Ionospheric Electron Content and Equivalent Slab Thickness in the Equatorial Region

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The ionospheric total electron content and equivalent slab thickness in the equatorial region around 75°E have been studied. It is found that the slab thickness exhibits a strong latitudinal dependence with a maximum at the magnetic equator and a minimum around the crest of the F_2 anomaly, indicating that the F region is thick near the equator and most skewed near the crest. The results are consistent with the electrodynamic drift and diffusion in the equatorial ionosphere.

It is known that at low latitudes during the daytime the maximum electron density of the F layer exhibits a pronounced latitude variation with the appearance of a trough at the magnetic equator and two crests around ±30° magnetic dip [*Appleton,* 1946]. Workers have sought to explain this latitude variation, known as the equatorial anomaly, on the basis of a vertical electrodynamic drift of ionospheric plasma at the magnetic equator and plasma diffusion along magnetic field lines [*Hanson and Moffett,* 1966, and references therein]. The top side sounder results revealed that shortly after sunrise a single ionization crest occurs above the magnetic equator at all altitudes, but later the equatorial anomaly develops in the form of an arch, along which the ionization is enhanced and which lies along different magnetic field lines [*Eccles and King,* 1969] with the buildup of electrodynamic force. The crests of the equatorial F_2 anomaly appear at a location where the arch following the magnetic field lines maps itself to the F_2 layer. Around noon, when the electrodynamic force attains its maximum value, the altitude of the field-aligned ionization arch becomes maximum at about 800 km over the magnetic equator, and the crests of the equatorial F_2 anomaly move farthest apart. In the late afternoon the process is reversed, and the crests come closer, merging finally into a single crest at the magnetic equator. Since the above geomagnetic control is a feature of considerable height range in the top side ionosphere, the ionospheric total electron content *TEC*, which is heavily weighed by ionization up to about 600 km, is expected to exhibit a latitude variation similar to the equatorial anomaly in F_2 ionization. The existence of such a latitude variation of *TEC* has been established [*de Mendonça et al.,* 1969; *Hunter,* 1970; *Das Gupta and Basu,* 1973]. The ratio of the total electron content of the ionosphere, *TEC*, and the maximum ionization $N_m F_2$, termed the equivalent ionospheric slab thickness, provides a measure of the skewness of the vertical ionization distribution. Since both *TEC* and $N_m F_2$ exhibit a marked latitude variation over the equatorial region, it is of interest to examine if their ratio, i.e., the slab thickness parameter, varies with latitude over the equatorial region. This study provides information on the nature of variation of the vertical ionization profile over the region where the equatorial F_2 anomaly is obtained. However, owing to the presence of a strong latitudinal dependence of *TEC* and $N_m F_2$, such a study of slab thickness requires overhead observations of *TEC* and $N_m F_2$ at each of the different stations. In the present paper the results on *TEC* and equivalent slab thickness obtained at Kodaikanal (10.2°N, 77.5°E geographic; 3.5°N magnetic dip) are combined with those of Hyderabad (17.3°N, 78.5°E geographic; 21.5°N dip), Ahmedabad (23°N, 72.5°E geographic; 34°N dip), and Delhi (28.6°N, 77.2°E geographic; 42°N dip) for a study of the latitude dependence of electron content and slab thickness. These four stations cover a dip range between 3.5°N and 42°N within a narrow longitude interval of 5° in the Asian sector, where the equatorial anomaly is most distinct and regular [*Hopkins,* 1972]. Each of the stations operates ionosonde and satellite beacon experiments. Hence unambiguous values of slab thickness pertaining to their respective locations can be obtained.

Figure 1 shows the diurnal variation of *TEC* at Kodaikanal during the winter of 1966–1967. These results have been obtained from the Faraday fading observations with satellite BEB by using *Ross*' [1966] first-order method of analysis for an equatorial station. The features, such as a presunrise minimum, rapid ionization buildup, and a midday bite-out, are similar to those obtained at the equatorial stations of Huancayo [*Bandyopadhyay,* 1970] in the American sector for the same period and Zaria in the African sector [*Skinner,* 1966]. There is also an indication of a secondary nighttime peak in *TEC*, but owing to limited data points no definite conclusion can be obtained. The diurnal range, defined by the ratio of maximum to minimum values of *TEC*, derived from the mean diurnal curve, is about 10.4, which is somewhat higher than the value of 8.7 at Huancayo. This may be due to the difference in the local seasons at the two stations or to the uncertainty in the minimum value of *TEC*.

Figure 2 shows the variation of mean diurnal maximum (around noon) and minimum (during the presunrise period) values of *TEC* with magnetic dip. It also depicts the variation of diurnal range with magnetic dip. In order to obtain these curves the analyzed *TEC* data of Kodaikanal have been combined with those from Hyderabad, Ahmedabad, and Delhi, reported by *Rama Rao et al.* [1969, and private communication, 1971], *Rastogi and Sharma* [1971], and *Somayajulu et al.* [1972], respectively. It is observed that at noon the *TEC* curve exhibits a pronounced maximum at Ahmedabad, situated near the crest of the equatorial anomaly, and a trough at Kodaikanal, located in the vicinity of the magnetic equator.

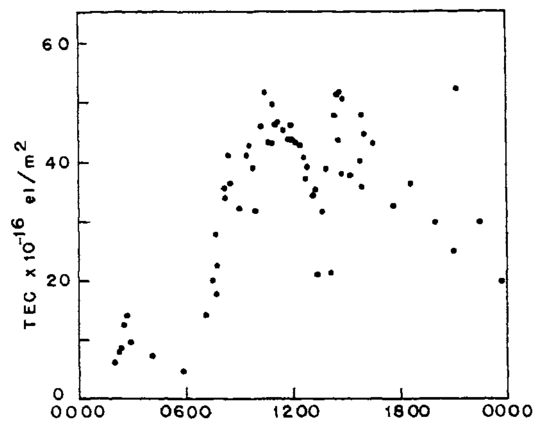

Fig. 1. Diurnal variation of *TEC* at Kodaikanal during the winter of 1966–1967.

The observed behavior indicates that vertical electrodynamic drift at the magnetic equator and diffusion of ionization along field lines deplete the electron content at the magnetic equator and enhance it around the crests of the equatorial anomaly. The features of total content in the equatorial region have been discussed by *Basu and Das Gupta* [1967], *Rufenach et al.* [1968], *de Mendonça et al.* [1969], *Golton and Walker* [1971], and *Das Gupta and Basu* [1973]. During the presunrise period, when the upward electrodynamic drift is not operative, the gradient of electron content with magnetic dip is expected to be opposite to that obtained during the daytime. This is indeed found to be the case, as is shown in the curve corresponding to minimum *TEC*. As a consequence a sharp maximum in the diurnal range is obtained around the crest of the equatorial anomaly, where *TEC* is maximum during the daytime.

Figure 3 shows the diurnal variation of slab thickness at Kodaikanal and three other stations situated around 75°E longitude. At Kodaikanal the slab thickness exhibits a predawn peak that is associated with a drastic depletion of maximum ionization N_mF_2 at the equator during this period [*Farley*, 1966]. Between 0600 and 0800 a trough is observed, which is caused by a relatively rapid buildup of ionization around the F_2 layer. An examination of N_mF_2 data at Kodaikanal substantiates this rapid buildup of ionization. Beyond 0800 the slab thickness increases and attains a high value around 1000 that is maintained throughout the day up to about 2200. The F_2 ionization does not show any significant change during this period. The high value of slab thickness during the daytime is consistent with electromagnetic drift (fountain effect), which enhances the content of the top side. The decrease in slab thickness after 2200 may be caused by the movement of the equatorial ionosphere to lower altitudes around this time [*Mahajan et al.*, 1968].

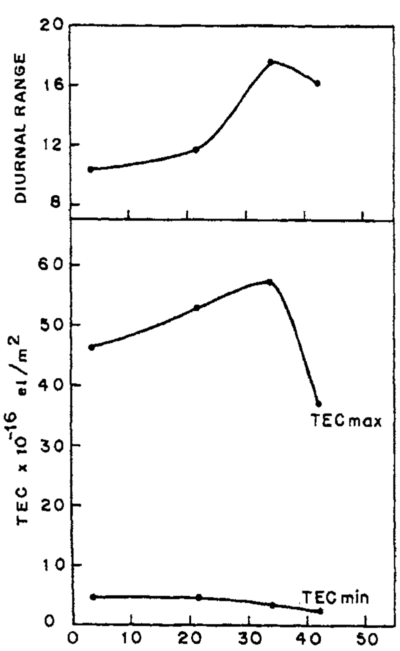

Fig. 2. Variation of *TEC* and diurnal range with dip around 75°E longitude during the winter of 1966–1967.

When the diurnal curves of slab thickness at Kodaikanal are compared with those of other stations, it is found that there exists a striking latitudinal dependence during the daytime. A decrease of slab thickness by about 100 km is encountered between Kodaikanal and Hyderabad, separated by only 7° in geographic latitude. However, the difference in dip value between these two stations is about 18°. At noon, when the equatorial anomaly is fully developed, the slab thickness falls off rapidly as one moves away from the magnetic equator, and it attains a minimum value at Ahmedabad, situated below the crest of the equatorial anomaly. Thus the slab thickness at a low-latitude station depends on its location with respect to the crest of the F_2 anomaly.

The above striking features of slab thickness in the equatorial region can be explained in terms of the 'fountain effect,' by which the ionization is lifted upward at the magnetic equator by the electrodynamic drift and diffuses along the geomagnetic field lines to be deposited at low latitudes. The ionization profile at the magnetic equator at altitudes above 300 km is mainly controlled by the electrodynamic drift. During the daytime with the development of the eastward electric field at the magnetic equator an upward drift velocity is imposed on the ionospheric plasma, which results in a thickening of the F_2 layer, often leading to stratification without any significant increase in N_mF_2 [*Huang*, 1974]. This explains the observed high value of slab thickness at Kodaikanal during the daytime. As the cross section of a field tube along which the plasma diffuses from the magnetic equator shrinks gradually with decreasing altitude, the vertical ionization profile becomes more skewed with increasing latitude. The profile attains maximum skewness at the crest of the equatorial anomaly, where the deposition of equatorial plasma is maximum. The computed profiles illustrated in Figure 4 of *Huang* [1974] demonstrate the above variation of profile skewness at low latitudes.

Balsley and Woodman [1969] have established that the vertical drift velocity at the magnetic equator is highly correlated with the equatorial electrojet current. As a result, the characteristics of the equatorial anomaly should be closely related to the strength of the electrojet current. This has been shown by several workers [*Dunford*, 1967, 1970; *Walker and Ma*, 1972; *Rush and Richmond*, 1973]. The latitudinal gradient of slab thickness, being primarily governed by the vertical drift velocity at the magnetic equator, should increase with the strength of the electrojet current.

Recently, *Titheridge* [1973, 1974], on the basis of extensive observational material, has established that at mid-latitudes the slab thickness parameter gives a measure of the exospheric neutral temperature. In the equatorial region the electrodynamic drift and appreciable horizontal plasma diffusion preclude a direct derivation of exospheric neutral temperature

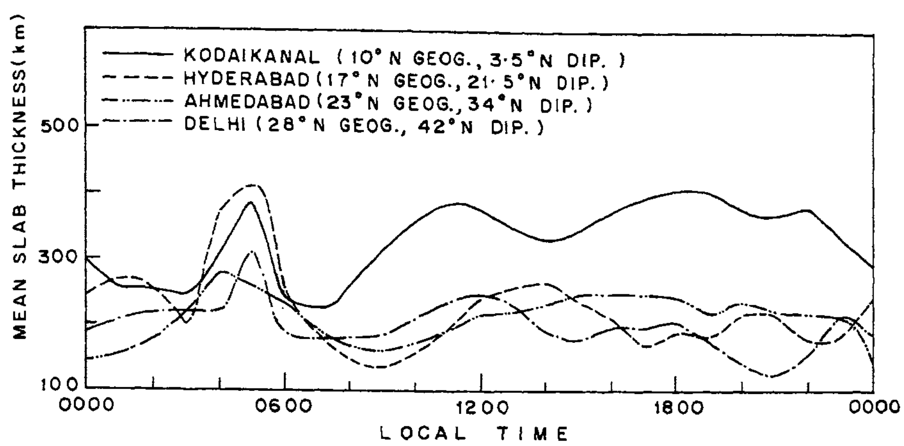

Fig. 3. Diurnal variation of slab thickness at Kodaikanal and other stations around 75°E longitude during the winter of 1966–1967.

from slab thickness. At locations where the dip angle is large the vertical electron scale height approximates the plasma scale height along a field tube, whereas at low latitudes these values differ considerably. However, under suitable approximations if the slab thickness at a low-latitude station can be related to the vertical electron scale height, a measure of plasma temperature along a field tube mapping into F_2 height can be obtained by converting the vertical scale height into the field-aligned plasma scale height [*Chandra and Goldberg*, 1964; *Thomas et al.*, 1966].

To summarize, the latitudinal variation of *TEC* in the equatorial region shows features similar to those of the F_2 ionization. The diurnal range, as defined by the ratio of maximum to minimum values of *TEC*, is found to be highest around the crest of the equatorial anomaly. A striking latitude gradient of daytime slab thickness is obtained in the equatorial region, indicating that the ionosphere is thick near the dip equator and most skewed around the crest of the F_2 anomaly. The observed features can be explained by considering electrodynamic drift and diffusion.

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