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Variation of ionospheric slab thickness over South Africa

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Abstract

Ionospheric slab thickness is defined as the ratio of TEC to maximum electron density of the *F*-region (*N*m*F*2), proportional to the square of the *F*2-layer critical frequency (*f*oF2). It is an important parameter in that it is linearly correlated with scale height of the ionosphere, which is related to electron density profile. It also reflects variation of the neutral temperature. Therefore, ionospheric slab thickness is a significant parameter representative of the ionosphere. In this paper, the International Reference Ionosphere (IRI) model, South African Bottomside Ionospheric Model (SABIM), and measurements from ionosondes in the South African Ionosonde Network were combined within their own limitations to develop a map of *fo*F2 values for the South African region. This parameter and vertical TEC values derived from the map using the IRI model were used to compute ionospheric slab thickness. Finally climatology of the slab thickness is described by diurnal and seasonal variations.

Keywords

*Fo*f2, ionospheric slab thickness, IRI, NmF2, South Africa.

1. Introduction

The ionosphere affects our lives in diverse ways, ranging from its usefulness in High Frequency (HF) radio propagation, to its attenuation of radio signals that have to pass through it. By extending our knowledge to lesser known areas of the ionosphere, the use of the ionosphere can be greatly enhanced and significant allowance can be made for the effects ionospheric behavior can have on signals passing through these altitudes. The ionospheric slab thickness is a parameter which provides information about the nature of the distribution of ionization at a specific location and is defined as the ratio of the vertical Total Electron Content (TEC) measured in TEC units to the maximum ionospheric electron density in the F-region (*N*m*F*2).

The ionospheric slab thickness is a significant parameter since it includes information regarding both the top and bottom sides of the ionosphere. Ionospheric slab thickness may also be regarded as the depth of an imaginary ionosphere that has the same TEC as the actual ionosphere and a uniform electron density that is equal to the maximum electron density of the actual ionosphere (Chuo, 2007). The study of slab thickness has been carried out by researchers (Bhonsle *et al.*, 1965; Huang, 1983; Bhuyan *et al.*, 1986; Davies and Liu, 1997; Gulyaeva *et al.*, 2004; Jin *et al.*, 2007). They have found that diurnal, seasonal, and solar activity variations in slab thickness show significant dependence on the location of the observing station.

The aim of this project is to develop a map of the ionospheric slab thickness over the South

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African region based on available data sources. For this purpose, a map of *fo*F2 values for the South African region was developed and then used to adapt the International Reference Ionosphere (IRI) model to generate vertical total electron content for this region. Finally, the ionospheric slab thickness was computed. The available sources are the International Reference Ionosphere (IRI) model, the South African Bottomside Ionospheric Model (SABIM) and scaled measurements from the 4 ionosondes in the South African ionosonde network. These sources were combined in such a way as to develop a map of the behavior of South Africa's ionosphere that is as accurate as possible.

2. Study Area

The data sources considered for the development of the map are the IRI model, SABIM, and measured data from the 4 South African ionosonde stations.

The International Reference Ionosphere (IRI) is the result of an international cooperation sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). Since first initiated in 1969, IRI is an internationally recognized standard for the specification of plasma parameters in the Earth's ionosphere. It describes monthly averages of electron density, electron temperature, ion temperature, ion composition and several additional parameters in the altitude range from 60 to 1,500 km. IRI has been steadily improved with newer data and better modeling techniques leading to the release of a number of several key editions of the model. The latest version of the IRI model, IRI-2012 (Bilitza et al., 2011) includees significant improvements not only for the representations of electron density, but also for the description of electron temperature and ion composition. These improvements are the result of modeling efforts since the last major release, IRI-2007 (Bilitza and Reinisch, 2007). IRI is an empirical model based on most of the available data sources for ionospheric plasma.

SABIM is a model of South Africa's bottomside ionosphere developed by Dr Lee-Anne McKinnell, a Space Physics researcher with the Hermanus Magnetic Observatory (HMO), and Rhodes University, South Africa (McKinnell 2008). SABIM was developed using an archive of data from the 3 South African ionosonde stations located at Grahamstown (33.3°S, 26.5°E), Madimbo (22.4°S, 30.9°E) and Louisvale (28.5°S, 21.2°E).

SABIM was developed using the technique of training Neural Networks (NNs) to learn from, and adapt to the pattern of archived data. A NN is simply a computer algorithm that is trained to learn the relationship between an output and a set of given input parameters (McKinnell, 2008).

McKinnell and Poole (2004) noted that the IRI model was inaccurate in the South African region due to an historical paucity of available data for the region. In their words; comparisons with the IRI global model showed that for Grahamstown, a NN-based model predicted the noon value of *fo*F2 more realistically than the IRI. Earlier works done by McKinnell (2002) showed that SABIM predictions were more accurate than IRI predictions over Grahamstown when compared to measured data from the Grahamstown ionosonde (Okoh et al., 2010).

The latest version of SABIM (version 3) was implemented as an executable produced from a code written in the C programming language for use in this study. A block diagram illustrating the process that the SABIM model follows in predicting the electron density profile is shown in Figure 1.

The South African Ionosonde Network currently comprises of 4 ionosonde stations as shown in Figure 2; the 3 already mentioned above and used in the development of SABIM plus the latest addition located at Hermanus (Western Cape, 34.4 S, 19.2 E). Since ionosonde measurements are the most accurate recordings of ionospheric behavior and reflect the true state of the ionosphere at a given time and location, real-time data from the 4 ionosondes were given first priority in the development of this map. In summary, the IRI model was incorporated into the model since it is an international standard for the ionosphere, SABIM was used since it is more adapted for the South African region, and the South African ionosonde network provides the most accurate real-time ionospheric information for the region (Okoh et al., 2010).

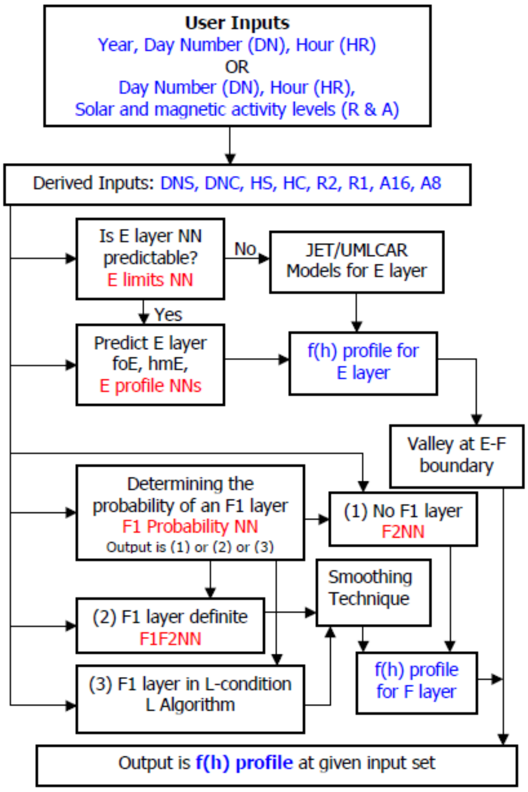

Fig. 1. A flow diagram illustrating the process followed by SABIM in determining the predicted profile (McKinnell, 2002)

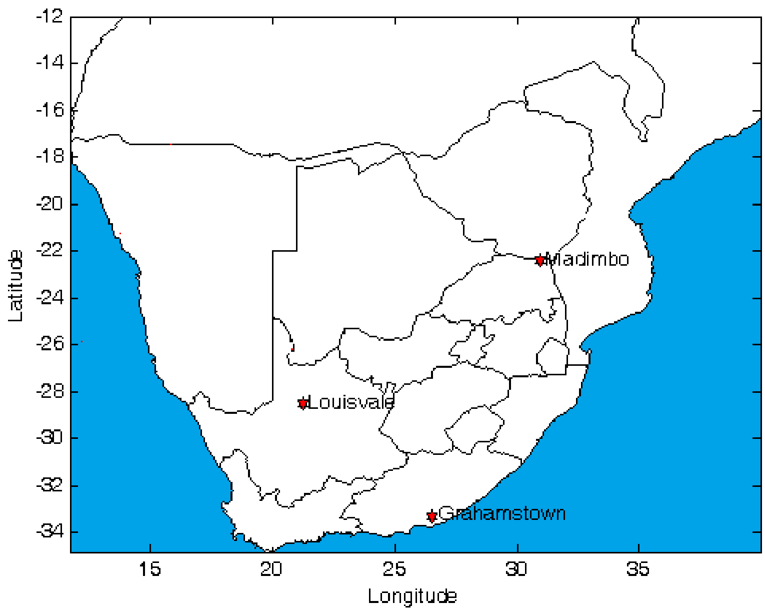

Fig. 2. Locations of the South African ionosonde stations. SABIM is used inside the marked triangular region

3. Materials and Methods

The basic theory about the physical and mathematical techniques used for developing the *F*2-layer critical frequency and vertical total electron content by combining the above data source in this study was given by Okoh et al. (2010).

To produce the *fo*F2 map, SABIM was used inside the triangular region as illustrated in Figure 1. The vertices of the triangle are at the 3 ionosonde stations which were used to develop SABIM. For locations outside of the triangular region where the IRI model was used, a smoothing function was introduced at the boundary between where these 2 models were used such that SABIM still contributed outside of the triangular region, but its contribution decreases with increasing distance from the closest edge of the triangle. The smoothing function used by Okoh et al. (2010) is thus:

$$f = f_s \cos^2 q + f_i \sin^2 q \tag{1}$$

where f_s is SABIM's *fo*F2 value for a location outside of the triangular region, f_i is IRI's corresponding *fo*F2 value for that location, and f is the resulting *fo*F2 value for the location. The angle q was arbitrarily defined to have a value of 0° anywhere on the triangular edge, and 90° at a distance of 10 longitudinal degrees from the closest triangular edge. In essence, IRI's contribution is zero for points on the triangular edge, increases with distance from the triangle and is 100% at a distance of 1117 km and beyond from the closest triangular edge (Okoh et al., 2010).

The rationale behind this combination is that SABIM is known to perform more accurately than the IRI model inside the triangular region bounded by the 3 ionosonde stations that were used to develop the model (Poole and McKinnell, 2000), however, its performance outside of that region has not been proven. Measurements from the ionosondes were further used to adapt the produced *fo*F2 map to fit the ionosonde measurements; for each ionosonde location, the program calculates the difference between the measured *fo*F2 and the *fo*F2 value calculated by the existing modeled map at the ionosonde location, and then fits a best plane by the least squares method of the differences over the whole map.

The general equation of a plane is:

$$Ax + By + Cz + D = 0 \tag{2}$$

where *A, B, C* and *D* are constants defining the plane. This plane is added to, or subtracted from, the existing modeled map in order to adapt it to the ionosonde measurements. To generate the vertical total electron content for a given location, the IRI model was used, but augments it with the location's *fo*F2 and hmF2 values as obtained from the map. The hmF2 values are obtained by exactly the same process used for obtaining *fo*F2 values.

Note that the vertical total electron content generated by adapting the IRI model with *fo*F2 and hmF2 values from the map are contributions from all 3 sources used in the development of the map since the *fo*F2 and hmF2 values come from a combination of data from all 3 sources. After producing *fo*F2 and VTEC values, the ionospheric slab thickness in kilometers can be calculate as follow:

$$t = \frac{TEC}{N_m F2} = \frac{TEC}{1.24 \times foF2^2} \times 10^3 \tag{3}$$

where TEC in $TECu$ and $N_m F2$ is the peak electron density in the F2-region.

4. Results and Discussion

4. 1. Variations over a typical day

Figure 3a to d illustrates how the t values (in kilometers) vary over a typical day in South Africa as determined by our map. The figures show t maps of the South African ionosphere at 08:00 UT (a South African morning), 12:00 UT (a South African afternoon), 16:00 UT (a South African evening), and 22:00 UT (the South African midnight) respectively for day number 13 (a summer day) in year 2010. The maps show that the t values are larger in the morning than at other times of the day. The early morning peaks in slab thickness may appear due to the fact that sunrise is earlier at heights above the F2-layer causing some production at the topside which tendsto give TEC a lead over NmF2 which is still decaying.

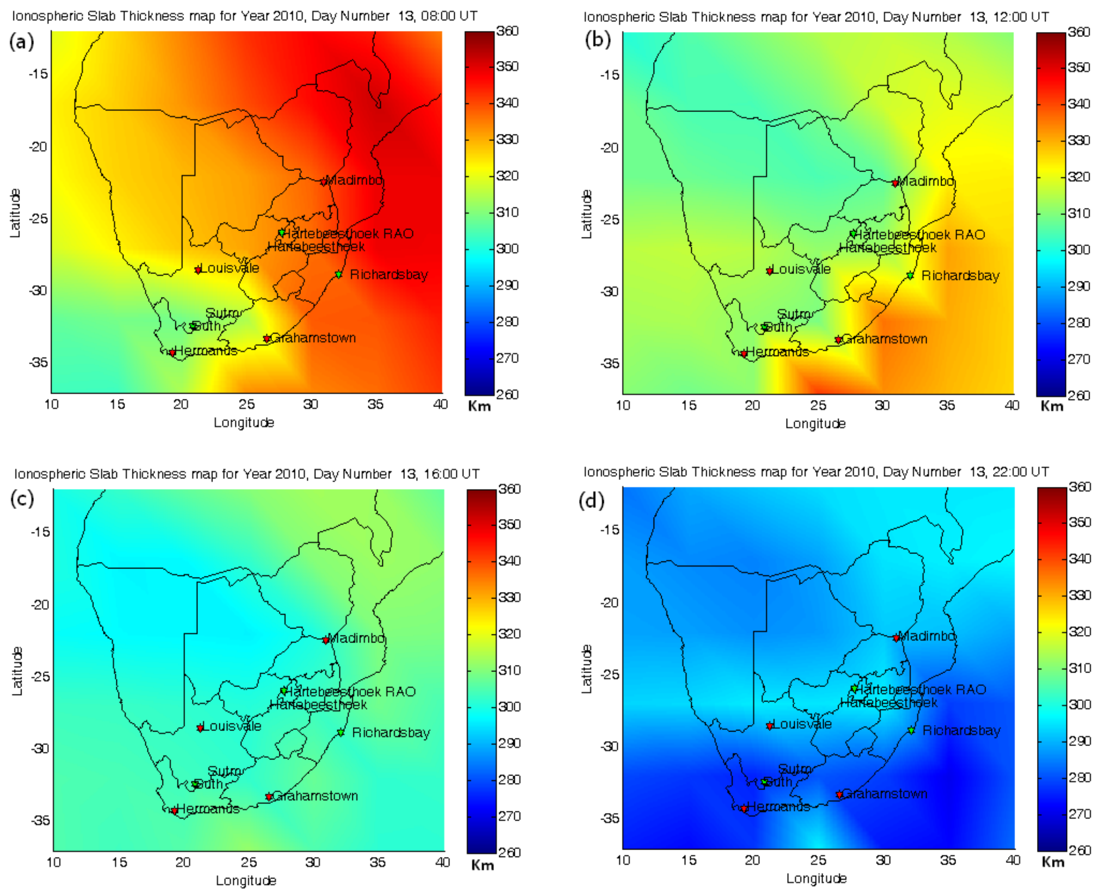

Fig. 3. Variations in *t* over South Africa for (a) a morning, (b) an afternoon, (c) an evening and (d) a midnight hour of a summer day in 2010

4. 2. Seasonal variations

The intensity of solar radiation reaching the ionosphere changes with the seasons of a year. Figure 4 a to d illustrate variations in the South African ionospheric slab thickness during the 4 seasons of year 2008. These figures are *t* maps for day numbers 13, 104, 195, and 285 of year 2008, respectively chosen to represent a day each in summer, autumn, winter, and spring. The maps are for 10:00 UT (midday local time) for each of the chosen days. As expected, the *t* values are greater for the summer day than for the winter day. The tilt of the Earth's rotational axis relative to the orbital plane coupled with the Earth's revolution round the sun gives rise to seasonal modulation of the solar flux. In summer, a given hemisphere is tilted towards the sun and so experiences greater solar intensity than in winter when the same hemisphere will be tilted away from the sun.

4. 3. Variations over a solar cycle

A solar flare is an intense burst of the radiation coming from the release of magnetic energy associated with sunspots. March 9th ended with a powerful solar flare and earth-orbiting satellites detected an X1.5-class; the explosion from behemoth sunspot 1166 around 23:23 UTC. This continues the recent trend of increasing solar activity associated with the sun's regular 11-yr cycle, conforming that the solar cycle 24 is indeed heating up, as expected by solar experts. The map exhibits the expected change in ionospheric response to varying degrees of solar activity. Figure 5a to c shows the *t* maps for identical periods in year 2000 (a year of solar maximum), year 2003 (a year of moderate solar activity), and year 2006 (a year of minimum solar activity), respectively. The maps are for 08:00UT and day number 50 (early autumn) of each of the chosen years. As expected, the maps show large *t* values for the year of minimum solar activity, moderate *t* values for the year of moderate solar activity, and lower *t* values for the year of maximum solar activity.

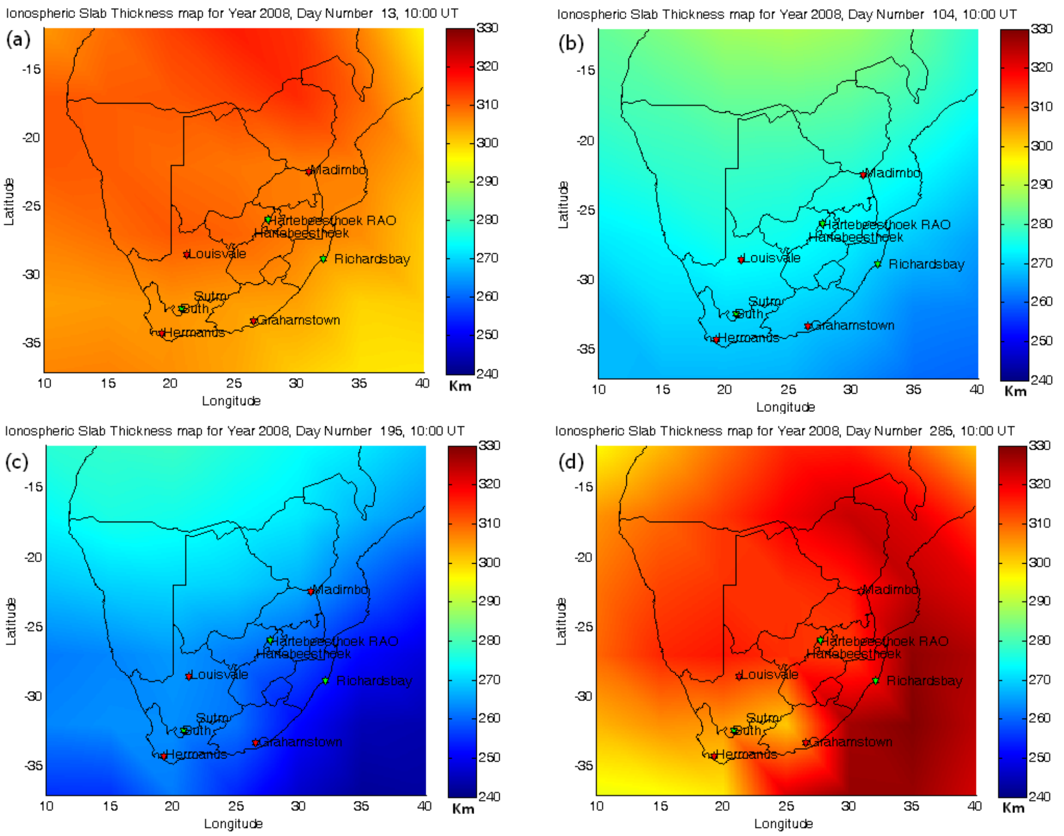

Fig. 4. Variations in *t* over South Africa for (a) a summer day, (b) an autumn day, (c) a winter day and (d) a spring day

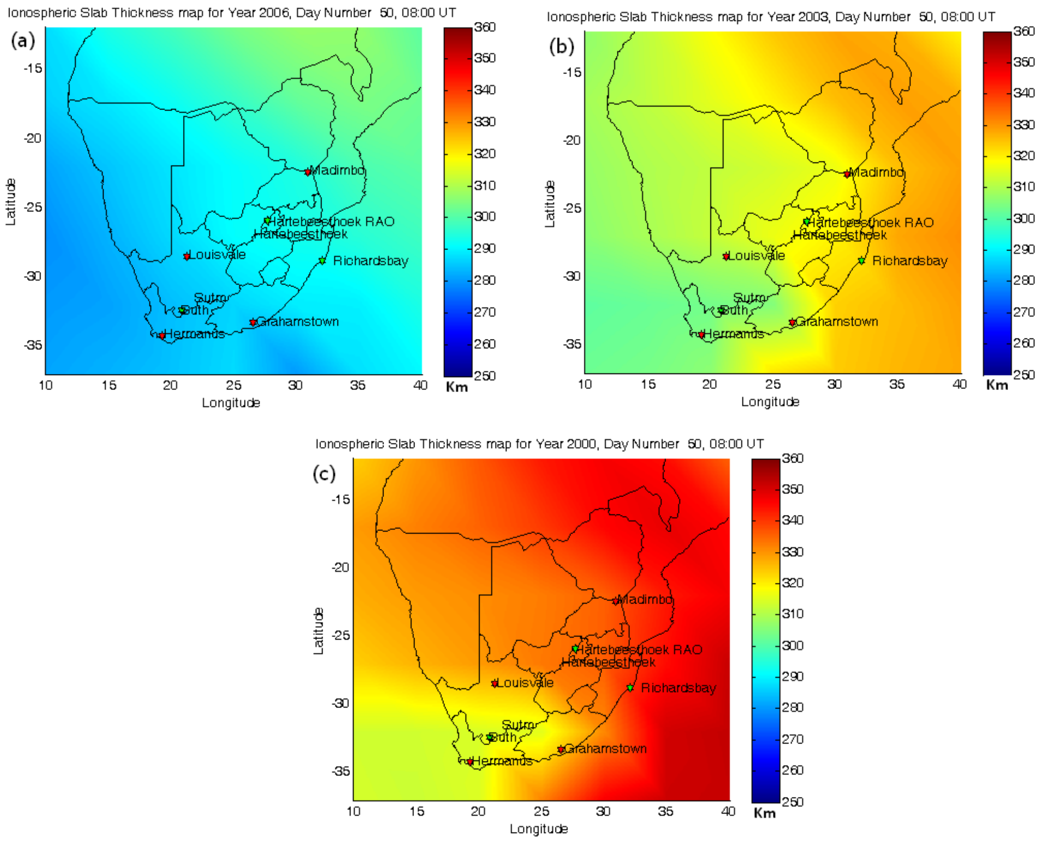

Fig. 5. Variations in *t* over South Africa for (a) a year of maximum solar activity, (b) a year of moderate solar activity and (c) a year of minimum solar activity

4. 4. Latitudinal and longitudinal variations

The sun is mostly overhead at locations on or close to the equator than at higher latitudes. For this reason, the sun's radiation is more intense at lower latitudes than at higher latitudes. The overall effect is a gradual degradation in ionospheric photo-ionization, and hence *fo*F2 values as we move from the equatorial regions to the Polar Regions. This degradation is evident in each of the *t* maps illustrated. Longitudinal variations are related to local-time variations; for a given locality, the intensity of solar radiation increases as the sun rises, peaks at about local midday and decreases as the sun sets.

5. Conclusions

Ionospheric slab thickness is defined as the ratio of TEC to the maximum electron density of the F-region (*N*m*F*2), proportional to the square of the F2-layer critical frequency (*fo*F2). This parameter has a great influence on the shape of ionospheric electron density profile Ne (h), and is also a convenient one parameter summary of the electron density profile that may be related to various physical processes. In this paper, the diurnal, seasonal and latitudinal behavior of the ionospheric slab thickness at South Africa has been investigated and the following important results have been obtained:

1. The slab thickness shows appreciable diurnal, seasonal, spatial, solar and geomagnetic activity variations.
2. It is observed that in the night time in this region, the value of the *t* is lower than day time values.
3. The slab thickness is significantly smaller in winter than in summer.

References

1. Bilitza, D., McKinnell, L., Reinisch, B., Fuller-Rowell, T., 2011. The international reference ionosphere today and in the future. J. Geod., 85, 909–920.
2. Bilitza, D., Reinisch, B.W., 2008. International Reference Ionosphere 2007: Improvements and new parameters, Adv. Space Res., 42, 599–609.
3. Bhuyan, P.K., Singh, L., Tyagi, T.R., 1986. Equivalent slab thickness of the ionosphere over 26◦N through the ascending half of a solar cycle, Ann. Geophys., 4, 131.
4. Bhonsle, R.V., Da Rosa, A.V., Garriott, O.K., 1965. Measurement of total electron content and equivalent slab thickness of the mid-latitude ionosphere, Radio Sc., 69D(7), 929.
5. Chuo, Y.J., 2007. The variation of ionospheric slab thickness over equatorial ionization area crest region, J. Atmos. Sol.-Terr. Phys., 69, 947–954.
6. Davies, K., Liu, X.M., 1997. Ionospheric slab thickness in middle and lowlatitudes, Radio Sci., 26(4), 997–1005.
7. Gulyaeva, T.L., Jayachandran, B., Krishnankutty, T.N., 2004. Latitudinal variation of ionospheric slab thickness, Adv. Space Res., 33, 862–865.
8. Huang, Y.N., 1983. Some result of ionospheric slab thickness observations at Lunping, J. Geophys. Res., 88, 5517.
9. Jin, S., Cho, J., Park, J., 2007. Ionospheric slab thickness and its seasonal variations observed by GPS, J. Atmos. Sol.-Terr. Phys., 69, 1864–1870.
10. McKinnell, LA., 2008. SABIM Model Version 3.0: A Bottomside Ionospheric Model for the South African Region. Technical Report for Grintek.
11. McKinnell, L.A., 2002. A neural network based ionospheric model for the bottomside electron density profile over Grahamstown, South Africa, PhD Thesis, Rhodes University.
12. McKinnell, L.A., Poole, A.W.V., 2004. Neural network-based ionospheric modelling over the South African region, South African Journal of Science, 100, 519–523.
13. Okoh, D.I., McKinnell, L.A., Cilliers, P.J., 2010. Developing an ionospheric map for South Africa. Ann. Geophys., 28, 1431–1439.
14. Poole, A.W.V., McKinnell, L.A., 2000. On the predictability of foF2 using neural networks, Radio Sci., 35, 225–234.