TEC DERIVED FROM GPS NETWORK IN INDIA AND COMPARISON WITH MODELS

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ABSTRACT

Total electron content (TEC) measured simultaneously using Global Positioning System (GPS) satellites at 18 locations in North-South and East-West directions across the Indian subcontinent during 2003-2004 were used to study their diurnal, seasonal and annual variations. The TEC exhibits features like the equatorial noon time bite out, annual and semiannual variations, the equatorial ionization anomaly and day-to-day variability. Measured TEC were compared with those predicted by the International Reference Ionosphere and an Indian regional TEC model. IRI overestimates TEC at about all locations. The predictability of the regional model was found to be better than that of the IRI.

INTRODUCTION

The Global Positioning System (GPS) is a satellite based positioning system widely used for navigation, relative positioning and time transfer. GPS also offers opportunities for Ionospheric research [1, 2, 3]. The dispersive ionosphere introduces a time delay in the 1.57542 GHz (L1) and 1.22760 GHz (L2) simultaneous transmissions from GPS satellites orbiting at 20,000 km. The relative Ionospheric delay of the two signals is proportional to the total amount of electrons along the ray path or the total electron content (TEC). Time delay measurements of L1 and L2 frequencies can, therefore, be converted to TEC along the ray path from the receiver to the satellite. Global distributions of TEC variations as well as its characteristics at equatorial, middle and high latitudes have been investigated by a number of workers. TEC measurements from GPS supplements TEC obtained from earlier beacon satellites.

In India, a coordinated TEC measurement campaign was undertaken in 1975 using the ATS-6 geostationary satellite. The receiving stations extended in latitude from the magnetic equator to low midlatitude along 75±2°E meridian and covered the longitude span of 75°E to 95°E. Characteristics of the equatorial and low latitude ionosphere such as the equatorial ionization anomaly, evening enhancement, noon time bite out, winter anomaly etc were studied using the TEC data obtained for the low solar activity period September 1995 to August 1996. After ATS-6 a number of satellites of opportunity like the ETS-11, Symphonic etc. were used to retrieve TEC over a number of locations viz. New Delhi, Calcutta, Visakhapatnam. However, coordinated measurements involving sufficiently large number of stations to effectively study the characteristics of TEC at equatorial and low latitudes including the equatorial ionization anomaly (EIA) for periods covering all levels of solar activity were not attempted so far. Since 2003, GPS receivers have been installed at 18 locations across India to monitor TEC. The present chain of GPS stations has provided the opportunity to attempt a comprehensive study of the Indian zone ionosphere. In this paper, we investigate the diurnal, seasonal and annual variations of vertical TEC at a few selected stations. Measured TEC were then compared with the TEC predicted by the International Reference Ionosphere, 2001 [4] and a regional TEC model developed for the Indian zone [5] to assess their predictability vis-à-vis the observations.

DATA AND MODELS

TEC from GPS

The total electron content of the ionosphere along the line of sight from the receiver to the GPS satellite (slant TEC) is given by the expression

$$dt = (40.36/cf^2) \times STEC \qquad 1$$

where dt is the time delay introduced during the passage of the signal through the ionosphere, c is the velocity of e.m. radiation and f is the transmission frequency. Davies etal. [6] had observed that TEC measurements using GPS are useful for study of long term behavior, day-to-day fluctuations and storm time effects. GPS slant TEC data were collected at 18 stations separated in latitude and longitude by ~5 degrees. They are: Trivandrum (8.5°N, 77°E), Agatti (10.75°N, 72.5°E), Port Blair (11.75°N, 92.5°E), Bangalore (13°N, 77.5°E), Mumbai (18.5°N, 72.5E), Hyderabad (17.5°N, 78.5°E), Vishakhapatnam (17.5 °N, 83°E), Ahmedabad (23 °N, 72.5°E), Bhopal (23°N, 77.25°E), Raipur (21°N, 81.5°E), Jodhpur (26.25°N, 73°E), Delhi (28.75 °N, 77.25°E), Aizwal (23.5°N, 93°E), Guwahati (26°N, 92°E), Bagdogra

(27°N, 88.5°E), Kolkata (22.5°N, 88.25°E), Shimla (31.08°N, 77.06°E) and Lucknow (27.25°N, 80.88°E) across India since April 2004. Slant or line of sight TEC data were then converted to vertical (overhead) TEC using a suitable mapping function. This period of observation correspond to moderate solar activity level ($F_{10.7}$ ~ 100).

International Reference Ionosphere (IRI)

The International Reference Ionosphere [4] provides the median or average value of electron density, electron content, electron and ion temperature, ion composition as a function of height, location, local time and sunspot number for magnetically quiet conditions. It is an empirical model based on data from world wide network of ionosonde stations, incoherent scatter radars, the ISIS and Alonette topside sounders and in-situ measurements on several satellites and rockets.

Regional TEC Model

Boruah and Bhuyan [5] had described the procedure adopted for modeling the TEC over the Indian region. In this model, the foF2 data measured by respective ionosondes at Tiruchirapally (10.8°N), Hyderabad (17.3°N), Ahmedabad (23.0°N) and Delhi (28.6°N) from 1960 to 1984 are subjected to a harmonic analysis to derive latitudinal contours of foF2 for low ($F_{10.7}$ =75), moderate ($F_{10.7}$ =150) and high ($F_{10.7}$ =200) solar activity periods. The F peak density NmF2 (=1.24 foF2) are then converted to TEC by assuming a Chapman density profile from a scale height below hmF2 (height of F peak density) to the top of the ionosphere.

RESULTS AND DISCUSSION

The TEC obtained at the abovementioned locations were examined for local time, monthly and seasonal variations. It was found that characteristics of TEC are dependent primarily on the position of the station with respect to the magnetic equator. For example, at the crest of the northern equatorial naomaly or higher latitude locations, TEC shows a single peak during the day whereas near the equator a broad daytime plateau with or without a depression near noon is observed. To illustrate those features, monthly mean TEC from February to November, 2004 are plotted in Fig.1a, 1b for Ahmedabad, Trivandrum and in Fig.2a, 2b for Delhi, Hyderabad. Ahmedabad is normally located at the crest of the northern equatorial anomaly whereas Trivandrum is on the magnetic equator. At Ahmedabad (Fig.1a), TEC exhibits the usual diurnal variation of a minimum in the pre sunrise hours (0500 LT) and a maximum between 1200 to 1400 LT. The morning rise and afternoon decay in TEC is sharp in the equinoxes. The forenoon rate of production and afternoon decay of ionization is faster in December solstice compared to that in the June solstice. The amplitude of the diurnal maximum is higher (~55 TECU) in the equinoxes and lower in the solstices thus exhibiting the same annual variation. Further, TEC is higher (~40 TECU) in the December solstice compared to that in the June solstice (~30 TECU), i.e. the 'winter anomaly' in seasonal variation is also observed. The time of occurrence of the diurnal maximum varies with season. TEC reaches its day time peak earlier (~1400 LT) in June solstice and later (~1500 LT) in the December solstice. In Delhi (Fig.2a), TEC shows the usual diurnal variation of a minimum around 0500 LT and the maximum

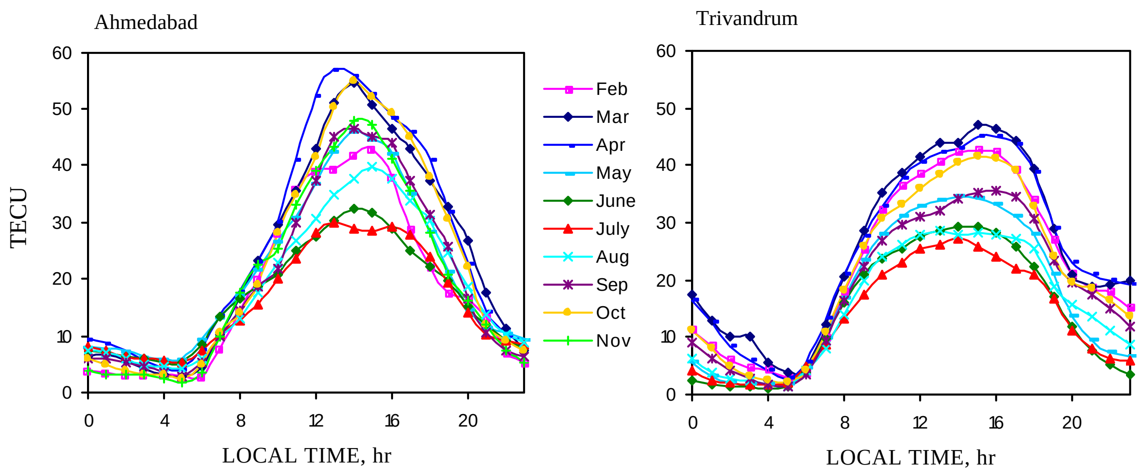

Fig.1a Monthly mean TEC from February to November, 2004 for Ahmedabad and Fig.1b Monthly mean TEC from February to October, 2004 for Trivandrum (TEC in units of 10^{16} m^{-2})

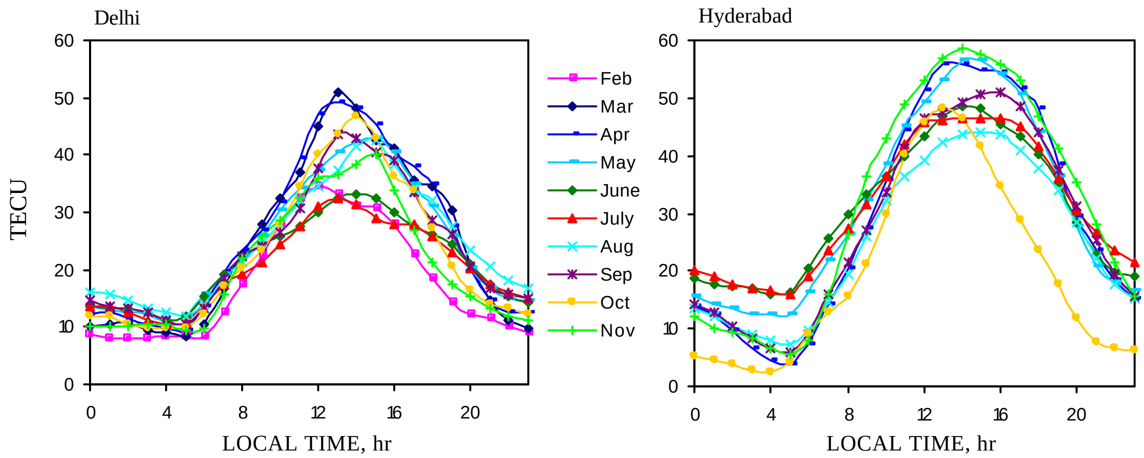

Fig.2a Monthly mean TEC from February to November, 2004 for Delhi and Fig.2b Monthly mean TEC from February to November, 2004 for Hyderabad

between 1200 to 1400 LT. In the equinoxes, the morning rise and afternoon decay of TEC is sharp compared to that in summer and winter. TEC reaches its daytime peak earlier (~1300 LT) in equinoxes and later (~1500 LT) in summer and winter. However, over the equator TEC rapidly rises from its morning minimum till about 0900 LT (Fig.1b). TEC then continues to rise at a slower rate and reaches the daytime peak at about 1800 LT. The semiannual variation and winter anomaly are seen over Trivandrum also. It may also be noted from Fig.1 that the TEC at the crest of the anomaly is higher than that measured over the equator during the daytime as a result of lifting of ionization by E×B vertical drift from equator and dumping of the same at anomaly crest locations. Fig.2b shows that, in Hyderabad, TEC rapidly rises from its morning minimum till about 1000 LT and then continues to rise at a slower rate and reaches the day time peak at about 1600 LT for the equinox season. In summer, the morning presunrise value is high and the peak value is low compared to that in equinoxes. In October, the time of occurrence of maximum TEC is earlier and afternoon decay of TEC is very sharp. Fig.3 shows the daily TEC for the month of October, 2004 at four selected locations. Delhi (28.6°) is normally beyond the northern crest of the EIA around Bhopal (23°), while Hyderabad (17.5°) is a low latitude station at its equatorward edge. It can be seen from the figure that TEC exhibits large day-to-day variability irrespective of location. The deviation of daily values from the monthly mean or median is minimum over Trivandrum and increases as the station latitude increases.

The solar ionizing radiation flux, magnetic activity and transport of ionization under the influence of neutral winds and diffusion are some of the principal factors that affect the level of ionization in the ionosphere, which is also reflected in the integrated total electron content at any given location. Earlier studies have revealed that the 'noon time bite out' over or near the magnetic equator shows a marked dependence on longitude, differing greatly between the American and Asian sectors. The afternoon peak is generally more pronounced in the Indian sector than in the American sector. The bite-out effect is also dependent on the solar cycle epoch. During high sunspot years the morning peak is the prominent one but in low sunspot years the afternoon peak gains prominence. The 'winter anomaly' effect is caused by

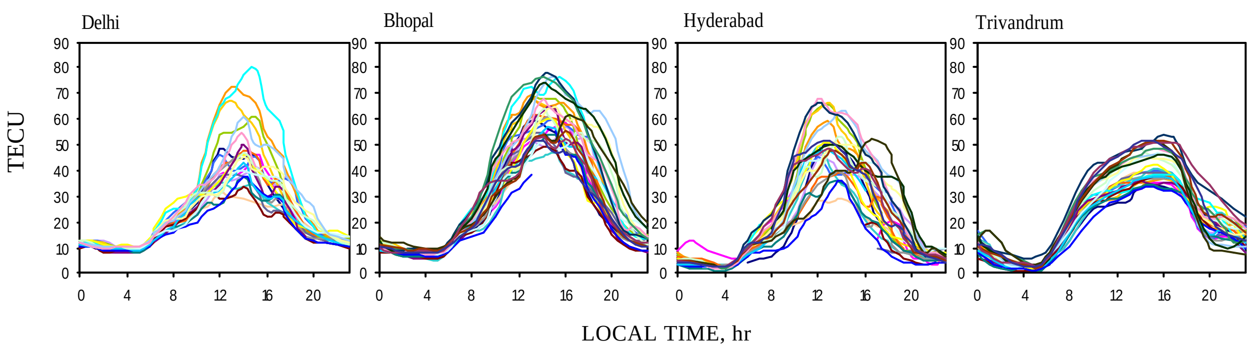

Fig.3 Day-to-day variability of VTEC for the month October, 2004 for stations Delhi, Bhopal, Hyderabad, Trivandrum.

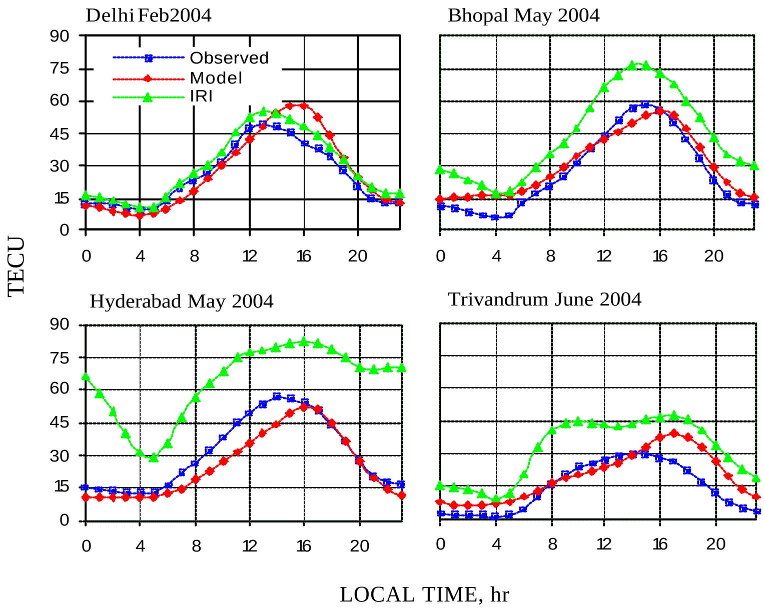

Fig.4 Comparison of measured TEC with that predicted by the IRI and the regional model for the stations Delhi, Bhopal, Hyderabad and Trivandrum.

the seasonal changes in neutral gas composition. Vertical winds are downward (upward) in the winter (summer) hemisphere resulting in increase (decrease) of the O/N_2 ratio. Consequently, recombination is weaker in the winter hemisphere, leading to higher electron concentration in the winter solstice than that in the summer solstice. Further, the earth's magnetic field is believed to guide plasma from the summer to the winter hemisphere. The semi-annual effect at low latitude is caused by semi annual changes in neutral composition. At solstice, the atmosphere is generally more mixed due to the summer upwelling and winter downwelling as well as transport of gases from the summer to winter hemisphere. Gases with higher molecular content (depleted O/N_2) are fed into the low latitudes from the summer hemisphere. So, O/N_2 is largest at equinox, and therefore, electron concentration.

The measured TEC were also compared with those predicted by the latest version of the IRI and the regional model. In Fig.4, TEC obtained from the two models are plotted with measured TEC for the four selected locations as representative cases of variations of the three different sets of TEC. The figure reveals that IRI overestimates TEC at every location. The difference between measured and predicted TEC is minimum at Delhi and maximum in Hyderabad. The amount of deviation of the IRI predicted TEC from measured data varies with the location and month season. Similarly, the regional model also deviates from the measured TEC but the offsets are lower compared to that between the other two sets. During some parts of the diurnal cycle, measured and the regional model predicted values are quite close. Fine tuning of the regional model is being undertaken to improve its predictability.

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