LONGITUDINAL PECULIARITY OF TOPSIDE ELECTRON DENSITY AT 1100 KM

Takashi Maruyama

Communications Research Laboratory
2-1 Nukuikita 4-Chome, Koganei, Tokyo, 184-8795 Japan, E-mail: tmaru@crl.go.jp

ABSTRACT

Morphology of the global topside ionospheric electron density as observed by the topside sounding satellite is analyzed. Discussion is focused on the longitudinal dependence of the equatorial electron density in the evening hours, which could be a measure of the evening enhancement of the zonal electric field or upward plasma drift. At low latitudes, after a strong evening enhancement of the upward drift of the ionosphere, equatorial spread *F* and severe ionospheric scintillations often occur. We found that the local time when the evening enhancement develops is controlled by the earth's magnetic declination angle. During the northern winter season, the local time of the enhancement is early at the longitudes of westward magnetic declination and it is late at the longitudes of eastward magnetic declination. However, the amplitude of the enhancement appears to be related with offset of the magnetic equator from the geographic equator; the largest enhancement was observed at the longitude of 60 to 120 degrees West.

INTRODUCTION

Most severe ionospheric radio scintillations occurring in satellite communication links are caused by plasma bubbles during the nighttime at low latitudes. The basic mechanism of the plasma bubble generation is known to be Rayleigh-Taylor instability operating on the bottomside of the ionosphere. One of the major conditions for the growth of Rayleigh-Taylor instability is the high layer altitude attained by the upward $\mathbf{E}\times\mathbf{B}$ drift motion of the plasma due to the zonal eastward electric field. The ionospheric vertical $\mathbf{E}\times\mathbf{B}$ drift at low latitudes directs upward during daytime and turns downward at the evening. Prior to the drift reversal in the evening hours, upward drift velocity often enhanced, which is called an evening enhancement or prereversal enhancement. The grater part of the morphology of ionospheric scintillations can be explained by the variability of the evening enhancement, including a combined longitudinal-seasonal variability and a large day-to-day variability. Thus for the study of the ionospheric scintillations at low latitudes, information on the evening enhancement of the upward plasma drift or zonal electric field is indispensable. There is a large database of plasma drift velocity measured by an incoherent backscatter radar at Jicamarca, Peru. However, the ionospheric electric field varies with the longitude and season. Therefore world-wide observations of the electric field is required to study the mechanism of variability of the electric field.

The vertical plasma drift greatly modifies the electron density distribution in the whole ionosphere in a different way depending on the altitude. The upward $\mathbf{E}\times\mathbf{B}$ drift motion of the plasma causes an increase in the electron density in the topside ionosphere. We infer the longitudinal variation of the evening enhancement from the global distribution of the ionospheric electron density observed at 1100 km altitude by the ISS-b satellite topside sounder and the cosmic radio noise measurements conducted simultaneously with the sounding. The observations are interpreted by an assist of model calculations.

DATA ANALYSIS

The Ionosphere Sounding Satellite, ISS-b, made topside sounding from 1978 through 1980, during the solar maximum period. The orbit of the satellite is nearly circular at the height of 1100 km and the inclination angle is 70 degrees. The frame rate is one ionogram per 64 seconds, and 400 ionograms a day were recorded. The *F* region ionospheric critical frequencies were scaled manually, but the whole traces of the echo have not been processed yet. In this study, the plasma frequencies or electron densities at the satellite height are evaluated from the cosmic radio noise, which were simultaneously recorded as an automatic gain control (AGC) voltage of the topside sounder receiver. For this purpose, an artificial neural network (ANN) is applied to the spectrum of cosmic radio noise intensity near the local plasma cutoff frequency. In order to train the ANN, local electron densities, which are the target of the ANN, were scaled from the plasma resonance spikes and the echo traces in the ionogram for about 600 ionograms. Input parameters to the ANN are the cosmic radio noise spectrum, the local electron gyrofrequency, and the galactic coordinates of the satellite position. Each pass contained about 100 frames of ionograms; it is not a very easy task to scale the local plasma parameters by an eyeball judgment for all passes. With the aid of a neural network application, we determined the *in-situ* electron densities for the rest of the data, which are about 150,000 ionograms. The details of the algorithm and performance of the ANN is described by Maruyama [1]. In this paper, hereafter, we refer the electron density at the satellite height of about 1100 km simply as the topside electron density.

Global mapping

The ionospheric electron density variation is owing to chemical and dynamical processes. The chemical processes are the production and loss of the plasma, which is predominant in the bottomside ionosphere. The major dynamical processes are the field aligned diffusion and the field perpendicular **E**×**B** drift due to the zonal electric field. Relative importance of each process varies with latitude and local time. In the topside ionosphere the dynamical processes are predominant. The topside electron density is affected by the production and loss processes at lower heights through the diffusion process along the field line, which is a major cause of the diurnal variation of the density. At the magnetic equator where the earth's magnetic field lines are horizontal, the vertical plasma drift due to the zonal electric field efficiently modifies the electron density distribution at a given height depending on the scale height of the vertical density profile. Thus the topside electron density distribution is expected to have information on the dynamical process. First of all, we analyzed the local time variation of the topside electron density at various latitudes by using harmonic functional expansion, i.e., a local time versus latitude map was drawn.

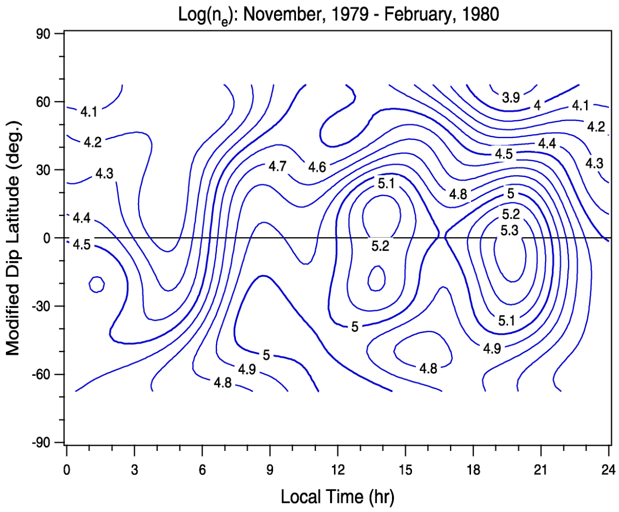

Fig. 1 Diurnal variation of the topside electron density.

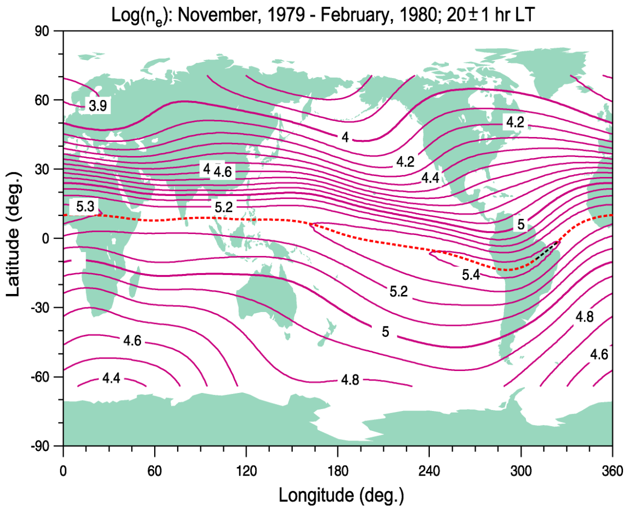

Fig.2 Constant local time map of topside electron density.

The result is shown in Fig. 1 for the periods from November, 1979 to February, 1980. The numbers are log n_e, where n_e is in a unit of cm^{-3}. The monthly mean solar activities during this period were high (F10.7 = 232, 204, 206, and 200). As a longitude parameter in the harmonic expansion, the hour angle is used, and therefore, possible geographical variations are averaged over the whole longitude. The figure reveals distinct two electron density peaks at around 1400 LT and 2000 LT. These density enhancements are directly related to the local time variation of the zonal electric field which points eastward during daytime and westward during nighttime with a evening eastward enhancement in the evening; resulting **E**×**B** drift is upward (daytime and evening) and downward (nighttime). The density enhancement at 2000 LT in the figure obviously corresponds to the strong evening enhancement of the upward **E**×**B** drift that is typically observed during a solar maximum period [2].

By the ground based and low altitude satellite measurements near the *F*-region peak height, it is known that the amplitude of the evening enhancement largely varies not only with solar activity but also with season, and longitude [2], [3], [4]. In order to examine the longitudinal peculiarity, a longitudinal distribution map of the electron density under the condition of constant local time (LT = 20±1 hr) was drawn for the same period with Fig. 1 and the result is shown in Figure 2. In the figure, in addition to a general north-south asymmetry and high electron density near the magnetic equator, longitudinal peculiarity is clearly shown for the equatorial region. The highest electron density is over the west coast of South America, where the offset of the magnetic equator from the geographic equator is the largest.

MODEL CALCULATIONS

In the previous section, global distribution maps are presented showing morphology of the topside electron density. Although the topside electron density contains information on the vertical **E**×**B** drift, electron density itself is dynamically determined by the prior ionospheric conditions and field aligned redistribution to compensate the non-equilibrium caused by the vertical **E**×**B** transportation. Therefore, it is not quite obvious that an enhancement of the electron density quantitatively corresponds to an upward drift velocity. In order to interpret the distribution maps and for further data processing, we made ionospheric model calculation, in which the continuity equation is solved using empirical models of vertical drifts and neutral winds.

There exists a large database of electrodynamic plasma drift near the *F*-region peak height at the equator from Jicamarca Radio Observatory. However, the vertical drift velocity is subject to change with height according to the condition of curl $\mathbf{E} = 0$ and the gradient of the zonal drift velocity. Thus the vertical drift in the topside ionosphere is synthesized from the published observational data and theoretical works [2], [4], [5]. The model calculations indicate that the equatorial topside electron density enhancement in the evening hour is primarily controlled by the upward drift enhancement. However, the upward drift velocity during the daytime and the local time of the evening enhancement also affect the topside electron density even when the amplitude and duration of the enhancement are identical. The local times of the electron density maximum correspond to the times when the upward drift reverses to downward, while the temporal changes in the electron density correspond to the upward drift enhancement. Rather temporal changes of the electron density could be a more adequate measure of the plasma drift than the electron density enhancement itself.

DIFFERENTIAL MAPS

Based on the modeling results, we calculated constant local time maps for each local time hour first, then, differential maps between the two consecutive local times are obtained. The results are shown in Fig. 3. Figs. 3(a) to (c) show the temporal evolution of the electron density from 1700 to 1800, 1800 to 1900, and 1900 to 2000 LT. Fig 3(d) is the map of the magnetic declination angle and the magnetic equator calculated from IGRF. A plus sign in the differential maps indicates an increase in the density and hence a large upward drift velocity. From the figure, it is evident that the development of the evening enhancement starts at early hours at the longitudes of westward magnetic declination, while it starts at late hours at the longitudes of eastward magnetic declination. The amplitude of the enhancement is the largest at the longitudes where the offset of the equator is the largest.

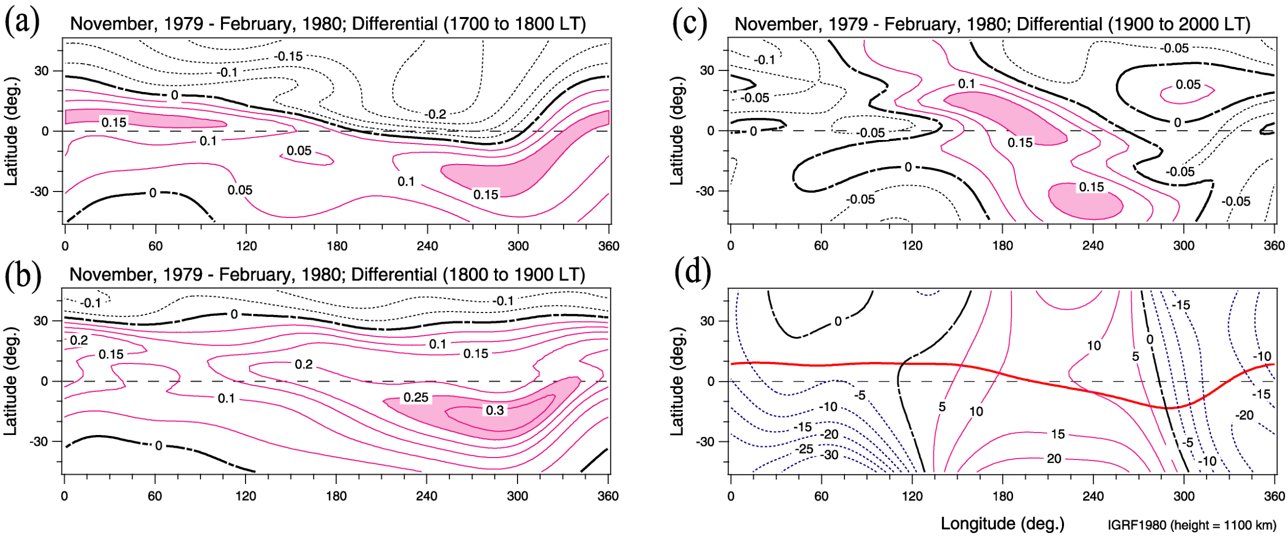

Fig. 3 Differential maps and earth's magnetic declination angle.

CONCLUSIONS

From the global distribution maps, with the assist of the modeling results, we found that the reversal time of the electric field or vertical drift is controlled by the declination angle of the earth's magnetic field, while the amplitude of the enhancement appears to be controlled by the offset of the magnetic equator from the geographical equator. The declination effect on the drift reversal times is clearly shown, which may connected with the changes in the F-region Pedersen conductivity caused by the transequatorial component of thermospheric neutral winds in the magnetic meridional plane, which is also subject to change with the magnetic declination angle, are suggested as a cause of the longitudinal peculiarity of the prereversal enhancement.

REFERENCES

[1] T. Maruyama, Retrieval of in-situ electron density in the topside ionosphere from cosmic radio noise intensity by an artificial neural network, *Radio Sci.*, in press.

[2] B.G. Fejer., Low latitude electrodynamic plasma drifts: a review, *J. Atmos. Terr. Phys.*, vol. 53, pp. 677-693, 1991.

[3] I.S. Batista, M.A. Abdu, and J.A. Bittencourt, Equatorial F region plasma drifts: Seasonal and longitudinal asymmetries in the American sector, *J. Geophys. Res.*, vol. 91, pp. 12,055-12,064, 1986.

[4] B.G. Fejer, E.R. de Paula, R.A. Heelis, and W.B. Hanson, Global equatorial ionospheric vertical plasma drifts measured by the AE-E satellite, *J. Geopohys. Res.*, vol. 100, pp. 5769-5776, 1995.

[5] J.A. Murphy and R.A. Heelis, Implication of the relationship between electromagnetic drift components at mid and low latitudes, *Planet. Space Sci.*, vol. 34, pp. 645-652, 1986.