Comparison of GPS Derived TEC with the TEC Predicted by IRI 2012 Model Over the Eastern Africa Region

Emmanuel D. Sulungu*[1,2], Christian B. S. Uiso[2], Patrick Sibanda[3]

[1]Department of Physics, College of Natural and Mathematical Sciences, The University of Dodoma, P.O. Box 338, Dodoma, Tanzania (Email: edsulungu@gmail.com)
[2]Department of Physics, College of Natural and Applied Sciences, University of Dar es Salaam, P.O. Box 35063, Dar es salaam, Tanzania (Email: edsulungu@gmail.com, cbuiso@uccmail.co.tz)
[3]Department of Physics, School of Natural Sciences, University of Zambia, Lusaka, Zambia (sibandapatrick.ps@gmail.com)

Abstract

Objective

Comparisons between TEC based on observation and that of the IRI models over the Eastern Africa region, especially the region in the southern hemisphere are scarce. Therefore, the objective of this study was to validate the TEC obtained from the IRI-2012 model with the GPS derived TEC data recorded at four stations (Nairobi (1.22°S, 36.89°E), Malindi (2.99°S, 40.19°E), Dodoma (6.19°S, 35.75°E) and Mtwara (10.26°S, 40.17°E)) over the Eastern Africa region (Figure 1).

Methods

GPS-derived TEC data has been obtained from the Africa array and IGS network of ground based dual-frequency GPS receivers within the Eastern Africa region available at UNAVCO website (http://www.unavco.org/).

The slant TEC (TECs) was obtained from the equation; $TECs = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)(P_1 - P_2)$ (1)

where P_1 and P_2 are pseudoranges observable on L1 and L2 signals, f_1 and f_2 are the corresponding high and low GPS frequency respectively. TECv is obtained from the TECs by use of a mapping function which takes the curvature of the Earth into account [6] as follows:

$$TECv = M(e) \times TECs - (b_s + b_r + b_{rx}) \tag{2}$$

where b_S is satellite bias, b_r is a receiver bias and b_{rx} is a receiver interchannel bias,

$$M(e) = \left[1 - \left(\frac{\cos(e)}{1 + {h}/{R_E}}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

Here e is an elevation angle of a satellite, h is ionospheric shell height, and R_E is the Earth's mean radius.

Validation of IRI 2012 model has been carried out by comparing GPS TEC with the TEC obtained from IRI 2012 model for the years 2012 and 2013. A typical quite day of each month representing the four seasons (March equinox, June solstice, September equinox and December solstice) has been used in the analysis. The three options for topside electron density have been

used to compute the TEC from IRI 2012 model. Correlation Coefficients between the two sets of data, the Root-Mean Square Errors (RMSE) of the IRI-TEC from the GPS-TEC, and the percentage RMSE of the IRI-TEC from the GPS-TEC have been computed using the following equations [5];

$$Correlation\ Coefficient = \frac{\sum_i (GPS_i - \overline{GPS}_i)(IRI_i - \overline{IRI}_i)}{\sum_i (GPS_i - \overline{GPS}_i)^2 \sum_i (GPS_i - \overline{GPS}_i)^2} \tag{4}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{i} (GPS_i - IRI_i)^2}{n}} \tag{5}$$

$$Percentage\ RMSE = \frac{RMSE}{RMS_{GPS}} \times 100, \quad where\ \ RMS_{GPS} = \sqrt{\frac{\sum_{i=1}^{n} (GPS_i)^2}{n}} \tag{6}$$

where GPS_i are GPS-TEC data, $\overline{GPS}_i$ is their mean, IRI_i are IRI-TEC data, $\overline{IRI}_i$ is their mean, and n is the number of them. RMS_{GPS} is the root-mean square value for the GPS-TEC data, and the subscripts 'i' denote numerical positions in the data, having integral values from 1 to n.

Results

The general structure of the diurnal variations curves from GPS TEC and from all the three topside Ne options of the IRI-2012 model are quite similar. Generally, IRI-2012 model with all three options overestimates the GPS-TEC for all seasons and at all stations, and IRI-2001 overestimates GPS-TEC more compared with other options, except at few stations. In addition, during around 10:00 – 16:00 UT of September solstices of the year 2012, GPS TEC values are higher than IRI-Neq and IRI-01-corr at all stations, and they approximately match IRI-2001 TEC values. It was further observed that, GPS TEC values are higher than IRI-Neq and IRI-01-corr at Mtwara for the year 2012 during March equinox, and are approximately equal to the IRI-2001 TEC values. On the other hand, IRI-Neq and IRI-01-corr were observed to have approximately equal values of TEC at all times and at all stations. Our results agree with the previous studies. Example; [4], [5].The disagreements of the GPS TEC values and those estimated by IRI 2012 model is due to the relatively small amount of data from the region considered in developing the model [1]; [2]. GPS-TEC values and IRI-TEC values using all the three topside Ne options shows very good correlation (above 0.9), except during September equinox of the year 2012 at Malindi and Nairobi, during March equinox of the year 2013 at Dodoma and during September equinox for IRI-Neq option where the correlation coefficients are around 0.84 and 0.88 which are also good. The TEC using IRI-Neq and IRI-01- corr had small deviations from the GPS measured TEC compared to the IRI-2001 as it was also observed by [4] and [5]. Chakraborty [3] associated the largest discrepancy in TEC with a poor estimation of the hmF2 and foF2 from the coefficients.

Conclusions

In the present study we validated the TEC obtained from the IRI-2012 model during the year 2012 – 2013 with the GPS derived TEC data recorded at Nairobi, Malindi, Dodoma and Mtwara located within Eastern Africa region. Our results showed that the general structure of the diurnal variations curves from GPS TEC and from all the three options of the IRI-2012 model is quite similar. Generally, IRI-2012 model with all three options overestimates the GPS-TEC for all seasons and at all stations, and IRI-2001 overestimates GPS-TEC more compared with other options, except for few stations. GPS-TEC values and IRI-TEC values using all the three topside Ne options shows very good correlation. The TEC using IRI-Neq and IRI-01- corr had small deviations from the GPS measured TEC compared to the IRI-2001.

References

[1] Adewale A.O., Oyeyemi E.O., Adeniyi J.O., Adeloye A.B., Aladipo O.A., (2011). Comparison of total electron content predicted using the IRI-2007 GPS observations over Lagos, Nigeria, Indian Journal of Radio and Space Physics, Volume 40, pages 21 – 25.

[2] Bilitza D., Reinisch B.W., (2008). International Reference Ionosphere 2007: Improvements and new parameters, Advances in Space Research, Volume 42, pages 599–609, doi:10.1016/j.asr.2007.07.048.

[3] Chakraborty M., Kumar S., Kumar De B., Guha A., (2014). Latitudinal characteristics of GPS derived ionospheric TEC: a comparative study with IRI 2012 model, Annals of Geophysics, Volume 57, Issue 5, A0539; doi:10.4401/ag-6438.

[4] Okoh D., Eze A., Adedoja O., Okere B., Okeke P.N., (2012). A comparison of IRI-TEC predictions with GPS-TEC measurements over Nsukka, Nigeria, Space Weather, Volume 10, S10002, doi:10.1029/2012SW000830, 2012.

[5] Rathore V. S., Kumar S., Singh A.K., (2015). A statistical comparison of IRI TEC prediction with GPS TEC measurement over Varanasi, India Journal of Atmospheric and Solar-Terrestrial Physics, Volume 124, pages 1–9, doi: 10.1016/j.jastp.2015.01.006.

[6] Shim J.S., (2009). Analysis of Total Electron Content (TEC) variations in the low and middle latitude ionosphere. PhD Thesis, Department of Physics, Utah State University.

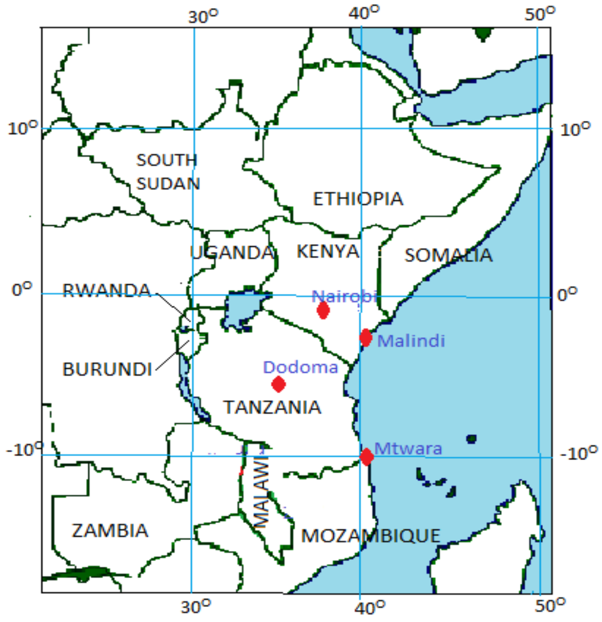

Figure 1: The map view of Eastern Africa region showing the locations of the stations used

Keywords: GPS, TEC, IRI 2012 model, Eastern Africa region.

Acknowledgement: I grateful thank The University of Dodoma for funding me in my PhD study.