Journal Homepage: - www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
Article DOI: 10.21474/IJAR01/1633
DOI URL: http://dx.doi.org/10.21474/IJAR01/1633

RESEARCH ARTICLE

MEASURED AND COMPUTED TOTAL ELECTRON CONTENT OVER GUWAHATI: OBSERVED THROUGH SATELLITE AND MODEL COMPUTATION.

Bornali Chetia[1*], Santanu Kalita [2], Minakshi Devi [1], Kamla Prsan Ray [3] and Ananda Kumar Barbara[1].

1. Department of Physics, Gauhati University, Guwahati 781014, Assam, India
2. Department of Computer Application, Mahapurusha Srimanta Sankaradeva Viswavidyalaya, Nagaon 782001, India
3. Society for Applied Microwave Electronics Engineering & Research (SAMEER) (DIT, MC&IT, Govt. of India),IIT Campus, Hill Side, Powai, Mumbai

Manuscript Info

Manuscript History

Received: 12 July 2016
Final Accepted: 13 August 2016
Published: September 2016

Key words:-
Geomagnetic storms; GPS; TEC; International Reference Ionosphere (IRI)

Abstract

The ionospheric total electron content (TEC) collected from GPS data at Guwahati (geographic latitude 26.2^0N, geographic longitude 91.7^0E, geomagnetic latitude 15.2^0N), during high, medium and low solar activity periods is analysed to examine the influence of geomagnetic storm on the TEC near the equatorial anomaly crest region, and to assess the predictability of the existing ionospheric model such as the International Reference Ionosphere (IRI) on the TEC for different solar activity conditions. The paper shows that the TEC values derived from the IRI-2012 model vary widely with solar activity and can be used only for predicting daytime quiet day TEC with fair accuracy over Guwahati during low solar activity (LSA) and medium solar activity (MSA) period, but the model computation for geomagnetic stormtime TEC is far more complex.

Introduction:-

For the last few decades many workers has studied the behaviour of the ionosphere over the equatorial anomaly region (Anderson, 1973; Rajaram, 1977; Moffett, 1979; Anderson, 1981; Walker, 1981; Stening, 1992). These and other related studies have showed that the EXB drifts from the equator as well as mid latitude effects make the ionosphere in the anomaly region rather complex. The knowledge on upper ionosphere, the profile shape of density beyond F2 peak, the interaction of protonosphere with magnetosphere and its consequent effects on the entire ionosphere become more important with the progress of satellite communication. Based on these observations ionospheric correction factors are introduced for accurate determination of satellite position and for such ionospheric corrections, TEC is used as one of the effective parameters (Hartmann and Leitinger, 1984). The TEC measured from the GPS observation has no doubt supplied a lot of input for mapping long term temporal variations in ionospheric parameters. Analyses of ionospheric TEC data have not only helped in understanding the physics of the ionosphere, but have also contributed significantly to modern space communication systems. But even though with these experiments and inputs, the anomaly region has yet to be understood completely.

Along with the experimentally observed ionization density, a large number of theoretical models to predict this parameter have been developed. Since the early 1970's, many mathematical models (Chiu, 1975; Anderson and Klobuchar, 1983; McNamara and Wilkinson, 1983; Rawer, 1984; Bailey et al., 1993; Balan and Bailey, 1995), both simple and comprehensive, have been developed and applied to a wide variety of problems. Among these all, International Reference Ionosphere (IRI) is the most popular one. IRI is a widely used empirical standard for the

Corresponding Author:- Bornali Chetia.
Address:- Department of Physics, Gauhati University, Guwahati 781014, Assam, India.

depiction of ionospheric densities and temperatures that was initiated in the late sixties by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) (Rawer et al., 1978) with the purpose of launching an international standard for the specifications of ionospheric parameters based on accessible data from ground-based as well as from satellite observations. The IRI model provides many parameters; electron temperature, ion composition, ion temperature, electron density and TEC are few among them for any given, time, date, latitude and longitude at height ranging from 60 to 2,000 km. The IRI model obtains TEC by integrating the electron density profile from the lower boundary to a user-specified upper boundary (Bilitza 2001). Many workers have verified the performance of IRI over a large number of stations covering low to mid-latitudes as well as for low solar activity (LSA) and high solar activity (HSA) periods (McNamara, 1983; McNamara and Wi1kinson, 1983; Bilitza, 1986; Brown et al., 1991; Barman et al., 1997).

Also a large number of stations have collected a fairly large volume of ionospheric (along with other solar/geomagnetic parameters) data which have been now used as pool by space researchers as well as communication engineers and scientists for computing models which could predict ionization density over a station at different solar activity and geomagnetic situations (McNamara, 1983; Brown et *al.,* 1991,Bilitza, 1986, Bilitza, 2001, Rawer and Bilitza, 1989 and Rawer and Bilitza, 1990). These models have now been very effectively used for ionospheric corrections needed for satellite positioning as well as for radar tracking.

The aim of the present work is to examine a current situation for the particular case of the low-latitude ionospheric F2-layer. As it is known that its most important morphological feature is the equatorial anomaly. In the innovative work done by Appleton (1946) this anomaly was identified as the critical frequency distribution with minimum at the magnetic equator and two maxima on either side of it (at the magnetic latitudes about±15º). Here we have studied the variations of the GPS-TEC and compared with those derived from the latest IRI-2012 model during solar activity period from 2007 to 2015. This type of simultaneous comparison of TEC for low latitude station using IRI-2012 model for different solar activity is of great important for characterizing different ionospheric behavior.

Data and Analysis:-

In the present work, the hourly mean TEC retrieved from ground-based GPS measurements have been used to validate the IRI-2012 model TEC during 2007 to 2015. At Gauhati University (GU) laboratory, a GPS receiving set up is used for collection of TEC data which can track up to 11 GPS signals at the L1 frequency (1575.42 MHz) and the L2 frequency (1227.6 MHz).

Here the assessment of TEC over Guwahati through IRI will be considered first. As has already been discussed by many workers that the TEC is received from Faraday rotation and it is the sum of rotations suffered by the plane of the wave in traversing the total ionosphere, the contribution of each height being proportional to the product of the local electron density and magnetic field. Therefore, the contribution to the TEC seems mainly to be from 100 to 1800 Km (Titheridge, 1972). But it is observed that the electron density changes from above 1000 Km also plays a role towards resultant TEC (McNamara and Wi1kinson, 1983). So to receive TEC, the electron density from bottom of ionosphere is to be integrated upto 2000 km at least. The electron density upto 1000 km is received as an output from the IRI.

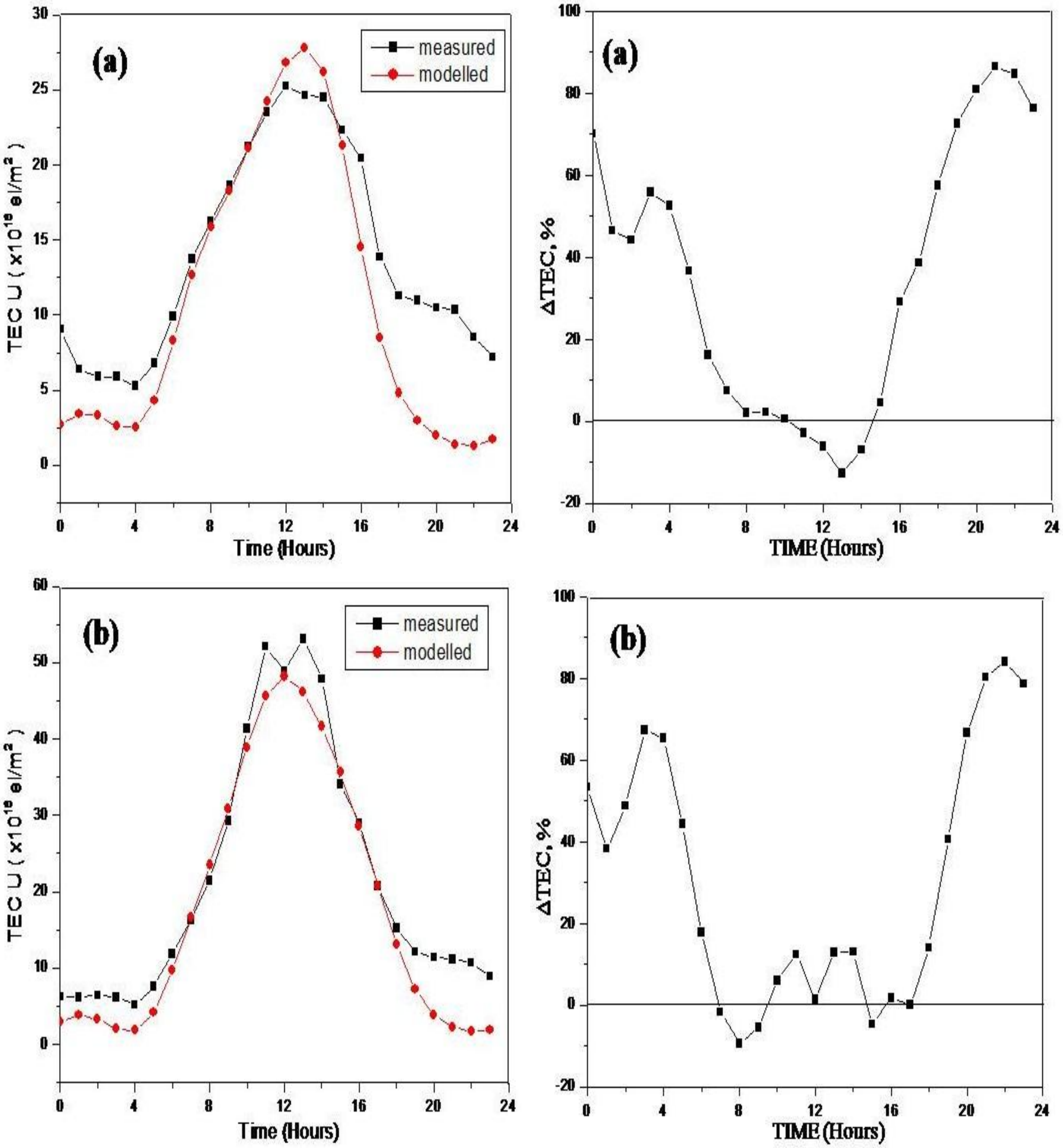
The percentage deviation between the collected TEC data from IRI-2012 and observed TEC at Guwahati station is calculated using the following formula:

TEC Percentage deviation (ΔTEC) $=\frac{x_o - x_m}{x_o} \times 100$,

where x_o & x_m represents the observed and modeled TEC values respectively.

Seasonal comparison of GPS-TEC with the IRI-2012 model for Low solar activity period:-

Fig 1 (a-d) shows the diurnal plots of the comparison between the measured GPS-TEC values and the IRI-2012 model prediction for LSA period. Here it is observed that for the December month, IRI-2012 model overestimate the GPS-TEC by 4 TECU at 1200-1400 hrs LT whereas for March and October equinoctial, IRI-2012 seems to underestimate the GPS-TEC model by 4 TECU (1100-1400 hrs) and 10 TECU (1000-1500 hrs) LT respectively. Same conclusion can be put forward for summer month where IRI-2012 model underestimate the GPS-TEC during the whole day. The percentage deviation (ΔTEC) as represented in the Fig 2(a-d) shows that the ΔTEC overestimate the morning hrs TEC by 70% for December, March and October EQUI and in the case of July, the ΔTEC overestimate the morning hrs TEC by 30%.



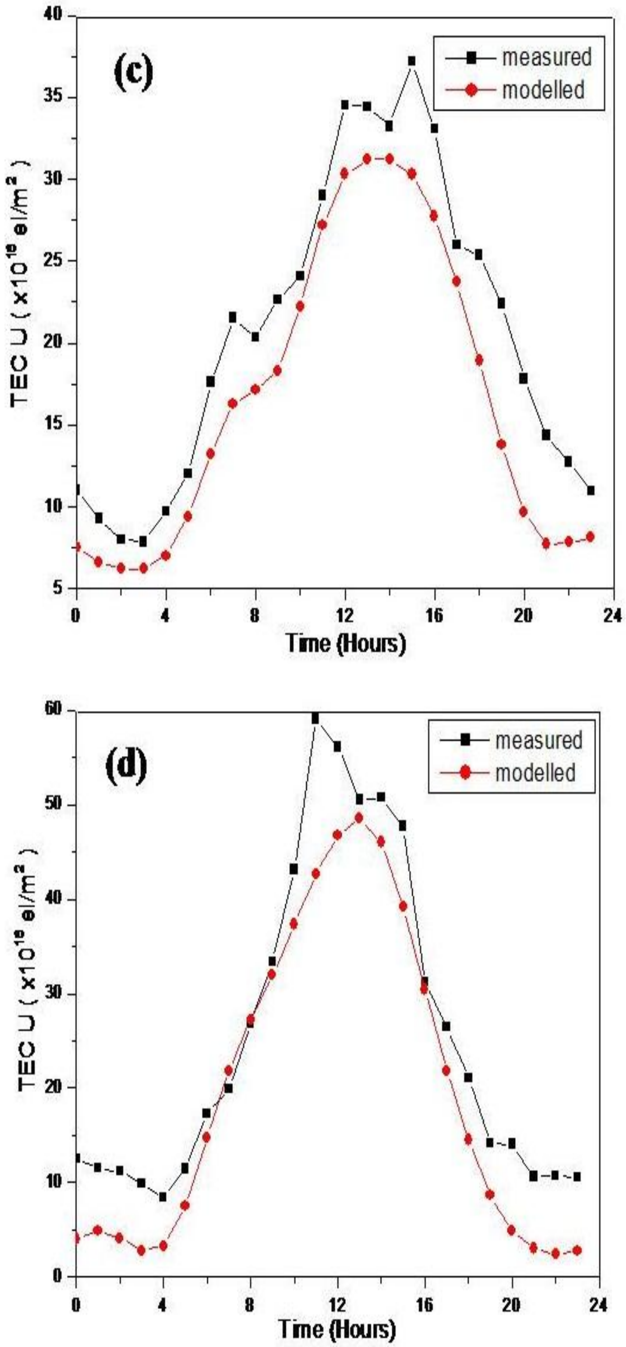


Fig 1:- Comparison between measured and IRI-predicted TEC values for (a) December 2008, (b) March 2008, (c) July 2009 and (d) October 2009

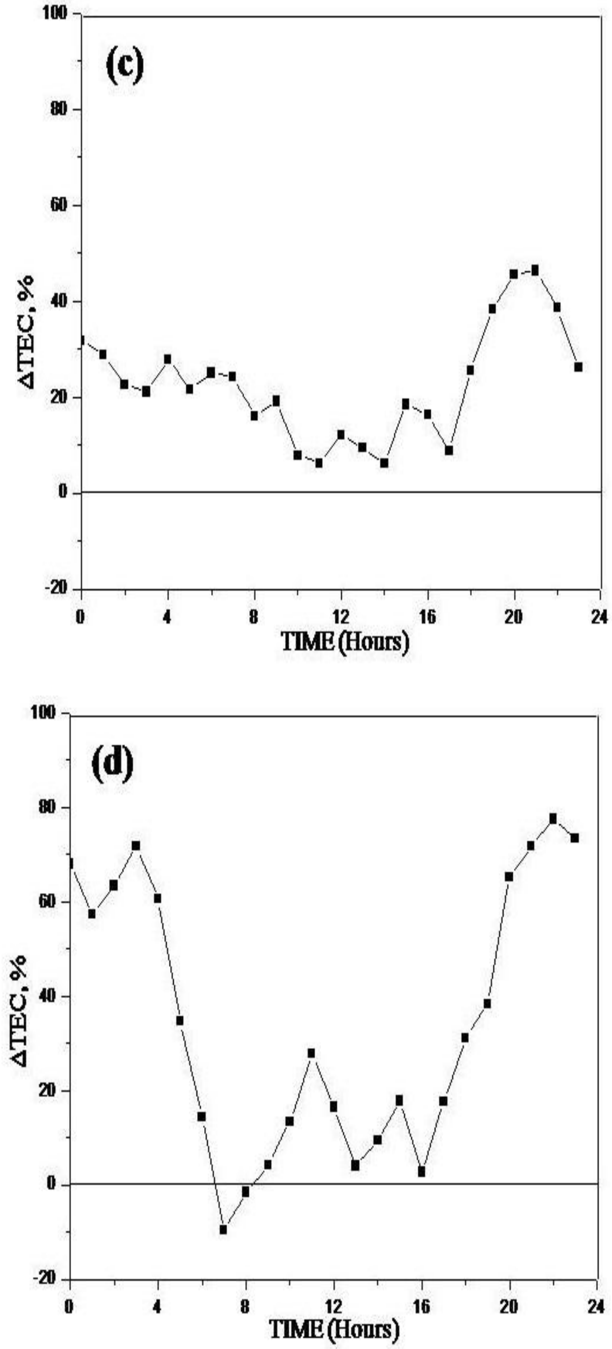
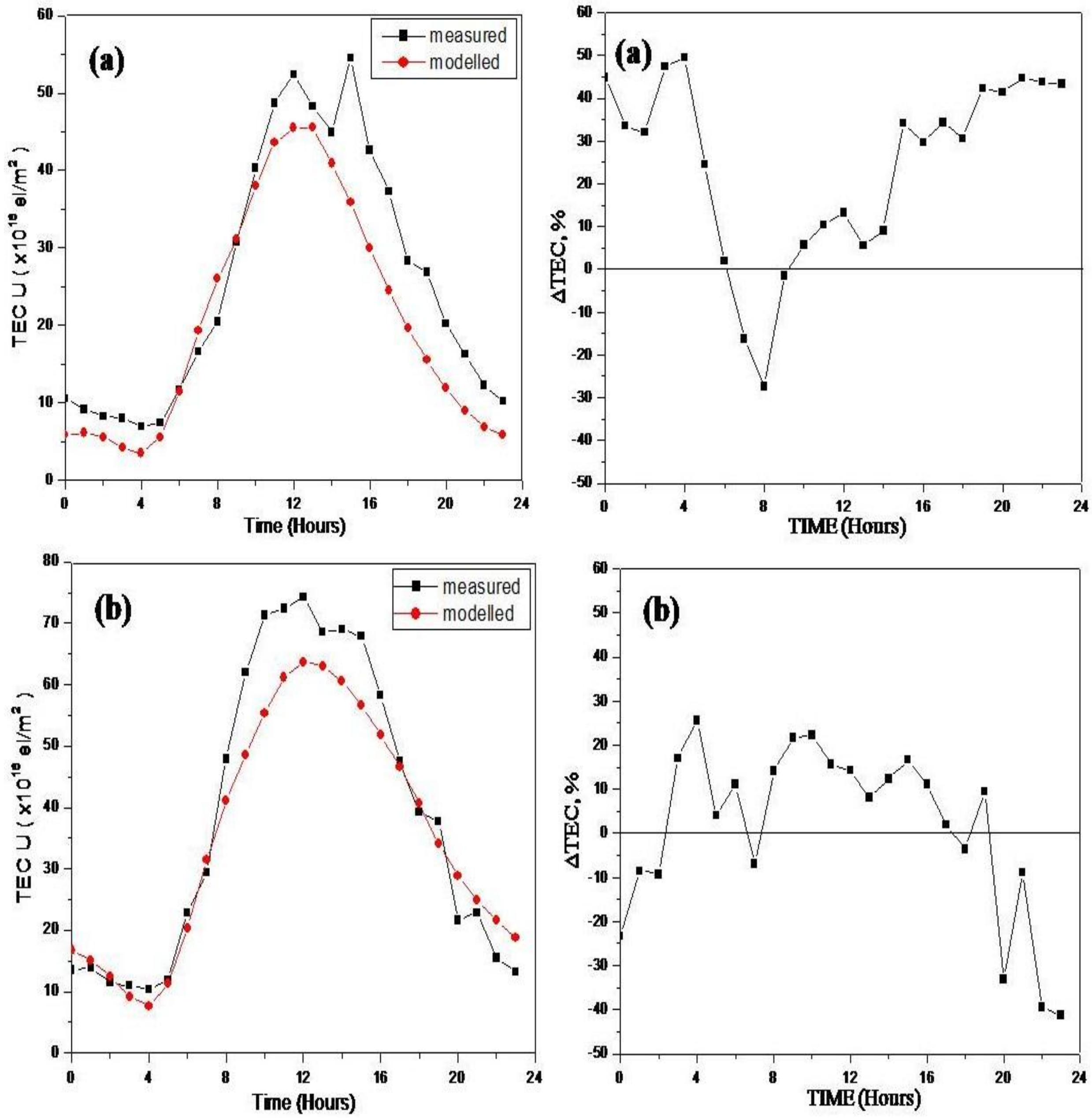


Fig 2:- Percentage deviation between the measured and IRI-predicted TEC values for (a) December 2008, (b) March 2008, (c) July 2009 and (d) October 2009

Seasonal comparison of GPS-TEC with the IRI-2012 model for Medium solar activity period:-



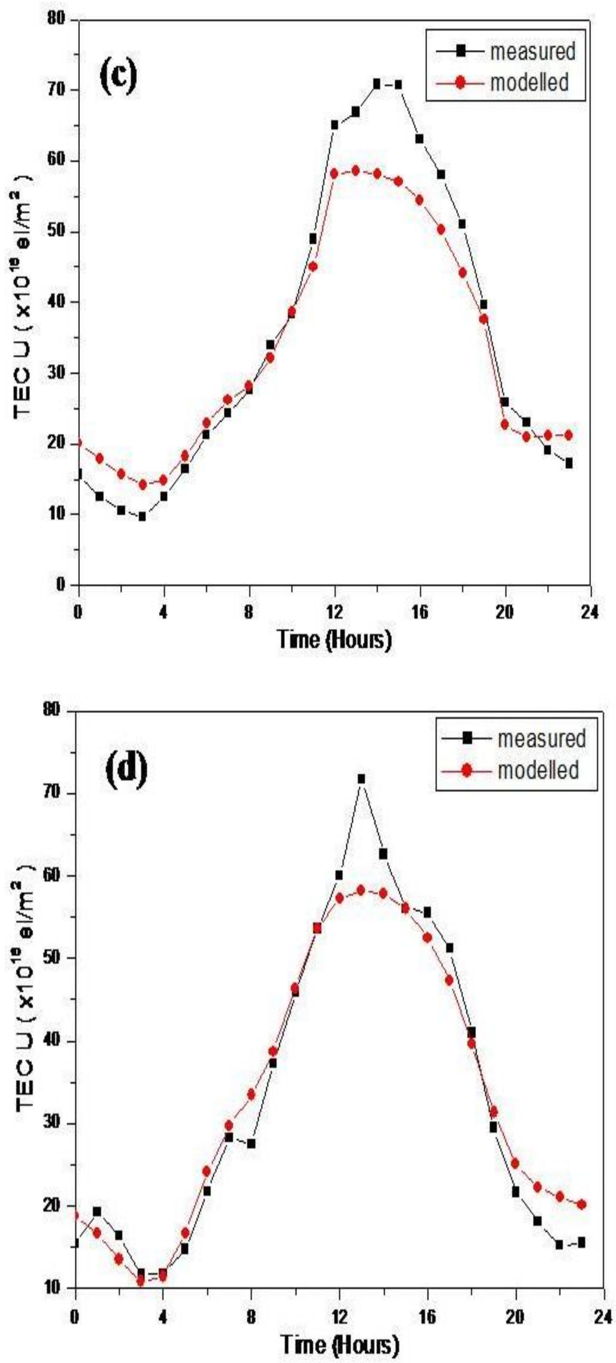


Fig 3:- Comparison between measured and IRI-predicted TEC values for (a) February 2011, (b) March 2012, (c) July 2012 and (d) September 2011

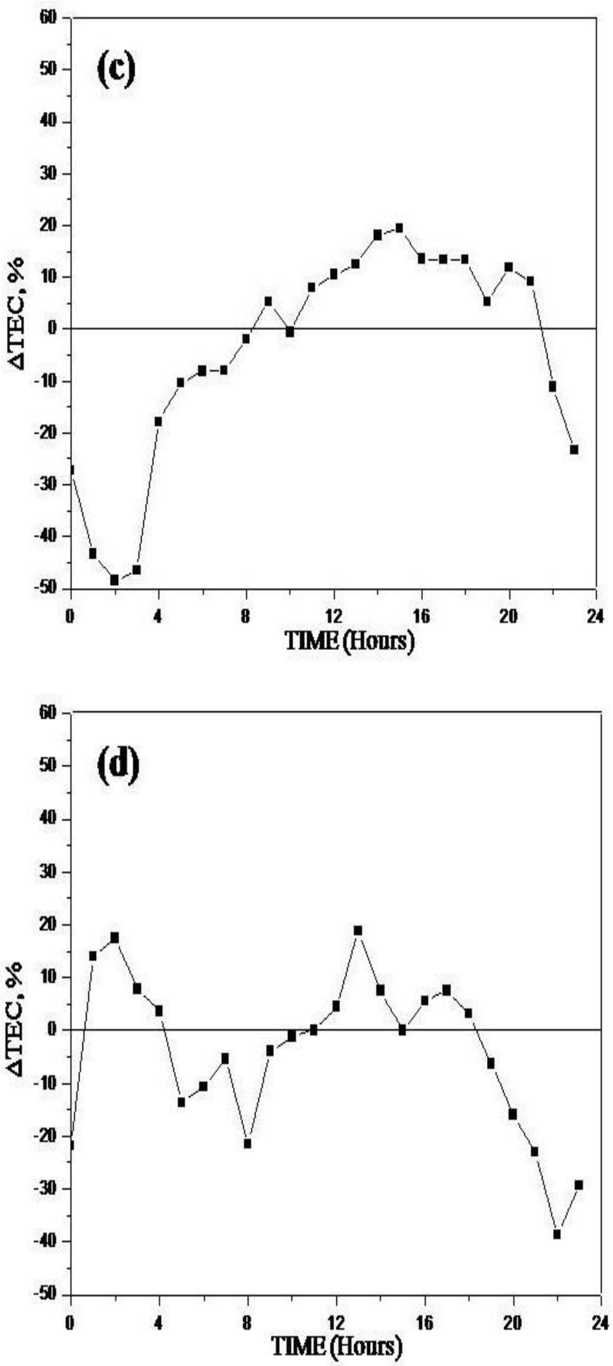
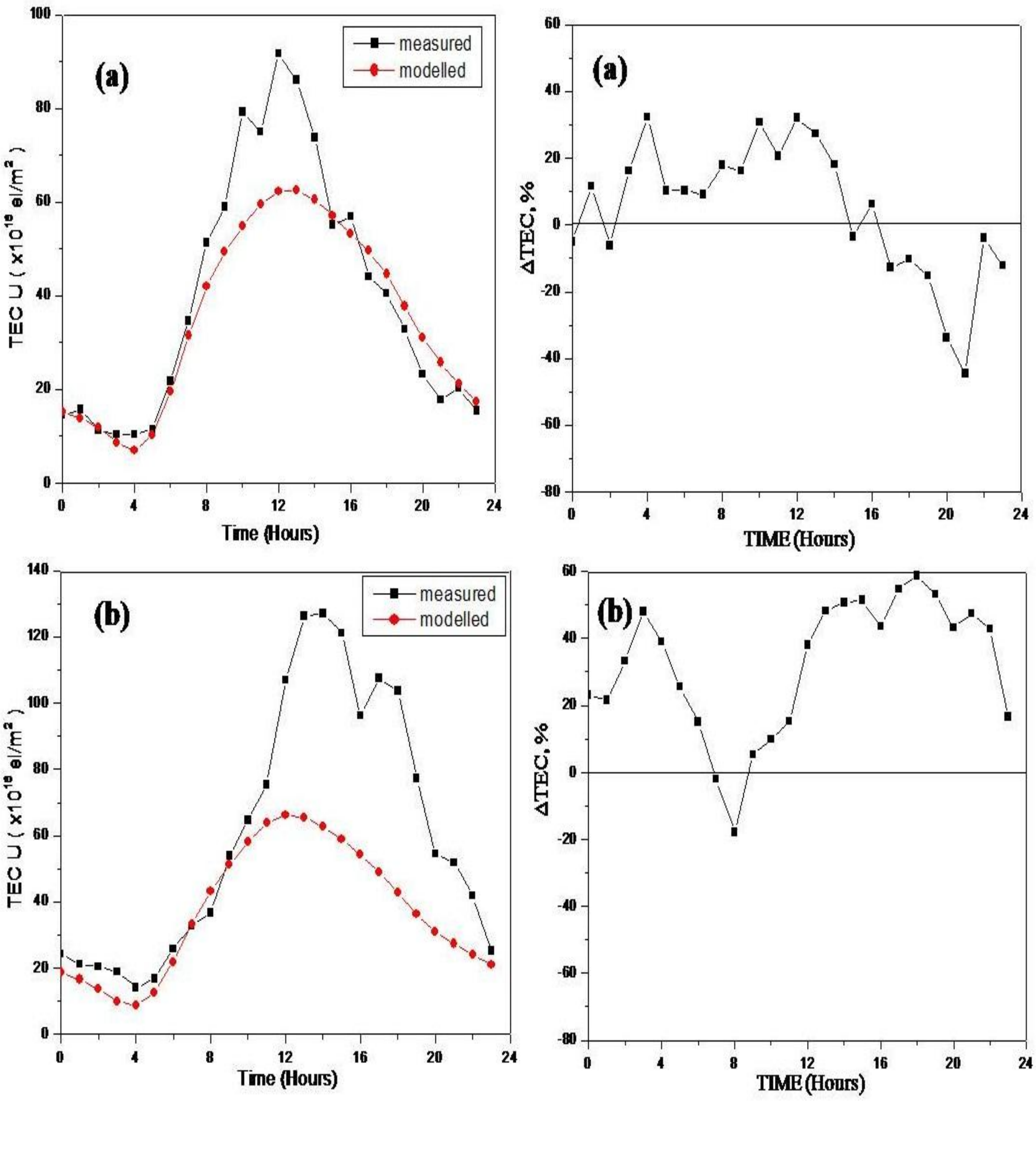


Fig 4:- Percentage deviation between the measured and IRI-predicted TEC values for (a) February 2011, (b) March 2012, (c) July 2012 and (d) September 2011

Fig 3 (a-d) represents the comparison between the measured GPS-TEC values and the IRI-2012 model prediction for MSA period. In all the seasons i.e. winter, vernal equinoctial, summer and autumnal equinoctial months, IRI-2012 model consistently underestimate the measured TEC during 1100-2300 hrs LT for February, 0800-1600 hrs LT for March, 1100-1900 hrs LT for July and 1200-1600 hrs LT for September EQUI month respectively. The percentage deviation drawn against each respective month is shown in the Fig 4(a-d). The ΔTEC overestimate the morning hrs

TEC by 50% in February. For the month of March and September equinoctial, the ΔTEC overestimate the TEC by 20-25% during the daytime but underestimate it by 40% during the nighttime. Fig 4(c) has drawn against July 2012 which shows that the ΔTEC underestimate the morning hrs TEC by 50% and it continues till 0800 hrs LT of the day.

Seasonal comparison of GPS-TEC with the IRI-2012 model for High solar activity period:-



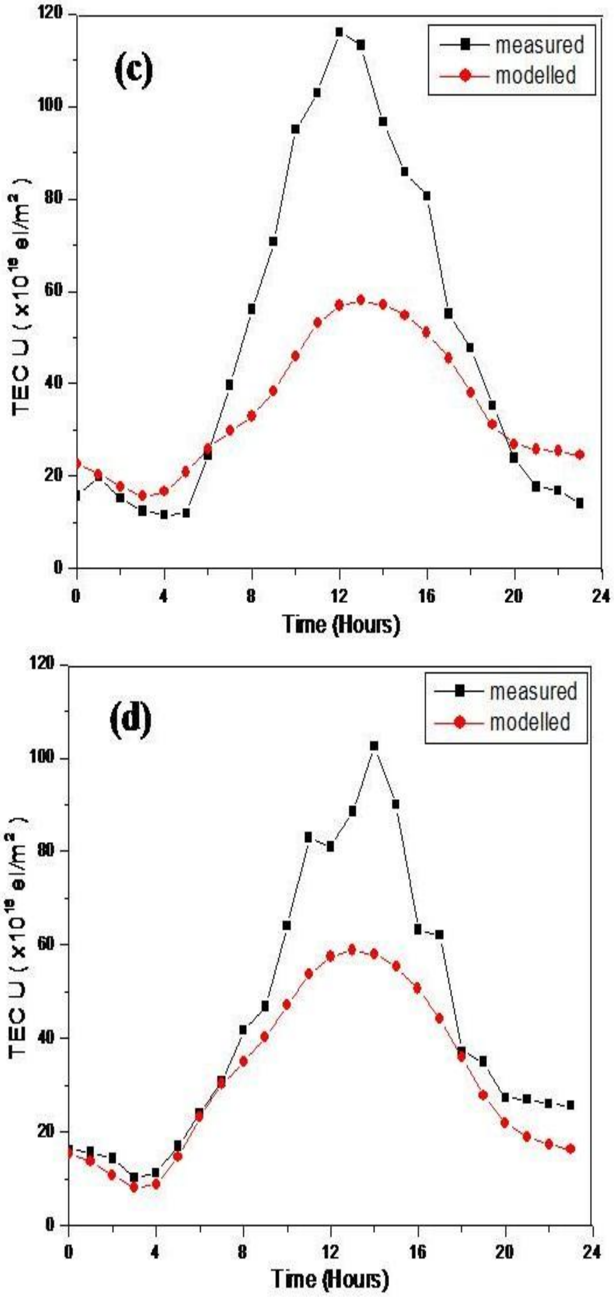


Fig 5:- Comparison between measured and IRI-predicted TEC values for (a) February 2014, (b) March 2015, (c) June 2015 and (d) September 2015

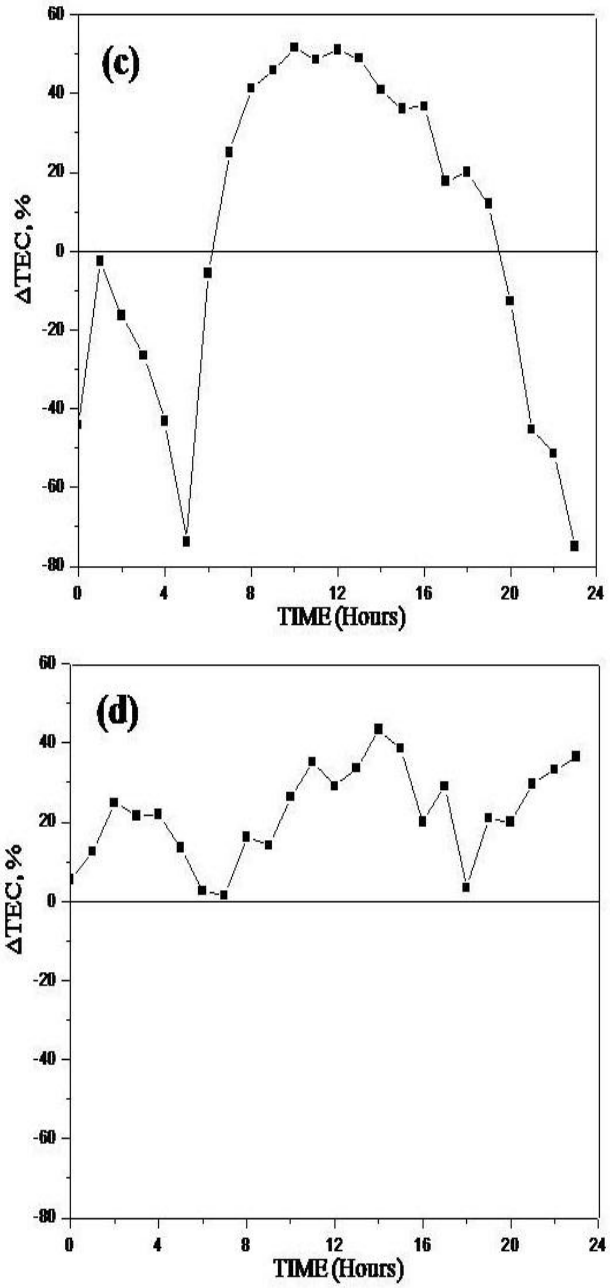


Fig 6:- Percentage deviation between the measured and IRI-predicted TEC values for (a) February 2014, (b) March 2015, (c) June 2015 and (d) September 2015

Next, the study has been carried forward for HSA period and the same method of analyses has been taken into consideration. Fig 5(a-d) and 6(a-d) represents the comparison between observed and IRI-predicted TEC values and percentage deviation, ΔTEC respectively. Here too in all the cases considered, IRI-2012 model consistently underestimate the measured TEC. The ΔTEC overestimate the morning hrs TEC by 20% - 40% in all the seasons except summer which shows that the ΔTEC underestimate the morning hrs TEC by 65%.This same feature can be seen for MSA period also or it can be said that for both HSA and MSA period, the summer ΔTEC underestimate the morning hrs TEC.

Next an attempt is made to compute TEC over Guwahati at geomagnetic disturbed condition by using the IRI model incorporating appropriate storm factor suitable for receiving measured TEC values. This factor will be evaluated by calculating the difference between IRI TEC and measured TEC values during geomagnetic storm and by taking the contribution of factors like storm induced electric field towards the changes in the stormtime TEC.

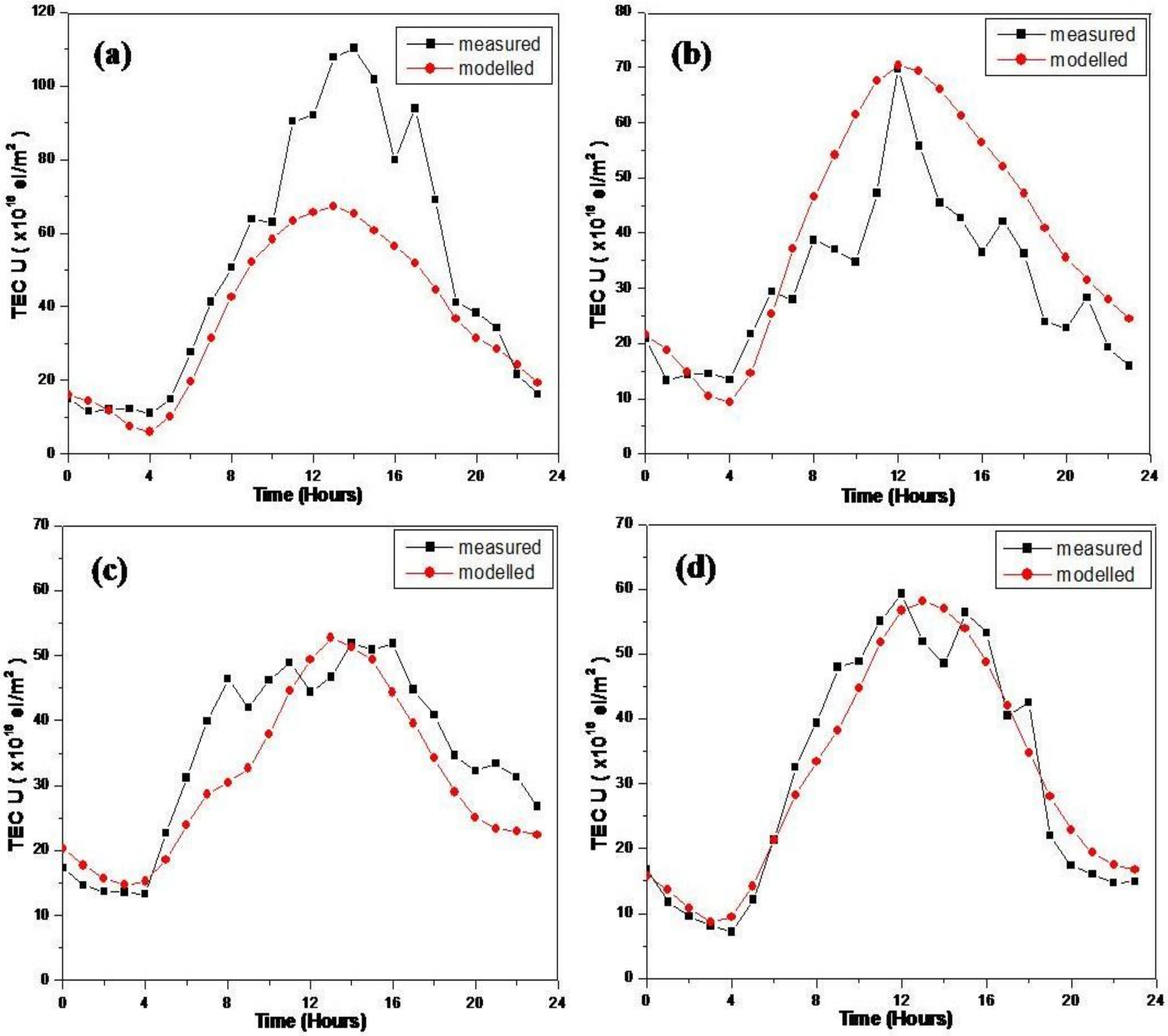


Fig 7:- Comparison between measured and IRI-predicted TEC values for (a) 19 February 2014, (b) 17 March 2015, (c) 23 June 2015 and (d) 9 September 2015 during geomagnetic disturbed condition.

Here, let us take the case of February storm of 2014. Fig.7 (a) shows difference in measured TEC on February 19, and the corresponding modelled values (IRI). It is seen from the figure that the TEC received through IRI never approaches the TEC observed during this storm day except for a short period of morning hours and on the other hand the IRI shows a fair representation of disturbed day TEC over Guwahati during noon to postnoon hours for March 2015, June 2015 and September 2015 geomagnetic storm day as represented in the figure 7 (b, c and d) respectively representing HSA period. The overall underestimation (quiet day) by the IRI (Fig. 5(a, b, c and d)) at all hours suggests that the EXB drift taken by IRI is low than its actual contribution. But it is seen that the same magnitude of drift values used for computing IRI TEC_I could represent measured TEC during disturbed days. So the EXB drift taken in the model is though much lower than the actual drift over Guwahati in quiet condition, the model drift value seems to be appropriate for receiving the geomagnetic disturbed day TEC_{noon} over Guwahati. On the other hand, the overestimation of IRI during the noon hours of the D day suggests inhibition of EXB drift during this hours of this day when on quiet days the model EXB drift on this hours seems to be appropriate to give the Q-day TECs. The fair representation of TEC during this period by the IRI suggests that the model assumes an EXB drift, the magnitude of which is very much lower than the normally existing one.

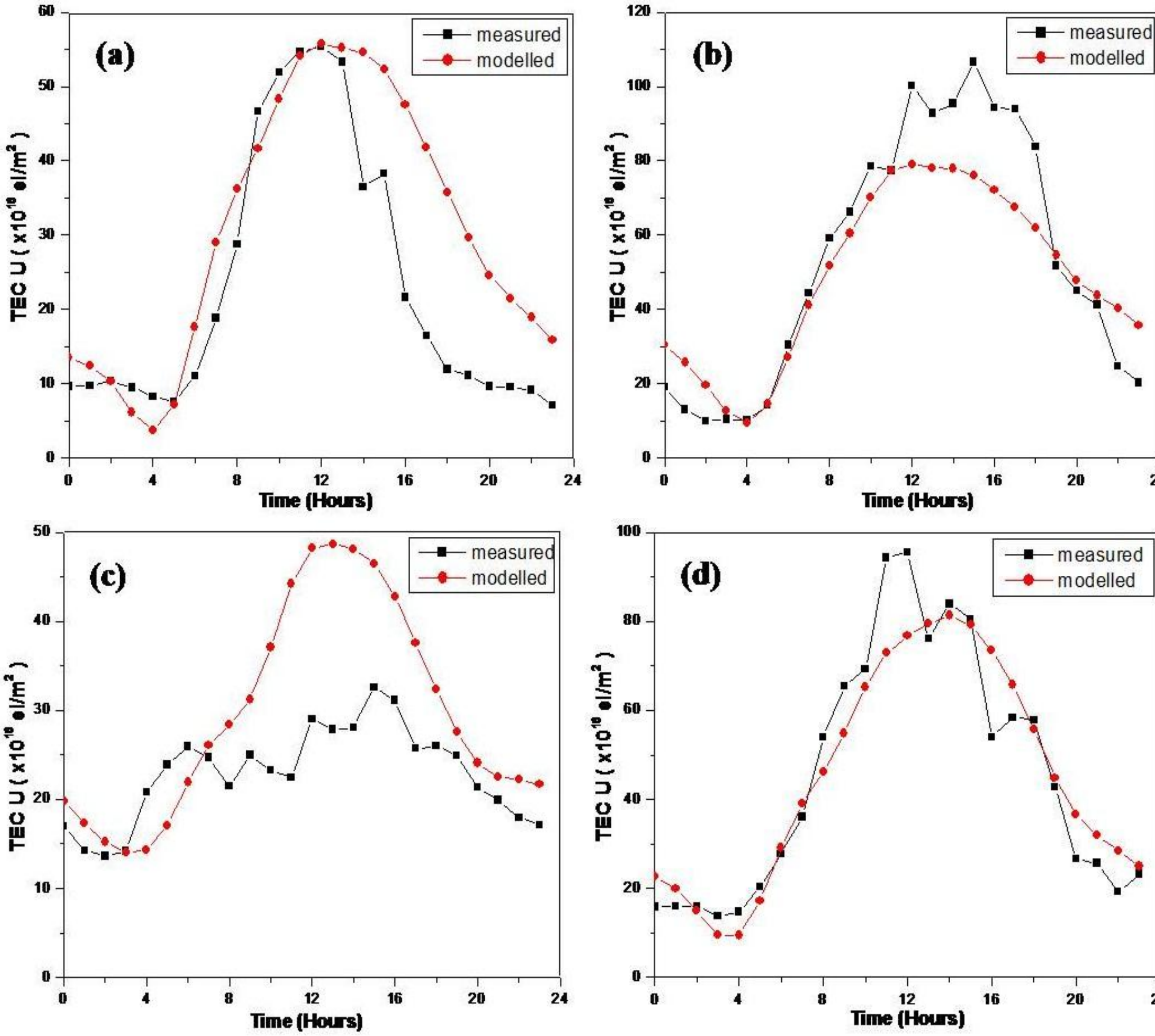


Fig 8:- Comparison between measured and IRI-predicted TEC values for (a) 4 February 2011, (b) 9 March 2012, (c) 15 July 2012 and (d) 26 September 2011 during geomagnetic disturbed condition.

Further study has been carried forward for MSA period under geomagnetic disturbed days. Figure 8(a) indicate a geomagnetic D-day for 4 February 2011 where it is seen that TEC decay rate is so slow that it crosses the mean quiet day value at postnoon hour which is due to extension of equatorial anomaly effect when eastward electric field shows an enhancement. It is assumed that suppression of TEC occurs due to weak eastward or development of westward field and enhancement in TEC is caused by presence of strong eastward field.

Discussion:-

The figures show that model prediction over this latitude is entirely different at low, medium and high solar activity conditions. It is also seen that the model when overestimates daytime winter TEC by 65%, it underestimates the same by 30% during summer day hours when solar activity is low; and in equinoctial period, the model output moves towards underestimation by 60%. This seasonal trend of LSA period changes during MSA and HSA period and it is observed that the model underestimates TEC by an average of 40% at all seasons. The analysis thus shows that the IRI can probably be used only for predicting daytime TEC with fair accuracy over Guwahati for LSA and MSA period, (Rz>140) for quiet day but model computation for stormtime TEC is far more complex. However at lower latitude the control of electric field is observed to be highly significant as has also been clearly seen from this study too.

A shift of the equatorial anomaly region with solar activity and with season (Walker *et al.*, 1988) makes model computations of the TEC over such region very difficult (Young *et al.*, 1970; Balan and Rao, 1987; Balan *et al.*, 1986; Joshi and Iyer, 1990). In low latitude stations, this model generally underestimates TEC (McNamara, 1983). It is also seen here that the IRI generally underestimates TEC at equatorial anomaly region stations. This may because of the EXB drift which play a major role in the shifting of .the crest from 14° to 20° magnetic latitude for low and high solar activity over Indian/Asian sector and this has been reported by many workers (Klobuchar et al., 1977; Balan and Iyer, 1983; Chen and Walker, 1984, Barman 1997). One of the reasons for underestimation of TEC from the IRI over Guwahati probably lies with its crest latitude defined at 14°N, would yield lesser TEC values than when the crest lies further up in actual situation. The solar activity control of the anomaly width introduces complexity in the model computation process for stations like Guwahati. However at lower latitude the control of electric field is observed to be highly significant. It is also seen from this study that it is extremely difficult to formulate a model which can represent TEC over an equatorial anomaly region like Guwahati.

Conclusion:-

In this paper, the comparative study of the IRI-2012 model TEC with ground-based GPS observation simultaneously from LSA period to HSA period over Guwahati station (26.2^0N, 91.7^0E) during the ascending phase of solar activity from 2007 to 2015 has been examined. The IRI-2012 shows a good agreement with GPS-TEC in all time and all seasons for quiet day LSA and MSA period but it shows less agreement for HSA period. Also, we note that the IRI model might be a better predictor for the daytime TEC, at least for magnetically disturbed summer and equinoctial high solar activity conditions. A slight underestimation in the TEC generated by the model lies within the standard deviation of the measured data for winter month. However, there are few discrepancies between the measured value and IRI-2012 model prediction. It is to be noted that the effect of E-field is the key factor in ' controlling TEC over equatorial anomaly crest region station like Guwahati. So, to make the model prediction more reliable, either the EXB drift magnitude needs to be reanalyze over this latitude or some other factors need to be introduced into the model computations in order to obtain better prediction of TEC over such anomaly crest region like Guwahati.

Reference:-

1. Anderson, D. N. (1973): A theoretical study of the ionospheric F-region equatorial anomaly-1. Theory. Planet. Space Sci.21, 409–419.
2. Anderson, D.N., and J.A. Klobuchar. (1983): Modeling the total electron content observations above Ascension Island. J. Geophys. Res., 88, 8020–8024.
3. Brown, L. D., R. E. Daniell, M. W. Fox, J. A. Klobuchar, and P. H. Doherty. (1991): Valuation of six ionospheric models as predictors of total electron content, Radio Sci., 25(4), 1007-1015.
4. Bailey, G. J., R. Sellek and Y. Rippeth. (1993): A modelling study of the equatorial topside ionosphere, Ann. Geophys., 11, 263.
5. Balan, N., and K. N. Iyer. (1983): Equatorial anomaly in ionospheric total electron content and its relation to dynamo currents, J. Geophys. Res., 88, 10,259.
6. Balan, N., Rao, P. B., and Iyer, K. N. (1986): Seasonal and solar variations of night-time anomalous enhancements in total electron content.Proc. Indian Acad. Sci., 95, 409–416.
7. Balan, N. and Rao, P. B. (1987): Latitudinal variations of night-time enhancement in total electron content, J. Geophys. Res., 92, 3436–3440.
8. Balan, N. and G. J. Bailey. (1995): Equatorial plasma fountain and its effects: possibility of an additional layer, J. Geophys. Res., 100, 21421.
9. Chiu, Y. T. (1975): An improved phenomenological model of ionospheric density, J. Atmos. Terr. Phys., 37, 1563-1570.
10. D. N. Anderson. (1981): Modeling the Ambient, Low Latitude F Region Ionosphere—A Review, J. Atmos. Terr. Phys. 43(8), 753–762.
11. D. Bilitza. (1986): International Reference Ionosphere: recent developments, Radio Sci., 21, pp. 343–346.
12. D. Bilitza. (2001): International Reference Ionosphere 2000, Radio Science 36, #2, 261-275.

13. Hartmann GK, Leitinger R (1984): Range errors due to ionospheric and tropospheric effects for signal frequencies above 100 MHz. Bull Geod 58: 109–136.
14. Joshi, H. P. and Iyer, K. N. (1990): On the nighttime anomalous enhancement in ionospheric electron content at lower mid-latitude during solar maximum, Ann. Geophysicae, 8, 53.
15. K. Rawer, S. Ramakrishnan, and D. Bilitza. (1978): International Reference Ionosphere 1978, International Union of Radio Science, URSI Special Report, 75 pp., Bruxelles, Belgium.
16. K. Rawer, D. Bilitza. (1989): Electron density profile description in the IRI, J. Atmos. Terr. Phys., 51, pp. 781–790.
17. K. Rawer, D. Bilitza. (1990): International Reference Ionosphere-plasma densities: status 1988, Adv. Space Res., 10 , pp. 5–14
18. Klobuchar, J.A., Iyer, K.N., Vats, H.O. and Rastogi, R.G. (1977): Indian J. Radio Space Phys., 6, 159.
19. Moffett, R.J. (1979): The equatorial anomaly in the electron distribution of the terrestrial F-region, Fund. Cosmic Phys., 4,313-391.
20. McNamara, L.F. and Wilkinson, P.J. (1983): Prediction of total electron content using the international reference ionosphere, J.Atmos. Terr.Phys. Vol-45,169-174.
21. M. K. Barman, A. K. Barbara and M. Devi. (1997): Measured and computed ionospheric electron content in the equatorial anomaly crest region. Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, No. 16, pp. 2069-2075.
22. Rawer, K. (1984a): Modelling of neutral and ionized atmospheres, in: Flügge, S. (Ed.), Handbuch der Physik, vol. 49/7, Geophysik III, part 7. Springer, Berlin, pp. 223-535.
23. Rawer, K. (1984b): New description of the electron density profile. Adv. Space Res. 4(1), 11-15.
24. Rawer, K. (1984c): Final summary and conclusions. Adv. Space Res. 4(1), 165-169.
25. Rajaram, G. and Obayashi (1977): Midlatitude electron density enhancement in the nocturnal topside ionosphere and its longitudinal inequalities. J. Geomag. Geoelectr.29, 507–517.
26. Stening, R. J. (1992): Modelling the low latitude F region, J. Atmos. Terr.Phys., 57, 433.
27. Titheridge, J.E. (1972): On the semiannual change in exospheric temperature. Journal of Geophysical Research 77: doi: 10.1029/JA077i010p01978. issn: 0148-0227.
28. Walker G. O.(1981): Longitudinal structure of the F region equatorial anomaly-A review, J. Atmos. Terr. Phys., 43, 763.
29. Young, D. M. L., Yuen, P. C., and Roelofs, T. H. (1970): Anomalous nighttime increases in total electron content, Planet Space Sci., 18, 1163–1179.