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A New Method for Computing Ionogram-Based TEC Based on Digisonde data for Disaster Prevention

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Abstract—This paper presents a new approach for calculating the ionogram-based total electron content so as to be applied alternatively for alarming and preventing the disasters, for example, earthquake, tsunami or other space objectives. The proposed ITEC is estimated using the analytical expression of NeQuick model, the autoscaled Digisonde data, and a new variable “m” of 1. The results are show that 1) the proposed B0 is close to the B0_obs of Digisonde compared to the B0_IRI and the B2bot of the NeQuick model, 2) the diurnal variation of B0_Pro is the same as that of B0_obs compared to those of B0_IRI and B2bot, 3) the proposed ITEC is also close to the ITEC of Digisonde and TEC_iri, excluding the observed GPS TEC, and 4) all of the studied TEC values behave similar diurnal variations. Since the proposed ITEC is based on the analytical functions, the improvement of TEC_B0_Pro can be conducted reliably in order to close to the GPS TEC possibly and apply it optionally to correct the positioning errors for GNSS and aviation systems.

Keywords—Bottomside ionosphere; Digisonde; GPS TEC; IRI-2016 model; ITEC; NeQuick 2 model; thickness parameter

I. INTRODUCTION

Satellite signals passing through the atmosphere encounter diffraction and refraction which lead to the propagation delays. A major counterpart for these delays is Ionosphere where the ionospheric delay is involved directly to the total electron content (TEC) and must be corrected for any GNSS systems, any navigation systems etc. It is thus important not only build an accurate TEC model, but also observe the reliable TEC values with several instruments for correcting ionospheric delays as well as using it to identify the disaster phenomena such as earthquake, tsunami. The TEC value can be used directly to compute the ionospheric delays (I) by the following equation:

$$I = \frac{40.3 \text{TEC}}{f^2} \quad (1)$$

where f is an operating frequency of any satellite systems and TEC represent either slant TEC (STEC) or vertical TEC (VTEC). For instance, if a considered satellite system employs a L1 carrier of 1,575.42 MHz, 1 TECU will lead to an ionospheric delay of 0.54 ns. Note that 1 TECU is equal to 10^{16} electrons/m². The STEC can be calculated using the integration of electron density along the whole path from the satellite to its receiver. Meanwhile, the VTEC can be determined using STEC and some parameters such as receiver bias, satellite bias, zenith angle, and elevation angle [1].

Moreover, TEC values can be obtained using the practical observations (e.g., GNSS satellites, incoherent scatter radar (ISR), and the ocean topography experiment (TOPEX) surface reflection) and the ionospheric models. The International Reference Ionosphere (IRI) model predict TEC and other parameters at a given location, date, and time. Likewise, the NeQuick 2 model provides the observed STEC values for transoceanic communication at given location, time and height. The IRI-predicted TEC values still differ from the observed TEC values, especially equatorial and high latitudes. Moreover, there are additional two sources of TEC observations in practice to analyze space weather for our globe and calculate ionospheric delays for compensating positioning error in GNSS, GBAS and aviation. The first TEC source is obtained from International GPS services for Geodynamics (namely, IGS TEC). Since GNSS receivers over the globe are increasing largely, hence the big database of TEC values is very useful to investigate space weather and provides GNSS data portals. Another TEC source is obtained from Digisonde in conjunction with an interpolation technique [2], so called ionogram-based TEC or ITEC. The ITEC generally behave the same variations as the observed TEC values from TOPEX and ISR observations over low and middle latitudes. Numerous studies have still been conducted to compare the observed TEC with the modelled TEC (IRI or NeQuick 2 model) and ITEC [3][5].

Recently, a new expression was proposed to determine the thickness parameter of bottomside ionosphere [5]. That equation was evolved from an analytical equation of the NeQuick model in [6] in which it was shown in terms of

VTEC, F2 layer peak electron density ($NmF2$), and F2 layer bottomside thickness parameter ($B2bot$), and topside shape parameter (k). Note that the $B2bot$ differ from the $B0$ of the IRI model and Digisonde, but they represent the thickness parameters of bottomside ionosphere. In the present study, an equation in Zhang et al. [6] and the observed parameters of Digisonde are utilized together to compute the ITEC as described in Section III. This concept is a new idea and a promising method for computing ITEC, which can be applied to GNSS, aviation and disaster prevention.

II. DATA USED

Data employed in this paper are hourly median values of $hmF2$ (F2 layer peak height), $M(3000)F2$ (F2 layer propagation factor), $foF2$ (F2 layer critical frequency), ITEC, and $B0$ at Grahamstown station, South Africa (33.3°S, 26.5°E; LT = UTC+2). Its location is illustrated in Fig. 1. Here, the ionospheric data were downloaded from DIDBase web site via <http://giro.uml.edu/didbase/scaled.php> [13]. The studied date is on March 5th, 2005 which is selected primarily as an example about the possibility of computing the ITEC values based on the expression in [6] and the Digisonde-based observation. Furthermore, the proposed ITEC values are compared with the Digisonde-based ITEC and the IRI2016-predicted TEC at Grahamstown.



Fig. 1. Location of Grahamstown, South Africa in black box.
(Source: <https://www.bing.com/maps?q=grahamstown+map> [14])

III. METHODOLOGY

NeQuick 2 model has provided TEC, ionospheric electron density, etc. at a given date, time, height, and location. This model was characterized by Epstein function where its major variables are the main parameters are bottomside thickness parameter ($B2bot$) and topside shape parameter (k). These two parameters show a close relationship between topside ionosphere and bottomside ionosphere. In the past, Zhang et al. [6] presented an important analytical equation for the NeQuick model as follow.

$$TEC = 2(1 + k)NmF2 \times B2bot, \quad (2)$$

where $B2bot$ denotes the thickness parameter of bottomside ionosphere and TEC denotes the observed VTEC at a considered location.

A. The $B2bot$ Computation of the NeQuick model

Primarily, the $B2bot$ in [2] can be calculated using these two below equations [7].

$$B2bot = \frac{0.385 \cdot NmF2}{\max(\frac{dNe}{dh})} \quad (3)$$

$$\max(\frac{dNe}{dh}) = (0.01) \cdot \exp\{-3.467 + 0.857 \ln(foF2^2) + 2.02 \ln(M(3000)F2)\} \quad (4)$$

where N represents the bottomside electron density (electron/m³) and $NmF2$ can be computed by the following equation [8]:

$$NmF2 = 1.24 \times (foF2)^2 \times 10^{10} \quad (5)$$

where $foF2$ is in unit: MHz. Meanwhile, k is the topside shape parameter [9] that is calculated using the following expression:

$$k = 3.22 + 0.0538 foF2 - 0.00664 hmF2 + 0.113 \frac{hmF2}{B2bot} + 0.00257 Rz12. \quad (6)$$

B. The proposed bottomside thickness parameter

Primarily, the $B2bot$ in (2) was considered separately with the observed GPS TEC in (1). In this present study, we have extended our previous study in [5] by considering the constant “2” in (1) with a new variable “ m ” and also rearranging (1) in a term of slab thickness (τ) as proposed in [5]. While considering $m = 1$, the new equation of bottomside thickness parameter proposed in this work is shown in a below equation:

$$B2bot_Pro = \frac{\tau - 0.113 hmF2}{P}, \quad (7)$$

where τ represents a slab thickness (unit: km) which can be determined by (8) and P , representing some terms in (6) which does not include term $B2bot$, is shown in (9).

$$\tau = \frac{TEC}{NmF2} \quad (8)$$

$$P = 4.22 - 0.0538 foF2 - 0.00664 hmF2 + 0.00257 Rz12 \quad (9)$$

Note that the variable “ m ” represents the ratio of any TEC values at any heights and the GPS TEC at 22,000 km. In this case, the $m = 1$ means the ITEC (ionogram-based TEC) value.

The ITEC details are described additionally in Subsection C. Further details for deriving (7) can be found thoroughly in [5]. Since it is not possible to have the observed ionospheric data from Digisonde and the observed GPS TEC from GNSS receiver over the globe, we have decided to utilize all of the observed parameters from the GIRO database (DIDBase web site). Moreover, the GIRO database and the famous IRI model represent the bottomside thickness parameter in a term of “B0”, hence, the B2bot_Pro in (7) is replaced with the B0_Pro for the consistency.

C. The proposed TEC

Refer to the studied results in [10], they disclosed that in general, the variations of ITEC behave the same trends as that of the observed TEC obtained from the TOPEX satellite as well as the IGS TEC. Also, we consider that the TEC in (1) is less than the GPS TEC as shown in Section IV. Hence, we proposed the variable “m” to represent the ratio between the GPS TEC with 22,000 km height and any TEC values with any heights. Surprisingly, if we considered “m = 1”, the TEC in (1) is equal to the approximated ITEC value as shown in Section III. The approximated ITEC proposed in this present work can be computed by the following equation:

$$\text{ITEC_B0_Pro} = NmF2 * B0_Pro * (1 + k). \quad (10)$$

Therefore, the variable “m” can be obtained as follow.

$$\text{TEC_sim} = m * (\text{ITEC_B0_Pro}). \quad (11)$$

Here, the TEC in (10) is considered as the simulated TEC that can be computed easily using the approximated ITEC. The TEC_sim might be the observed TEC values up to the interested TEC values of any instruments such as GPS TEC, IGS TEC, etc. Hence, it is out of scope for the present study.

IV. STUDIED RESULTS AND SOME DISCUSSIONS

The comparisons among the studied bottomside thickness parameters and TEC values are conducted in this section. Fig. 2 shows the hourly median values of bottomside thickness parameters on March 5th, 2005, at Grahamstown, South Africa. This selected date is only an example to study a new equation for computing the ionogram-based TEC value (ITEC). The GPS TEC at Grahamstown on this date can be obtained from [11]. Also, the IRI-predicted B0 with ABT-2009 (namely, B0_IRI) is selected for studying the B0_IRI in this work and can be downloaded from the IRI-2016 web site [12]. Likewise, the maxima and minima along with their occurrence times for all of the studied bottomside thickness parameters are illustrated in Table 1 and Table 2 shows the maximum and minimum differences in conjunction with their occurrence times for all of the studied bottomside thickness parameters.

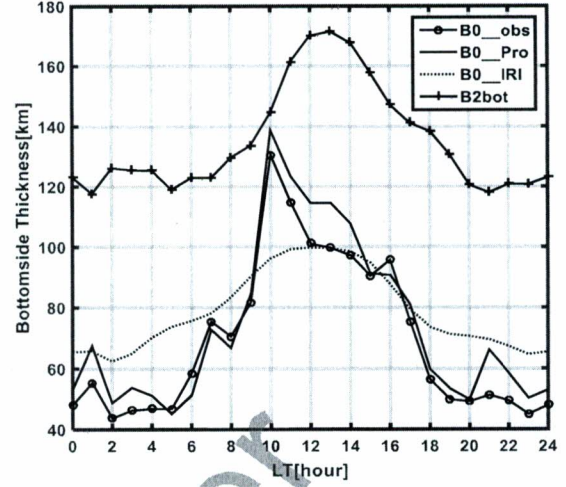


Fig. 2. Variations of bottomside thickness parameter on March 05th, 2005.

Table 1. The daily median values of the bottomside thickness parameters.

Values (km)	B0_obs	B0_Pro	B0_iri	B2bot
Maxima (Occurrence time)	130.55 (10 LT)	138.74 (10 LT)	99.80 (12 LT)	171.61 (13 LT)
Minima (Occurrence time)	43.80 (02 LT)	45.11 (05 LT)	62.50 (02 LT)	117.69 (01 LT)

Table 2. Differences among the studied bottomside thickness parameters.

Values (km)	B0_obs - B0_Pro	B0_obs - B0_iri	B0_obs - B2bot
Maximum Differences (Occurrence time)	14.78 (13 LT)	34.25 (10LT)	82.45 (02 LT)
Minimum Differences (Occurrence time)	0.57 (20 LT)	0.20 (13LT)	14.53 (10 LT)

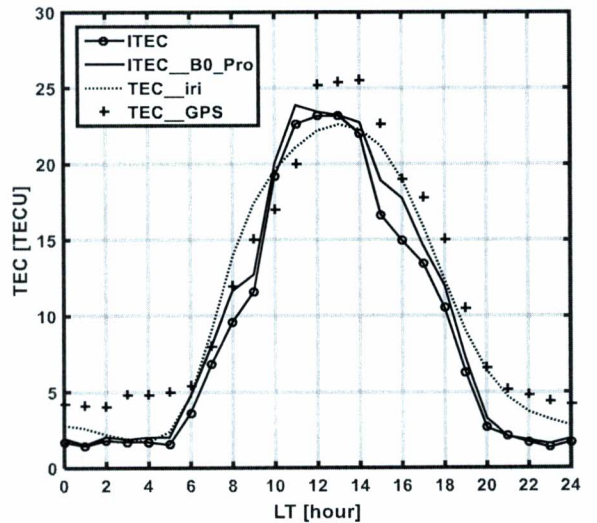


Fig. 3. Variations of the TEC values on March 05th, 2005.

Table 3. The daily median values of the TEC values.

Values (km)	ITEC	ITEC_B0_Pro	TEC_iri
Maxima (Occurrence time)	23.20 (13 LT)	23.88 (11 LT)	22.60 (13 LT)
Minima (Occurrence time)	1.35 (23 LT)	1.53 (01 LT)	1.70 (04 LT)

Table 4. Differences among the studied TEC values.

Values (TECU)	ITEC- ITEC_B0_Pro	ITEC- TEC_iri	TEC_iri - ITEC_B0_Pro
Maximum Differences (Occurrence time)	2.82 (17 LT)	5.80 (10 LT)	4.65 (10 LT)
Minimum Differences (Occurrence time)	0.02 (22 LT)	0.00 (05 LT)	0.00 (04 LT)

In Figure 2, the B0_Pro are comparable to the B0_obs, and also behave the same diurnal variations as the B0_obs obviously compared to the original B2bot and the B0_iri. The maximum absolute difference between the B0_obs and the B0_Pro is lowest of 14.78 km. Also, the minimum absolute differences between the B0_obs and the B0_Pro/the B0_IRI are lowest of 0.57/0.20 km, respectively. Note that the derivation of B2bot differs from the B0_IRI, so the value and the diurnal variation of B2bot are quite different from those of B0_IRI. We also show the B2bot value in order to show the B2bot derivation of (1) in this work.

Figure 3 shows the hourly median values of TEC values on March 5th, 2005, at Grahamstown, South Africa. The IRI-predicted TEC (namely, TEC_iri) can also be downloaded from the IRI-2016 web site [14]. The maxima and minima along with their occurrence times for all of the studied TEC values are illustrated in Table 3. Furthermore, Table 4 shows the maximum and minimum differences in conjunction with their occurrence times for all of the studied TEC values. In Figure 3, both the TEC_B0_Pro and the TEC_IRI are close to the ITEC as well as all of the TEC values behave similar variations, but the TEC_B0_Pro are closer to the ITEC. Here, the maximum absolute difference between the ITEC and TEC_B0_Pro is lowest of 2.82 TECU. The minimum ones among all of the TEC values are estimated closely to be 0.00 TECU at different local times. The observed GPS TEC in Fig. 3 are highest, because the GPS TEC are obtained from the integration of STEC for the total path from the ground toward the GNSS satellite. Also, the diurnal variation of TEC_GPS is also the same as those of other TEC values.

V. CONCLUSIONS

A new method for computing the ionogram-based TEC (ITEC) of Digisonde (ground-based observation) is proposed in this work. Here, the new variable "m" is used to modify the original equation of NeQuick 2 model. Our result shows that if $m = 1$, a new equation of bottomside thickness parameter (namely, B0_Pro) can be used to calculate the approximated ITEC successfully. The proposed ITEC is useful to be another

signature for alarming and preventing the disasters such as earthquake, tsunami. In the future, the validation of the proposed ITEC with the large observed data should be conducted. Also, the improvement of TEC_B0_Pro should be continued so as to be close to the GPS TEC and use it alternatively to correct the positioning errors for GNSS and aviation system or other space objectives.

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