had not started yet.

KOMPSAT-1 passed the region near 0°E during the main phase of the Bastile storm. Figure 3 shows the results obtained from this pass around 23:00 UT on July 15. A dramatic distortion is evident: a deep and extensive low latitude trough of electron density developed between 5°N and 16°N geographic latitude where the electron density N_e dropped sharply from 4×10^5 cm^{-3} to less than 2×10^4 cm^{-3}. Unfortunately we were unable to obtain the exact values of N_e within the depletion but they were estimated to be lower than 1.0×10^3 cm^{-3}, the dynamic limit of the instrument. The depletion region extended over 1400 km along the satellite track. The electron temperature was also seen highly disturbed during the storm. In the low latitude region, T_e was enhanced from the quiet time value and reached 1800 °K, except in the trough region where the electron temperature was not reliably estimated. T_e increased sharply with latitudes outside the low latitude region, attaining a value of 3000 °K with severe fluctuations at high latitudes. At the southern boundary of the trough, the satellite encountered small scale density depletions with corresponding temperature fluctuations. We believe these features are the so called equatorial bubbles.

Greenspan et al. (1991) postulated that the formation of the equatorial trough, which was observed dur-

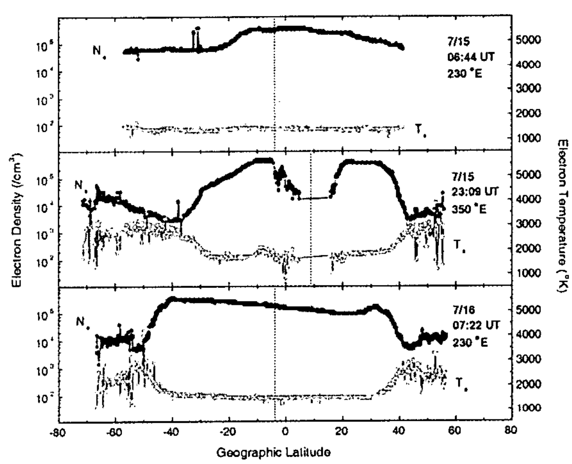

Fig. 3.— The electron density (closed circles) and temperature (open circles) measured by KOMPSAT-1 before (top), in the main phase of (middle), and during the recovery phase (bottom) of the 15 July 2000 storm. The vertical dotted lines indicate the positions of the magnetic equator. Universal time is given at the equator crossing.

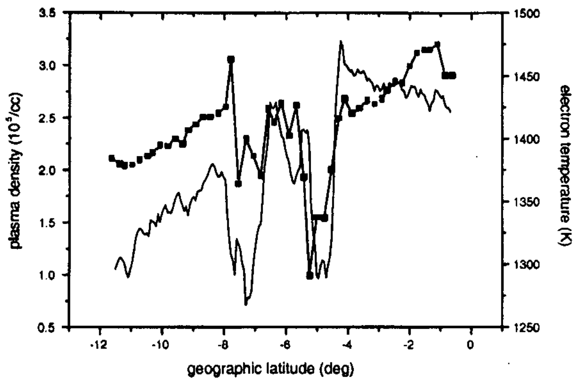

Fig. 4.— An example of EPBs observed by KOMPSAT-1. The thick line with square dots represents the electron density and the thin line represents the electron temperature.

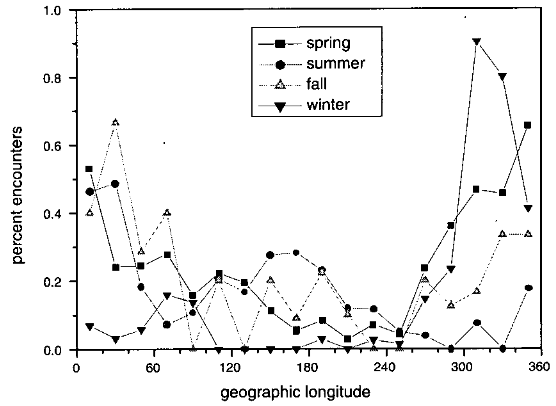

Fig. 5.— Seasonal and longitudinal distribution of occurrence probability of bubbles.

ing the 14 March 1989 storm with DMSP F9, could be attributed to an anomalously large eastward electric field that lifted entire nighttime low latitude F2 layer above 840 km due to a rapid upward $\mathbf{E} \times \mathbf{B}$ plasma drift, while DMSP F9 observed the bottom side F region where N_e is very low. The model simulation by Rasmussen & Greenspan (1993) verified this by demonstrating that large eastward electric field could produce the dramatic depletions in the plasma density. While the upward ion flow due to the $\mathbf{E}\times\mathbf{B}$ drift cannot be determined by the KOMPSAT-1 data only, the evolution of the density vs. magnetic latitude profiles observed by DMSP spacecraft F14 and F15 indicates that the equatorial ionosphere was being pushed upward.

(b) Equatorial plasma bubbles

Figure 4 shows an example of the equatorial plasma bubbles (EPBs) obtained by KOMPSAT-1. The electron density data are provided by LP and the electron temperatures are calculated from the ETP data. Two bubbles are seen in this figure around -5° and between -7° and -8° geographic longitude, and the electron temperature is lowered inside both of the bubbles. Large databases from satellite observations have been analyzed statistically to obtain the seasonal and longitudinal variations of bubble occurrences (Maruyama & Matuura 1984; Watanabe & Oya 1986; McClure et al. 1998; Huang et al. 2001). The result shows EPBs occur frequently over the Atlantic sector, while in the Pacific sector the occurrence frequency is much lower. Huang et al. (2001) attributed the reason to relatively larger equatorial magnetic fields at F layer altitudes in the Pacific sector than at Atlantic longitudes. They also suggested the enhanced EPB activity during the summer season in the central to eastern Pacific, where the magnetic declination is eastward, was in good agreement with the solar terminator model by Tsunoda (1985). We also observe similar seasonal and longitudinal dependence in the KOMPSAT-1 data.

Figure 5 shows the seasonal and longitudinal distribution of the bubble occurrence probability. It is seen that the bubbles occur at all longitudes in the equinoctial seasons, with peak occurrence in the south American-Atlantic-African region, while in the winter season most bubbles occur in the narrowed region of south America-Atlantic ocean and some in the Indian sector. Bubbles are scarcely seen in the Pacific region during the wintertime. It is interesting to see that bubbles are virtually non-existent in the south American-Atlantic sector in the summer season and the region of peak occurrence has moved to the African sector. Bubble activity also seems to be enhanced in the Pacific region during the summertime. Most of these findings are consistent with the statistical analysis of Huang et al. (2001) using the DMSP satellites.

Thermal nature of EPBs has not been explored well since most of the satellite data used for statistical study do not provide necessary information. Other than a brief report by Brace et al. (1982), only the results from the Hinotori satellite have been published (Oyama et al. 1988). Hinotori data showed that the electron temperature inside the plasma bubble could be either higher or lower than the ambient temperature outside, depending on the local time and position. Heating of electrons inside plasma bubbles was seen at times over the South Atlantic Anomaly and over the Hawaiian anomaly where particle precipitation is frequently observed. Oyama et al. (1993) calculated the temperature changes with suitable energy input to the plasma bubbles and showed the results were consistent with the Hinotori observations. The ETP on KOMPSAT-4 measured the electron temperature reliably inside most of the bubbles. Figure 6 shows the longitudinal distribution of EPBs with the electron temperature depressed more than 50 °K from the ambient tempera-

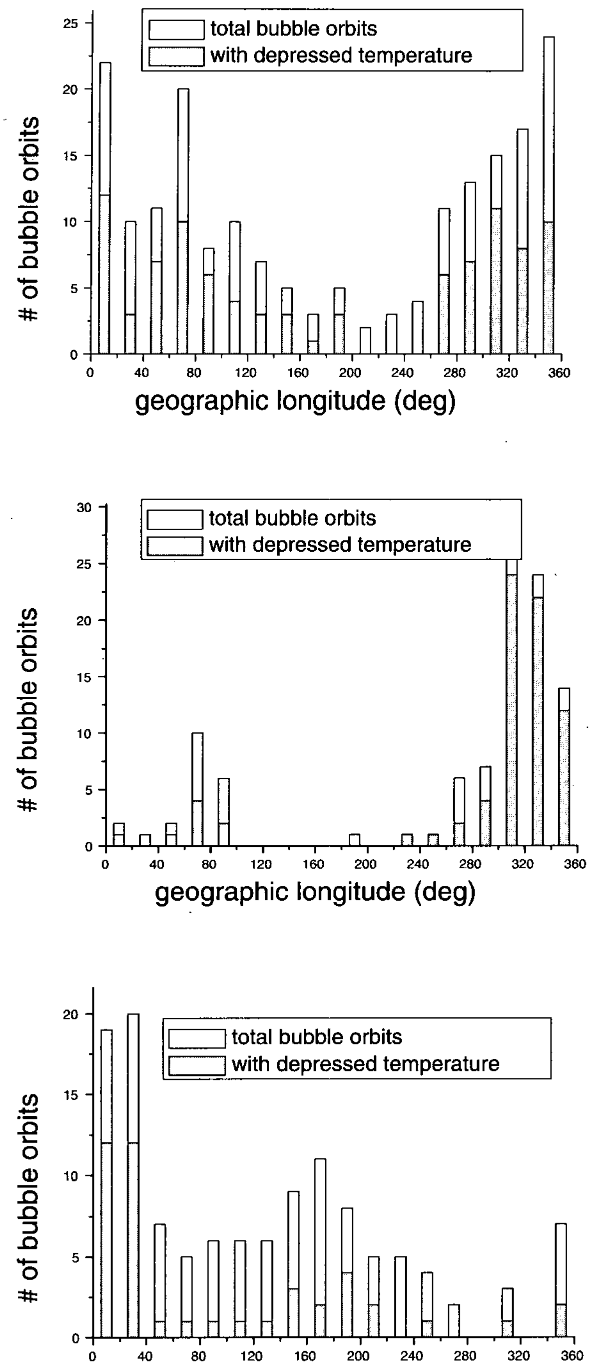

Fig. 6.— Longitudinal distribution of the EPBs with depressed electron temperature compared with the total number bubbles: (a) spring and fall equinox, (b) December solstice, and (c) June solstice.

ture. It is compared with the total number of bubbles. It is seen that the temperature is depressed in about 50 % of the bubbles. It is also seen that the bubble temperature does not seem to have any correlation with the seasons, except that most bubbles in the south American-Atlantic region during the wintertime have lowered electron temperature. It seems only a small fraction of the bubbles of the summer season have depressed temperatures in the region other than the African sector, but the statistics is rather low in this case. While it is not shown here, the bubbles with enhanced temperature in the south-American sector seem to be located toward the South Atlantic Anomaly, southward when compared with the general bubble locations.

(c) Seasonal variation of the global nighttime ionosphere

KOMPSAT-1 observation covered a whole year during the solar maximum period. We plot the quiet time ionosphere in Figure 7 by selecting the data for Kp smaller than 4. The data are averaged with 2.5° interval in latitude and 5° interval in longitude. It is seen in the figure that the equatorial region is well defined along the magnetic equator in the KOMPSAT-1 data. In low latitude regions the electron density and temperature observed by KOMPSAT-1 are higher than the IRI values while in mid-latitudes KOMPSAT-1 electron density and temperature are lower than those of the IRI model. It is also seen that the equatorial features shift toward the summer hemisphere. The density suddenly changes around the latitudes of $\pm 15°$ respectively in summer and winter. A close look at the summer density profile reveals that the density peak at longitude -40° shifts more northward compared to those at longitudes 30° and 210°. In addition, the density at longitude -40° in the mid-latitude region of the southern hemisphere is lower than those at longitudes 210° and 30°. These variations can be explained by the inter-hemispheric plasma transport (Venkatraman & Heelis 1999). During solstices the meridional neutral wind blowing from the summer to the winter hemisphere drives the plasma upward along the magnetic field line in the summer hemisphere and downward in the winter hemisphere (Oyama 1996).

III. DISCUSSION

A simple Langmuir probe operated for a little more than a year on KOMPSAT-1 measured various ionospheric phenomena including magnetic storm disturbances and plasma bubbles. Full coverage of four seasons also makes it possible to study the seasonal variation of the nighttime upper ionosphere and compare it with the IRI model. Though not presented in this paper, the mid-latitude to high latitude observations also reveal many interesting features such as subauroral ionospheric troughs in which plasma density abruptly decreases and the corresponding electron temperature

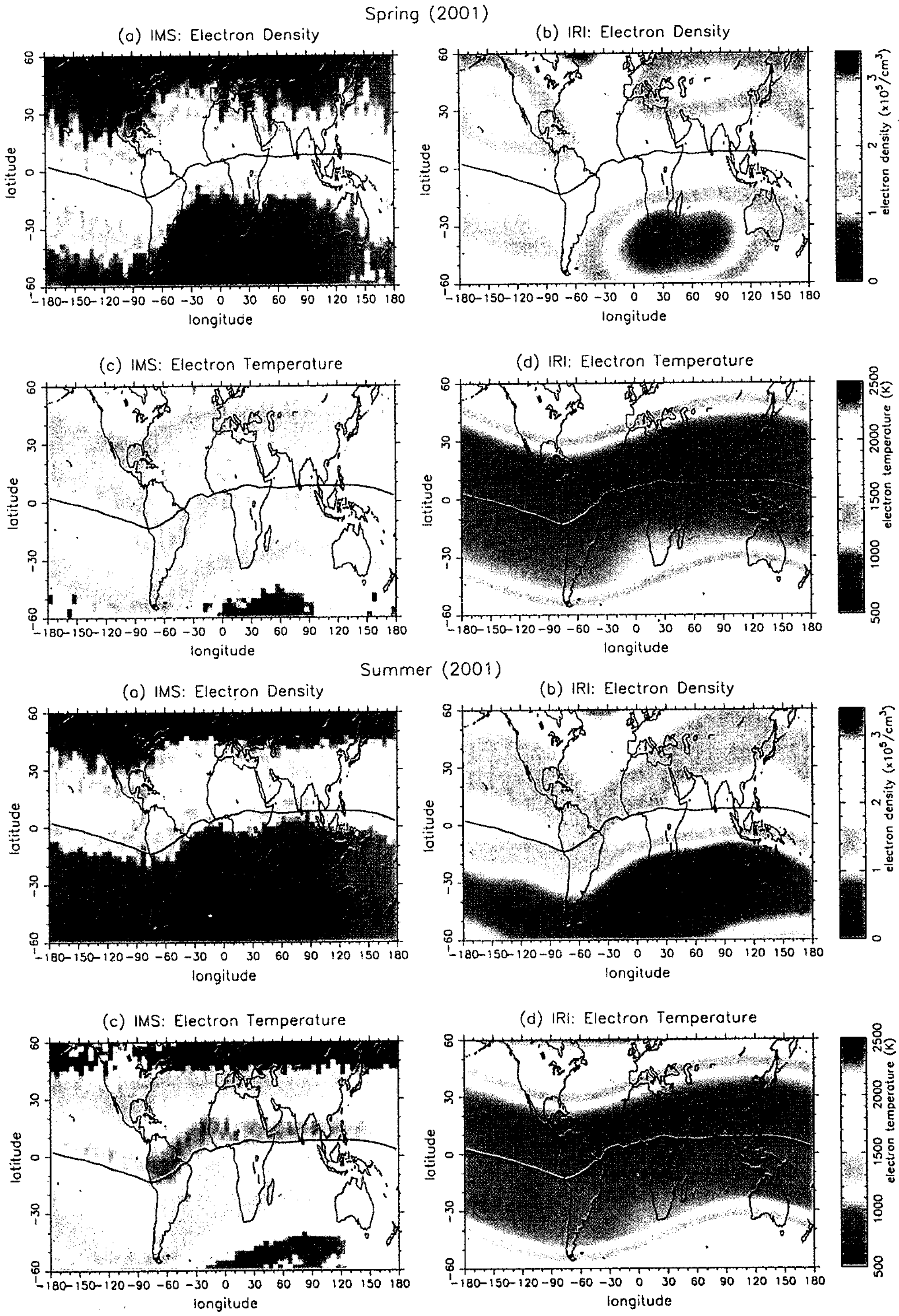

Fig. 7.— Global distribution of nighttime electron density and temperature at 685 km altitude, as compared with the IRI model.

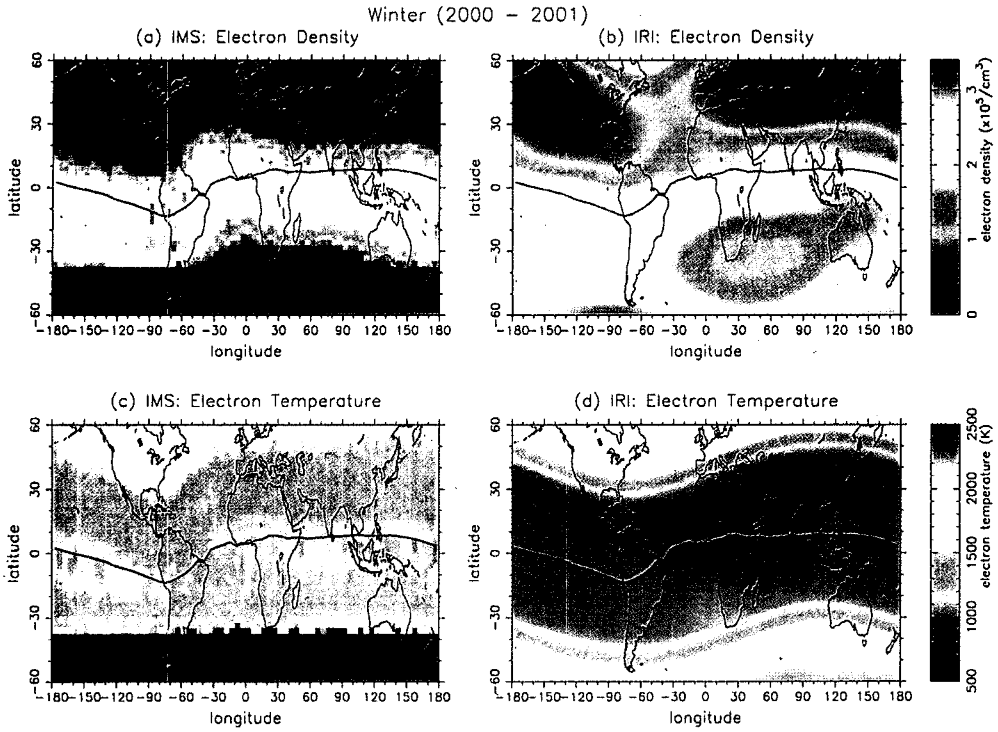

Fig. 7.— *continue*

increases. Nevertheless, the Langmuir probe theory intrinsically assumes thermal equilibrium of plasmas, which may not be true especially in high latitude regions where auroral particle precipitation occurs. Also, it is not clear whether the electron temperature parallel to the geomagnetic field is the same as the perpendicular temperature.

Two sets of revised Langmuir probes on KAISTSAT-4 will improve the situation. Following the Druyvestein method, the new Langmuir probe will measure the electron energy distribution directly without assuming its Maxwellian distribution. Also, the two probes located on the two far ends of the solar panels are perpendicular to each other and over the polar region, where the geomagnetic field is predominantly vertical, one of the probes is parallel to the ambient magnetic field and the other is perpendicular to it. Since the probes are a cylindrical type, the parallel probe is sensitive only to the perpendicular temperature while both the perpendicular and the parallel temperatures affect results of the perpendicular probe. The Langmuir probe observation will also be compared with the results of precipitating electron measurement to be obtained from the Electrostatic Analyzer (ESA) on board the same KAISTSAT-4 spacecraft, as well as those from the Solid State Telescope (SST) and the Far-ultraviolet Imaging Spectrograph (FIMS). The KAISTSAT-4 is scheduled for launch in August 2003.

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REFERENCES

Brace, L. H., Theis, R. F., & Hoegy, W. R. 1982, A Global View of F-region Electron Density and Temperature at Solar Maximum, Geophys. Res. Lett., 9, 989

Greenspan, M. E., Rasmussen, C. E., Burke, W. J., & Abdu, M. A. 1991, Equatorial Density Depletions Observed at 840 km during the Great Magnetic Storm of March 1989, J. Geophys. Res., 96, 13931

Huang, C. Y., Burke, W. J., Machuzak, J. S., Gentile, L. C., & Sultan, P. J. 2001, DMSP Observations of Equatorial Plasma Bubbles in the Topside Ionosphere near Solar Maximum, J. Geophys. Res., 106, 8131

Lee, J. J., Min, K. W., Lee, E. S., & Kim, J. 2000, Observation of Nighttime Ionosphere using KOMPSAT-1, Publ. Kor. Ast. Soc., 15S2, 37

Lee, J. J., Min, K. W., Kim, V. P., Hegai, V. V., Oyama, K. -I, Rich, F. J., & Kim, J. 2002, Large Density Depletions in the Nighttime Upper Ionosphere during the Magnetic Storm of July 15, 2000, Geophys. Res. Lett., 29, 10.1029/2001GL013991

Maruyama, T., & Matuura, N. 1984, Longitudinal Variability of Annual Changes in Activity of Equatorial Spread-F and Plasma Bubbles, J. Geophys. Res., 89, 10903

McClure, J. P., Singh, S., Bamgboye, D. K., Johnson, F. S., & Kil, H. 1998, Occurrence of Equatorial F Region Irregularities: Evidence for Tropospheric Seeding, J. Geophys. Res., 103, 29119

Oyama, K. -I., Schlegel, K., & Watanabe, S. 1988, Temperature Structure of Plasma Bubbles in the Low Latitude Ionosphere around 600 km Altitude, Planet. Space Sci., 36, 553

Oyama, K. -I., Watanabe, S., & Oya, H. 1993, Energetics in the Plasma Bubbles, Adv. Space Res., 13, 293

Oyama, K. -I., Watanabe, S., Su, Y., Takahashi T. & Hirao, K. 1996, Season, Local Time, and Longitudinal Variations of Electron Temperature at the Height of 600 Km in the Low Latitude Region, Adv. Space Res., 18, 269

Rasmussen, C. E., & Greenspan, M. E. 1993, Plasma Transport in the Equatorial Ionosphere during the Great Magnetic Storm of March 1989, J. Geophys. Res., 98, 285

Rich, F. J. & Sultan, P. J. 2000, Comparison of Ion Densities Measured in the Topside Ionosphere at Low Latitudes and Midlatitudes with Calculations of Ionospheric Models over a Full Solar Cycle, Radio Sci., 35, 1193

Tsunoda, R. T. 1985, Control of the Seasonal and Longitudinal Occurrence of Equatorial Scintillations by the Longitudinal Gradient in Integrated F-region Pedersen Conductivity, J. Geophys. Res., 90, 447

Venkatraman, S. & Heelis, R. 1999, Longitudinal and Seasonal Variations in Nighttime Plasma Temperatures in the Equatorial Topside Ionosphere during Solar Maximum, J. Geophys. Res., 104, 2603

Watanabe, S., & Oya, H. 1986, Occurrence Characteristics of Low Latitude Ionospheric Irregularities Observed by Impedance Probe on Board the Hinotori Satellite, J. Geomagn. Geoelectr., 38, 125