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TEC and Equivalent Slab-Thickness at Low & Midlatitudes – A Comparative Study

D S V V D PRASAD, K NIRANJAN & P V S RAMA RAO
Space Research Laboratories, Department of Physics, Andhra University, Waltair 530 003

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Using the simultaneous data of TEC recorded at Waltair (17.7°N) and Tokyo (35.7°N) during the high solar activity period of March 1978 to December 1978 at 136.1123 MHz from the ETS-II satellite, a comparative study of the variations in the diurnal and seasonal characteristics in TEC and the equivalent slab thickness were studied. In general, the level of ionization both during day and night at the low latitude station, Waltair, is much higher (30-40%) than that at the midlatitude station, Tokyo. At Waltair there is a significant maintenance of nighttime ionization with a short-lived (around 0500 hrs) day minimum as compared to a long duration day minimum (2200 to 0500 hrs) at Tokyo. The post-sunset increases in TEC observed at Waltair are not seen at Tokyo. The seasonal variation in the build-up and decay rates of ionization and the day maximum values in TEC at both the locations exhibit a significant semi-annual variation with equinoxial peaks around April and October. The equivalent slab thickness (τ) at Waltair shows an irregular diurnal variation in contrast to a nearly constant (around 250 km) value of τ at Tokyo in all the seasons. Significant early morning increases in τ observed at Waltair are attributed to the earlier illumination of the topside of the ionosphere preceded by a significant decrease in the peak electron density of the F-layer, particularly, in the equatorial region.

1 Introduction

It has been realized that the variations of the different ionospheric parameters significantly depend on the geographic location of the observing station. Of such parameters, the total electron content (TEC) and the equivalent slab thickness (τ) are two, which can be used to monitor the temporal and spatial behaviour of the ionosphere. The TEC is very much subjected to significant dynamical changes, particularly in the equatorial and low latitude regions[1], owing to the changes in the electric fields. But at midlatitudes, these effects are not significantly seen, where the dynamical processes are mainly controlled by neutral winds. The results on a comparative study of the variations of TEC and slab thickness at typical low and midlatitude stations, namely, Waltair (17.7°N) and Tokyo (35.7°N), are reported here. As the total electron content is heavily weighted by the F-region ionization, these anomalies are well reflected in the TEC variations as well. A study of the equivalent slab thickness, which is a measure of the skewness of the ionospheric electron density profile, and is also believed[2] to be a measure of the neutral temperature of the ionosphere, is of immense use in understanding the nature of variations of the upper atmosphere. With this objective in mind, a study has been carried out on the relative variations of TEC and slab thickness parameters at the two locations.

2 Data and Method of Analysis

The TEC data obtained at Waltair from the measurement of the Faraday rotation of the radio beacon at 136.1123 MHz from the Japanese geostationary satellite ETS-II during the high solar activity period March 1978-December 1978 has been used in the present study. The equivalent slab thickness which is defined as $\tau = N_T/N_m\text{F2}$ has been evaluated for Waltair. Since simultaneous data of N_mF2 either from Waltair or from Bombay (discontinuous) were not available, the values of τ were computed using the hourly TEC values of Waltair and the N_mF2 values of Ahmedabad (long., 72.6°E) after making due time correction for the longitude difference. As the difference in the latitude of the two stations, namely Waltair (17.7°N, 83.3°E) and Ahmedabad (23.1°N, 72.6°E), is not much, it can be expected that the f_0F2 values at both the locations are nearly equal. Hence, the f_0F2 data for the period March 1978-December 1978 of Ahmedabad are used for the present study. Further, the slab thickness for Waltair was also computed for a few days, using the simultaneously available data of N_mF2 derived from the ionograms taken at Waltair. The data of equivalent slab thickness (τ) derived from the N_mF2 values of Waltair and Ahmedabad, presented in Fig. 1, show similar characteristic variations and thus the use of N_mF2 data of Ahmedabad in conjunction with Waltair TEC data to derive τ is justified. The

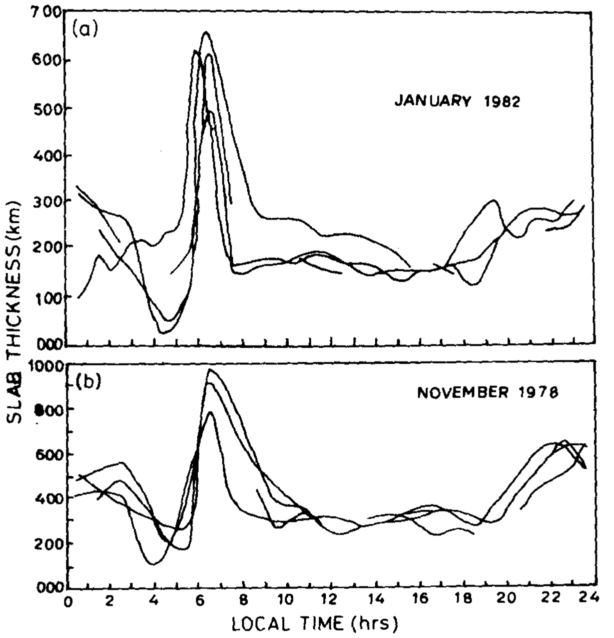

Fig. 1—Typical plots of slab thickness calculated using the N_mF2 data of (a) Waltair and (b) Ahmedabad

corresponding TEC and the equivalent slab thickness values for Tokyo are taken from the published data bulletin[3] of March 1985. From the monthly mean diurnal variation plots of TEC, the different diurnal characteristics such as the day maximum, day minimum, diurnal ratio, build-up and decay rates of ionization are computed for both the locations and a comparative study of the different parameters is made. A comparison of the variation in the diurnal and seasonal features of the equivalent slab thickness at the two stations has also been made.

3 Results and Discussion

3.1. Diurnal Changes in TEC

An examination of the diurnal and seasonal behaviour of TEC and the equivalent slab thickness at Waltair and Tokyo show marked differences. From the contour plots of TEC drawn for the two different stations presented in Figs. 2(a) and 2(b) and the seasonwise diurnal variation plots presented in Fig. 3, the following characteristic differences in the diurnal variation of TEC are observed. At Waltair the TEC starts decreasing from its nighttime value of about 30 TEC units around 0000 hrs to a day minimum value of about 5 TEC units around 0400-0500 hrs LT. This decay from 0000 hrs to 0500 hrs LT is steady and gradual at the low latitude station, Waltair, whereas at Tokyo the nighttime TEC is almost flat at its minimum level of about 10 TEC units during most of the nighttime hours, i.e. from around 2200 hrs to 0500 hrs LT, depicting a broad day minimum, in contrast to a shortlived and sharper day minimum in the pre-dawn period at Waltair. The mean pre-sunrise downward-to-upward reversal time for the **E** × **B** drifts as observed by phase path techniques[4] at Waltair is found to be around 0200 to 0300 hrs LT indicating that the descent of the F-layer continues till early morning hours at Waltair. Consequently, the loss of ionization will be more due to higher recombination rates at the lower altitudes. As such the TEC shows a steady decrease till early morning hours.

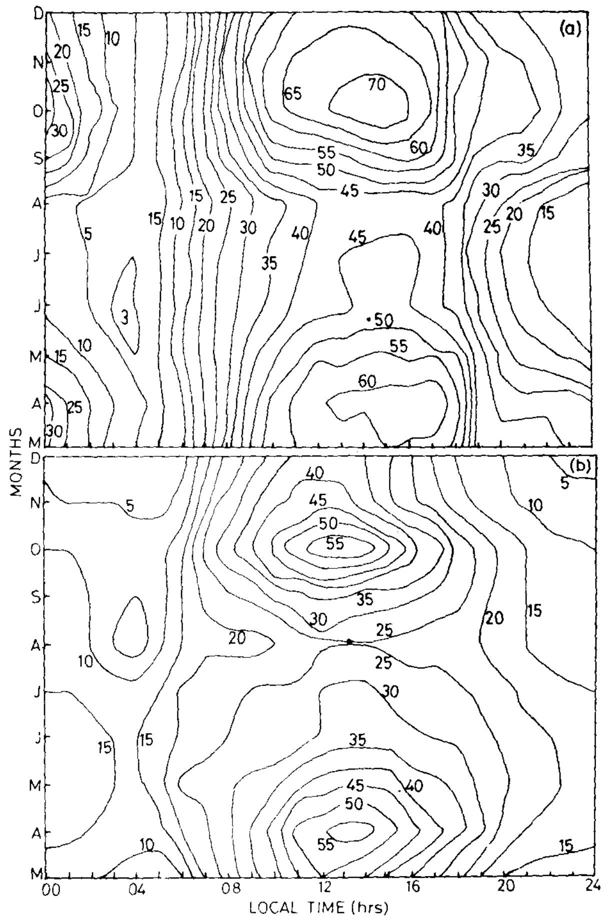

Fig. 2—Contour plots of monthly mean values of TEC as a function of local time and month for the period March 1978 to December 1978 at (a) Waltair and (b) Tokyo

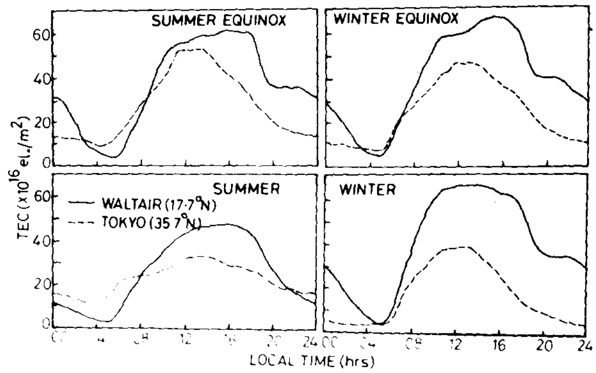

Fig. 3—Seasonal variation of TEC at Waltair and Tokyo

Further it can be observed from Figs. 2(a) and 2(b) that the morning build-up of ionization at Waltair is mostly linear between 0600 and 1000 hrs LT while at Tokyo it shows a two-step variation with a sharp build-up between 0600 and 0800 hrs LT followed by a comparatively reduced build up rate from 0800 to 1000 hrs. In general, the mid-afternoon maximum is much broader at Waltair compared to that at Tokyo. The diurnal peak is centred around 1200 to 1300 hrs LT at Tokyo while it is delayed and occurs around 1600 to 1700 hrs LT at Waltair. From a comparison of the day maximum values of TEC at the two stations, it is observed that the values at Waltair are in general much higher particularly during winter and winter equinoxes (~ 70 TEC units) compared to those at Tokyo (~ 40 TEC units). The higher values of TEC at Waltair are attributed to the additional contribution of the plasma transported from the equatorial ionosphere as a consequence of the fountain effect which is more predominant, particularly during high solar activity periods.

The phenomenon of a trough or depletion in noontime electron content with peaks on either side of the trough, commonly referred to as noontime bite-out, is frequently observed at this low latitude station, Waltair. Such a phenomenon is absent at Tokyo, the midlatitude station. The manifestation of this phenomenon at this low latitude station, Waltair, is attributed to the **E** × **B** drifts associated with the equatorial electrojet and counter electrojet current systems at the equator coupled with the prevailing neutral winds. Therefore, the occurrence of this phenomenon is restricted to the equatorial and low latitude regions[5-8]. By about 1700 hrs LT, the TEC at Waltair starts decreasing rapidly and reaches about 50% of its day maximum value around 2000 hrs LT from where the nighttime shouldering starts. However, at Tokyo the decrease starts earlier, i.e. from about 1400 hrs LT followed by a smooth decay to reach its day minimum value by about 2200 hrs LT.

3.2 Post-Sunset Enhancements in TEC at Low Latitudes

Anomalous post-sunset increases in TEC similar to those observed in N_mF2 (Ref. 9) are consistently seen at Waltair, particularly during winter and equinoxial months (80% of the days) whereas such a phenomenon is absent at Tokyo. The possible mechanisms responsible for producing the observed nighttime increases in TEC at this low latitude station, Waltair, are primarily believed to be due to the electrodynamic drift (**E** × **B**) at the equator and the movement of neutral winds. The increase in the equatorward wind velocity during these nighttime hours (i.e. around 2200 hrs LT) as reported by Stroble and McEleroy[10] results in an increased flow of ionization across the ray path, and may contribute for the observed increase in TEC. More recently, Anderson and Klobuchar[11] have theoretically computed the post-sunset increases in electron content at Ascension Island (lat. 8°S) and the vertical drift at an equatorial station, Jicamarca, and compared with the observed increases in TEC at Ascension Island. Their calculations were found to reproduce better the observed post-sunset enhancements in TEC by introducing both the meridional and zonal components of the neutral winds in the post-sunset vertical drift model at the equator. The observed post-sunset upward drift at the equator is believed to be due to the sudden increase in the conductivity of the E-layer during the post-sunset hours and a consequent development of the polarization electric fields in the F-region altitudes that results in the (**E** × **B**) vertical drift of the ionization at the equator. This vertical transport of the plasma to higher altitudes at the equator results in the downward diffusion of ionization along the field lines to produce the observed increases in the electron content in the subtropical latitudes. Since the magnitude of this vertical drift at the equator is smaller compared to that during daytime hours, the ionization lifted up at the equator reaches relatively lower altitudes and thus the dumping of plasma occurs only at lower latitudes close to the equator. Further, it is interesting to note that these nighttime enhancements are significantly seen only during high solar activity periods, wherein the post-sunset vertical drifts at the equator, centred around 1900 to 1930 hours are reported[12] to be higher as compared to those during low solar activity period and thus may account for the observed nighttime increases in TEC. Further, it may be stated here that this phenomenon is observed significantly only at the subtropical latitudes like Waltair and is not reported either at the equator[13] or at the crest region[14] and thus the sub-tropical dumping of ionization followed by the post-sunset vertical drift at the equator appears to be justified. However, these enhancements are also controlled by the zonal and meridional components of the prevailing neutral winds[15].

3.3 Seasonal Variation in TEC

With a view to making a quantitative study of the build-up and decay rates of ionization, the time rate of change of electron content is computed by fitting a straight line to the build-up region (0600-1000 hrs LT) and the decay (1600-1900 hrs LT) of the monthly mean diurnal plots of TEC for each of the months. The month-to-month variation of the build-up and decay rates thus computed are presented in Fig. 4 along with the day maximum and day minimum values of TEC for each of the months. It is seen from Fig. 4 that all the parameters listed above excepting the

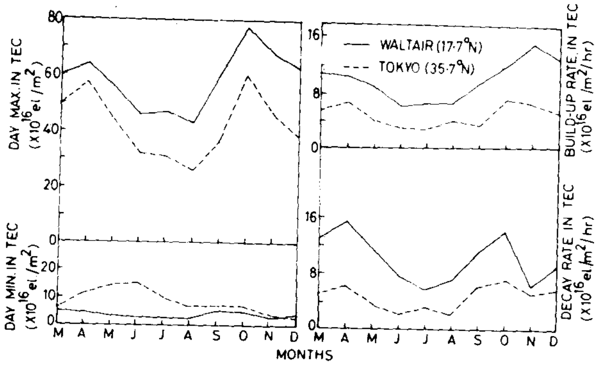

Fig. 4—Month-to-month variation of TEC parameters at Waltair and Tokyo

day minimum values of TEC exhibit a significant semi-annual variation at both the stations (Waltair and Tokyo) with equinoxial peaks around April and October and a trough around August. The average day maximum values of TEC during all the 10 months of observation at Waltair are found to be 30-40% higher than those at Tokyo. The day minimum TEC values at Waltair vary between 2 and 6 TEC units with higher values around February, Setpember and October, and minimum during summer months. But at Tokyo, the day minimum values varied from a minimum of 4 TEC units to a maximum of 15 TEC units with a significant summer maximum.

The semi-annual variation observed in the different parameters of TEC referred to earlier, is attributed to the strong control of sun's radiation on the level of ionization during equinoxial months. The diurnal ratios are found to be smaller at higher latitudes compared to those at equatorial latitudes because of the relatively smaller change in the sun's zenith angle at higher latitudes[16]. Further, near the equator and low latitude regions the diurnal ratios increase markedly because the magnetic field prevents the vertical transport of ionization to lower loss regions[16].

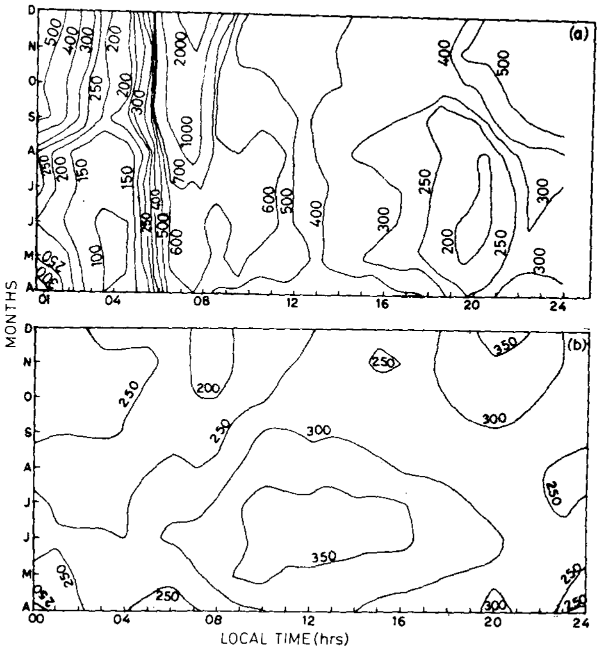

Fig. 5—Contour plots of monthly mean values of slab thickness as a function of local time and month for the period April 1978 to December 1978 at (a) Waltair and (b) Tokyo

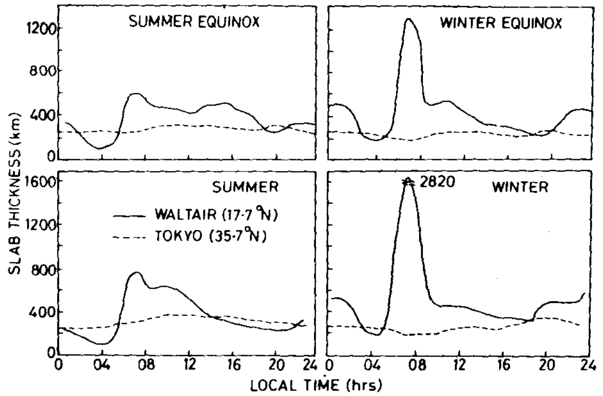

Fig. 6—Seasonal varition ot slab thickness at Waltair and Tokyo

3.4. Equivalent Slab Thickness

Measurements of the electron density at the peak of the ionosphere (N_m) have been obtained for several decades. More recently, it has also been possible to obtain continuous records of the TEC of the ionosphere (N_T) using radio signals recieved from geostationary satellites. The ratio of these two quantities gives the effective or slab thickness of the ionosphere[2] ($\tau = N_T/N_m$) which is a measure of the skewness of the electron density profile of the ionosphere. With a view to studying the slab thickness parameter (τ) at the low and mid latitude stations, the data of TEC and N_mF2 from the two locations were used to compute the hourly values of τ. The values thus computed are presented as contour plots in Figs. 5(a) and 5(b) for the two locations, Waltair and Tokyo, for the period from March 1978 to December 1978. At Waltair [Fig. 5(a)] the slab thickness is generally found to vary between 250 and 600 km (excepting in winter early morning hours where the equivalent slab thickness is as high as 1000-2000 km) whereas at Tokyo the diurnal variation of τ (Fig. 6) is found to lie in the range 250-350 km. At Waltair, the slab thickness reaches a minimum value (75-150 km) around 0400 hrs LT. During summer months the daytime values both at Waltair and Tokyo are found to be higher (400-650 km for Waltair, 200-300 km for Tokyo) compared to winter and equinoxial months (300-400 km for Waltair, 250-300 km for Tokyo). The most interesting feature in the diurnal variation of equivalent slab thickness at Waltair is the large morning peak around 0630 to 0730 hrs LT followed by a very sharp decrease within about 2 hr; it thereafter depicts broad daytime maximum. The early morning peak could arise from an increase in TEC due to the earlier illumination of the topside of the ionosphere preceded by a significant decrease in the peak electron density of the F-layer, particularly in the equatorial region[12]. It is also interesting to note that a pre-midnight increase in the slab thickness is observed at Waltair particularly during winter and equinoxes while it is absent at Tokyo. The increase of slab thickness during winter nights at Waltair may be associated with the observed post-sunset increases in TEC. Further, the decrease in the height of the transition level of O^+/H^+ ions during the winter nights decreases the mean ion mass in the topside of the ionosphere, resulting in an increase in the electron scale height[17]. This may also result in an increase in the slab thickness. This is particularly important at low latitudes where the slab thickness is proportional to scale height ($\tau = 4.13\ H$).

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