Regional ionospheric TEC modelling; working towards mapping Africa's ionosphere

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Abstract

Currently the available data over the African continent does not allow for the construction of a truly representative ionospheric map for the purposes of long term predictions. In addition, the forecasting of the ionospheric variability over long term is a complicated task. This is because the ionospheric medium is continuously changing, it exhibits behavior that is not easily predictable and also requires a continuous and reliable database for comprehensive empirical models to be developed. However modelling ionospheric total electron content (TEC) changes over the short term is feasible especially during quiet conditions. In order to work towards generating ionospheric TEC maps to represent Africa's ionosphere, we have undertaken a feasibility study by using the South African Global Positioning System (GPS) receiver network to construct a regional model. This model generates TEC maps over the Southern African region at the minimum temporal resolution of 1 minute. The GPS TEC data as well as the modelled TEC are validated using ionosonde data. This paper will present an overview of regional GPS TEC modelling over Southern Africa and give a future direction towards continental TEC mapping.

1 Development of a regional TEC prediction model

In order to develop the regional model (referred to as the South African TEC prediction (SATECP) model in this paper), single station modelling was first carried out. This involved the derivation of GPS TEC using an algorithm based on spherical harmonics [1]. The derived GPS TEC data was then used to construct linear and non-linear regression models to reproduce TEC variability. TEC is influenced by solar and magnetic activity, diurnal and seasonal variations as well as the latitudinal component of the location over which the TEC data is derived. From a single station modelling point of view, only the first four were considered in both the regression and empirical models. In empirical modelling, artificial neural networks were employed. This technique has been found desirable in approximating ionospheric parameters due to their non-linear variability [2,3]. Comparative analysis indicated an improvement of $\sim 10\%$ for neural networks over the linear regression techniques employed in single station modelling [4]. For this reason, the former was adopted for regional TEC modelling. For both single station and regional models, the input space (for independent variables) was classified into periodic, random and positional components. The periodic component corresponds to diurnal and seasonal variations (represented by hour of the day, H_r and day number of the year, D_n) exhibited in TEC behaviour) [5]. The random component is represented by the complex and strong changes that influence TEC due to variations in solar and geomagnetic activities [5]. The positional component (G_p) takes into account the different positions of the points where the satellite-ground rays cross the ionospheric shell (over the GPS receiver stations) and are represented by geographic latitudes and longitudes ($G_p == lat, long$) [6]. For consistency, minutes are converted to hours (for the temporal input) and later split into cyclic trigonometrical components in order to take into account the adjacency of the last hour of the day and the first hour of the next day [2,3]. For the same reason the D_n is split into two trigonometrical components. The components for H_r and D_n are mathematically given [2,3] as

$$D_{ns} = \sin\left(\frac{2\pi \times D_n}{365.25}\right) \qquad D_{nc} = \cos\left(\frac{2\pi \times D_n}{365.25}\right) \tag{1}$$

$$H_{rs} = \sin\left(\frac{2\pi \times H_r}{24}\right) \qquad H_{rc} = \cos\left(\frac{2\pi \times H_r}{24}\right) \tag{2}$$

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GPS receiver/ionosonde station	Station code	Latitude (° S)	Longitude (° E)	Verification year
Thohoyandou	TDOU	23.08	30.84	2005
Grahamstown	GRTN	33.3	26.5	2005
Madimbo	MDBO	22.40	30.90	2004
Louisvale	LVLE	28.50	21.20	2004

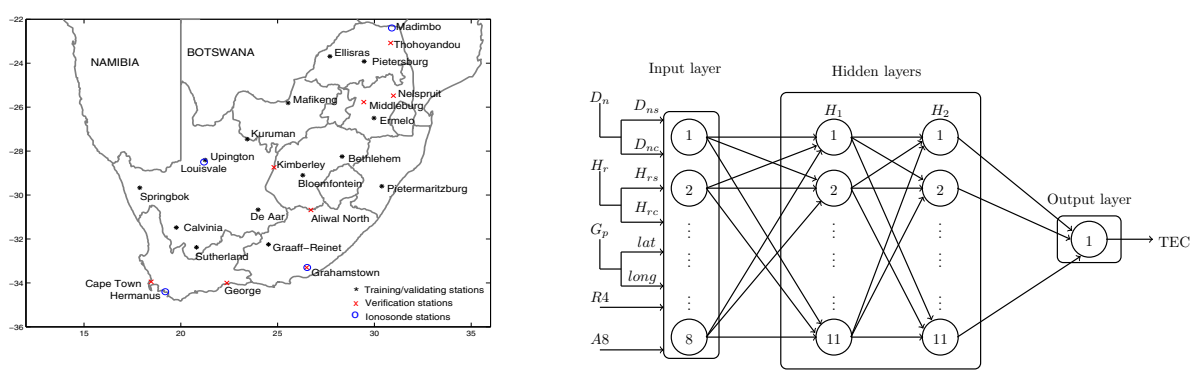
Table 1: Geographical location of the GPS receiver and ionosonde stations within South Africa over which the verification results of the regional model are shown in this paper. Over GRTN, there are both ionosonde and GPS receiver co-located. The other ionosonde stations are indicated in bold.

where $D_{ns}, D_{nc}, H_{rs}, H_{rc}$ are the sine and cosine components of day number (D_n) and hour (H_r) respectively. The final modelled TEC can be mathematically expressed [4,6] as

$$\left.\begin{array}{l} T_m \equiv f(D_n, H_r, R4, A8, G_p) \\ \text{where} \\ D_n == \{D_{nc}, D_{ns}\} \\ H_r == \{H_{rc}, H_{rs}\} \\ G_p == \{lat, long\} \end{array}\right\} \quad (3)$$

where T_m represents TEC generated by the regional model, $R4$ is the 4-month running mean of sunspot number and $A8$ is the average of the previous eight 3-hourly magnetic A index values (A8) derived from the archived K-index data recorded at the Hermanus Magnetic Observatory (34.43°S,19.23°E), South Africa.

The current version of the regional model uses data from about 20 GPS receiver stations in its development as shown in fig. 1(a). The final architecture of the regional model is built using data for dependent



(a) A South African map showing GPS stations used in the development and validation of the regional model [4].

(b) A schematic illustration of the regional model architecture [4,6].

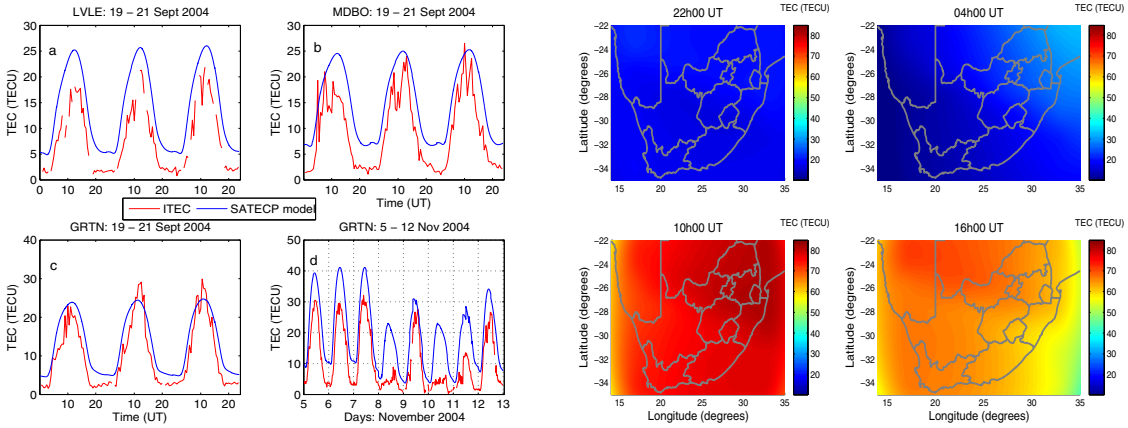
Figure 1: Southern Africa map showing the infrastructure used in the development of the regional model, and its architecture.

and independent variables as shown in fig. 1(b). Table 1 shows the geographical locations for GPS receiver and ionosonde stations over which the verification of the regional model was carried out.

2 Results and discussions

Fig. 2(a-c) shows the 1 minute TEC variability generated by the SATECP model over the three ionosonde stations for 19-21 September 2004. Superimposed on these plots is ITEC at intervals of 30 minutes corresponding to these particular days. Although there is the presence of a modelled topside profile within the

ITEC, it gives an idea about the general diurnal quantitative measure of TEC since the plasmasphere is known to contribute some electron content to TEC derived from GPS [7]. In fig. 2(c) the ITEC is greater than modelled TEC during some periods. The reasons for this are not currently known and are still under investigation. Fig.2d shows the capability of the SATECP model to generalise ionospheric behaviour during

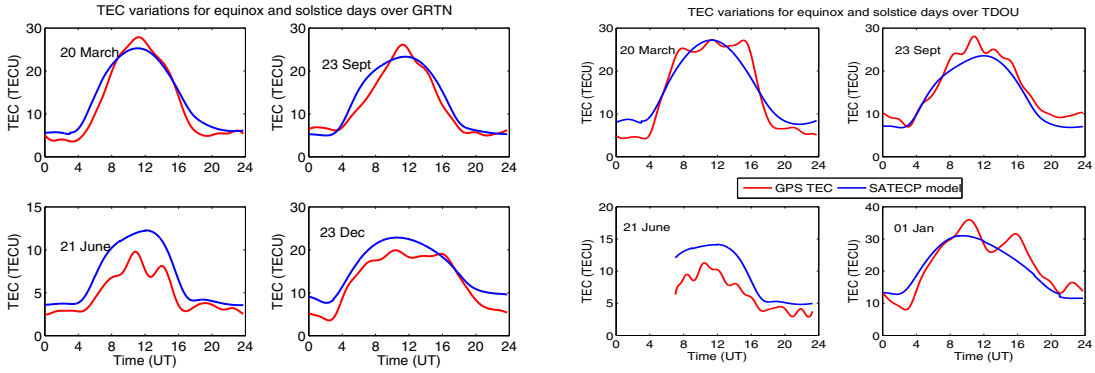


Comparison of ionosonde TEC (ITEC) and modelled TEC over ionosonde stations [4,6].

Reconstructed TEC variations over Southern Africa at local midnight, sunrise, midday and sunset for 20 March 2002 [4].

Figure 2: Comparison of ionosonde and modelled TEC and reconstructed TEC maps over Southern Africa.

storm conditions. A general depletion of TEC is observed from both modelled and ionosonde TEC. An example of TEC behavior over the entire region is shown in fig. 2 at local midnight, sunrise, midday and sunset displaying the expected TEC variational pattern for these times. Fig. 3 shows the diurnal TEC variations for days representing solstice and equinox days over GRTN and TDOU in 2005. The root mean square error (RMSE) estimates between GPS TEC and modelled TEC for the autumn equinox (20 March 2005) are $\sim$ 2.857 TECU and 1.983 TECU over TDOU and GRTN respectively. These values change to $\sim$ 2.218 TECU and 2.089 TECU for the spring equinox (23 September 2005) and this demostrates how close and comparable the predictions are on similar days over these verification stations with a latitudinal separation of $\sim 10°$. Results and their statistical analyses demonstrate the ability of the regional model to correctly reproduce TEC variational patterns at all latitudes considered. Details can be found in [4].



(a) GPS and modelled TEC over GRTN.

(b) GPS and modelled TEC over TDOU.

Figure 3: Diurnal variations of both GPS and modelled TEC over GRTN and TDOU for solstice and equinox days in 2005.

3 Conclusion

Though with some unresolved shortcomings of our current model, efforts are underway to improve the model to cover the entire African continent. Work towards having an African TEC model is in its initial stages. The success of the African model will depend on the availability and accessibility of enough data. In the continental model, we expect the geospatial conditions to be reproduced including the ionospheric variability over the equator. For this particular reason we are considering replacing geographic latitudes and longitudes with geomagnetic latitude. The back ground and status of this project with emphasis on working towards mapping Africa's ionosphere will be discussed in this paper.

4 References

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