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Proceedings of ICCIS 2021

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Preface

This book contains outstanding research papers as the proceedings of the 3rd International Conference on Communication and Intelligent Systems (ICCIS 2021), which was held on 18–19 December 2021 at National Institute of Technology Delhi, India, under the technical sponsorship of the Soft Computing Research Society, India. The conference is conceived as a platform for disseminating and exchanging ideas, concepts, and results of researchers from academia and industry to develop a comprehensive understanding of the challenges of the advancements of intelligence in computational viewpoints. This book will help in strengthening congenial networking between academia and industry. This book presents novel contributions in areas of communication and intelligent systems, and it serves as reference material for advanced research. The topics covered are intelligent system: algorithms and applications, intelligent data analytics and computing, informatics and applications, and communication and control systems.

ICCIS 2021 received a significant number of technical contributed articles from distinguished participants from home and abroad. ICCIS 2021 received 476 research submissions from 43 different countries, viz. Australia, Bahrain, Bangladesh, Brazil, Bulgaria, Burkina Faso, Chile, China, Ecuador, Egypt, Ethiopia, Finland, Germany, India, Iran, Iraq, Italy, Japan, Liberia, Malaysia, Mauritius, Morocco, Nepal, Oman, Poland, Portugal, Romania, Russia, Saudi Arabia, Serbia, Singapore, Slovakia, South Africa, South Korea, Sri Lanka, Thailand, Turkey, Ukraine, United Arab Emirates, UK, USA, Viet Nam, and Yemen. After a very stringent peer-reviewing process, only 92 high-quality papers were finally accepted for presentation and final proceedings.

This book presents novel contributions in areas of communication and intelligent systems, and it serves as reference material for advanced research.

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New Delhi, India	Vivek Shrivastava
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Positioning Comparison Using GIM, Klobuchar, and IRI-2016 Models During the Geomagnetic Storm in 2021

Worachai Srisamoodkham, Kutubuddin Ansari, and Punyawi Jamjareegulgarn

Abstract This paper compares the positioning accuracy obtained from the GIM VTEC, the Klobuchar model, and the IRI-2016 model at Chiang Mai and DPT9 stations, Thailand, during an intense geomagnetic storm of 2021 (on May 12, 2021). The results show that the diurnal variation of the Klobuchar modeled VTECs show the same trend as that of the observed GIM VTECs with the same peaks and the maximum deviation of 22.5% at 05:00 UT. Meanwhile, the IRI2016-predicted VTECs show its peak at 07:00 UT and are not available obviously during 13:00–21:00 UT due to the impact of this intense geomagnetic storm. Most of the ionospheric delays obtained from the Klobuchar model underestimate those of the GIM VTEC, whereas they overestimate those of GIM VTEC during after midnight and pre-sunrise period. At both stations, the mean ionospheric range delays of the GIM VTEC are highest during daytime period while those of the IRI-2016 model are largest during nighttime period. The positioning errors at higher latitude (CHMA station) are larger than those at lower latitude (DPT9 station).

Keywords GIM TEC · IRI-2016 model · Klobuchar model · Positioning

1 Introduction

The ionosphere is a layer of Earth's upper atmosphere ranging from 50 to 1,000 km. It is characterized by highly dynamical plasma density where the free ions and electrons

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affect largely both the refraction and the retardation of satellite signals. Hence, the ionospheric delay is one of the main error sources of the global navigation satellite systems (GNSSs), for example, GLONASS, Galileo, Beidou, QZSS, and GPS, etc., which have been employed increasingly for numerous applications. The ionospheric delay is proportional to the total electron content (TEC) along the line of sight (LOS), and inversely proportional to the signal frequency. Generally, the ionospheric error covers from a few meters to tens of meters at the zenith and can increase beyond 100 m under extreme space weather situations. The violence of delay errors relies on time of day, location, season, solar cycle, and other anomalies and irregularities [1–3]. The estimation failures of the ionospheric error make both the cycle slip correction and the ambiguity resolution more difficult and result in positioning errors in long baseline solutions [4]. It is well known that the ionospheric delay can be eliminated by using range measurements for any dual-frequency GNSS receivers. In contrast, it can be compensated to get the actual positions using the ionospheric models for single-frequency GNSS receivers. Models using ionospheric parameters broadcasted along with navigation messages have been widely employed to mitigate the ionospheric influences on signal propagation for the users of single-frequency GNSS receivers.

The ionospheric delay can be mitigated up to different levels based on various ionospheric error mitigation techniques. The main solution to neglect the ionospheric effects can be conducted by considering the GNSS observation during nighttime period, which assumes that the ionospheric condition is almost quiet. The most widely used model for single-frequency GPS receiver is the Klobuchar model [5]. Klobuchar developed an algorithm to give 50% root mean square correction for the ionospheric delay. The coefficients were computed from an empirical model of global ionospheric behaviors as functions of solar activity and time of year and broadcasted through the GPS navigation message. It can be used to compute a slant ionospheric delay to each satellite at various elevation and azimuth directions that are then applied to determine the final pseudoranges. However, the accuracy of Klobuchar model is deteriorated because of the intensities of solar activity and geomagnetic storm.

Thailand is located close to the geomagnetic equator within the equatorial ionization anomaly (EIA) region at $\pm$ 15° in latitude where the TEC often fluctuates and can be affected by the geomagnetic storm. So, the positioning accuracy can be deteriorated at the EIA region [6]. Hence, this paper is aimed to identify the positioning accuracy of Klobuchar model and IRI-2016 model during the most intense geomagnetic storm of this year till now (on May 12, 2021) over Thailand region.

2 Data Used

The raw data on an intense geomagnetic storm of year 2021 (storm level G3, Ap = 42 and Kp = 7 between 12:00 and 18:00 UT) were gathered from the GNSS stations at Chiang Mai, namely CHMA (lat. 18.84°N, long. 98.97°E) and DPT9 (lat. 13.76°N, long. 100.57°E) stations from Department of Public Work and Country

Planning. Afterward, the raw data were converted to the RINEX (Receiver Independent Exchange Format) files which include the navigation data, observation data, and Klobuchar coefficients. This information was employed to estimate the ionospheric delay as described in the next section. Moreover, the vertical total electron content (VTEC) values from Global Ionospheric Model (GIM) map were also employed in this paper that can be downloaded through a web site: https://urs.earthdata.nasa.gov/. Likewise, the VTEC values obtained from the IRI-2016 model were also used to compare with the GIM VTEC and Klobuchar modeled VTECs and can download from a web site: https://ccmc.gsfc.nasa.gov/modelweb/models/iri2016_vitmo.php.

3 Ionospheric Delay

Firstly, we start computing the ionospheric delay of Klobuchar model. The Klobuchar model has been utilized to compensate the GPS positioning accuracy for single-frequency GPS users since 1987. The GPS satellites broadcast eight coefficients of the Klobuchar model to estimate the ionospheric delay using two main issues as follows: (a) the electron content is assumed to be concentrated as a thin layer at the height of 350 km and (b) the slant delay is computed from the vertical delay at the ionospheric pierce point (IPP) multiplying by an obliquity factor. Mathematical equations for computing the ionospheric delay of Klobuchar ionospheric model can be thoroughly found in [7]. Here, we show shortly the equation to compute vertical ionospheric time delay (I_d) of L1 frequency (1.575 MHz) in unit: ns as follow:

$$\mathrm{I_{d\_Klo}} = \begin{cases} \left[5 \cdot 10^{-9} + A_I \cdot \left(1 - \frac{X_I^2}{2} + \frac{X_I^2}{24}\right)\right];\ |X_I| \leq 1.57 \\ 5 \cdot 10^{-9};\ |X_I| > 1.57 \end{cases} \tag{1}$$

where A_I and X_I are the amplitude and phase of the ionospheric delay, respectively.

Afterward, the VTEC of Klobuchar model ($\mathrm{VTEC_{KLO}}$) can be computed as follow.

$$\mathrm{VTEC_{KLO}} = \frac{\mathrm{I_{d\_klo}} \cdot c \cdot f_{L1}^2}{40.3} \tag{2}$$

where c is the light velocity.

Secondly, the GIM VTEC data ($\mathrm{VTEC_{GIM}}$) are routinely computed and stored in a large database owned by International GNSS Service (IGS). The ionospheric delay based on GIM VTEC data can also be determined by the following expression.

$$\mathrm{I_{d\_GIM}} = \frac{40.3 \times \mathrm{VTEC_{GIM}}}{c \cdot f_{L1}^2} \tag{3}$$

Thirdly, the IRI VTEC data ($VTEC_{IRI}$) are also retrieved from a large database owned by the NASA and NSF organizations. The ionospheric delay based on IRI VTEC data can also be calculated by the below expression.

$$I_{d\_IRI} = \frac{40.3 \times VTEC_{IRI}}{c \cdot f_{L1}^2} \quad (4)$$

As for Eqs. (3) and (4), we assume that the GNSS receivers can receive and process the $VTEC_{GIM}$ and $VTEC_{IRI}$ values and employ them to compute the I_{d_GIM} and I_{d_IRI} values, respectively.

4 Ionospheric Range Delay

The ionospheric range delay (I_r) of each considered model can be computed as follow.

$$I_{r*} = I_{d*} \times c \quad (5)$$

where I_{d*} represent the ionospheric delays of the observed GIM VTECs, the Klobuchar modeled VTECs, and the IRI2016-predicted VTECs, respectively; then, the I_{r*} denote the respective ionospheric range delays (i.e., I_{r_GIM}, I_{r_KLO} and I_{r_IRI}).

5 Results and Discussion

As for our experiments, we start calculating the ionospheric delays and VTEC values for all GNSS constellations at both CHMA and DPT9 stations over Thailand region during the most intense storm of year 2021 till now (on May 12, 2021). We find that the QZSS constellations can provide the best Klobuchar modeled VTEC values that behave the same trend as the GIM VTEC values. Therefore, all parameters related to the Klobuchar model in this paper are owned by the QZSS constellations. Firstly, the VTEC values obtained from the observed GIM, the Klobuchar model, and the IRI-2016 model are processed and analyzed. Their VTEC results are shown in Fig. 1 and Table 1. It is seen that the diurnal variation of the Klobuchar modeled VTECs shows the same trend as that of the observed GIM VTECs with the same peaks and the maximum deviation of 22.5% at 05:00 UT (12:00 LT). Meanwhile, the IRI2016-predicted VTEC values show differently its peak at 07:00 UT. Also, they are not available during 13:00–21:00 UT due to the impact of this intense geomagnetic storm.

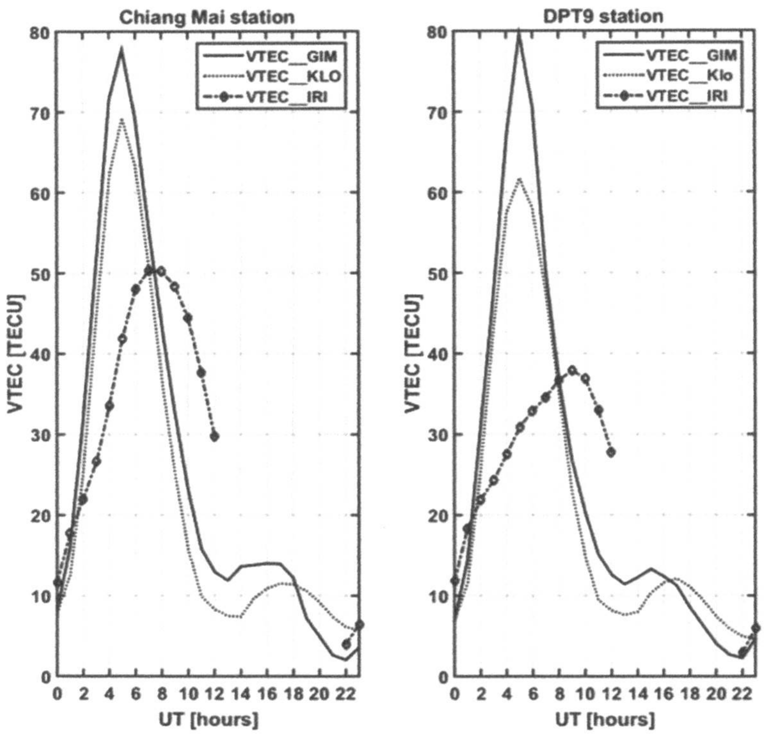

Fig. 1 The studied VTEC values obtained from CHMA and DPT9 on May 12, 2021

Table 1 The VTEC statistics (unit: TECU) of the observed GIM VTEC, Klobuchar model, and IRI-2016 models at Chiang Mai and DPT9 stations on May 12, 2021

Periods	VTEC statistics (occurrence time)	Chiang Mai station		
		Observed GIM	Klobuchar	IRI-2016
Daytime	Max. VTEC	77.75 (5 UT)	69.28 (5 UT)	50.3 (7 UT)
	Min. VTEC	8.16 (0 UT)	7.73 (0 UT)	11.6 (0 UT)
Nighttime	Max. VTEC	14.00 (16 UT)	11.49 (17 UT)	
	Min. VTEC	2.03 (22 UT)	5.72 (23 UT)	–
		DPT9 station		
Daytime	Max. VTEC	79.66 (5 UT)	61.73 (5 UT)	37.9 (9 UT)
	Min. VTEC	6.90 (0 UT)	6.90 (0 UT)	11.8 (0 UT)
Nighttime	Max. VTEC	13.29 (15 UT)	12.11 (17 UT)	–
	Min. VTEC	2.26 (22 UT)	4.65 (23 UT)	–

At both stations, the ionospheric delay statistics of the observed GIM are mostly higher than those of the Klobuchar model and the IRI-2016 model during the storm day. However, the ionospheric delays during the whole day at CHMA station are mostly larger than those at DPT9 station as shown in Fig. 2 and Table 2. It can be seen obviously that the ionospheric delays during daytime period are bigger than those during nighttime period because of the existence of photoionization process. Refer to the ionospheric delay differences between the GIM and Klobuchar models of these two stations, the maximum and minimum values during daytime period are about 4.59–9.70 ns around 5:00 UT and about 0.00 ns at 0:00 UT, respectively. Meanwhile, those values during nighttime period are smaller of 2.41–3.38 ns around 13:00 UT and about 0.00 ns at different hours, respectively. It is worthy to note that most of the ionospheric delays obtained from the Klobuchar model underestimate those of the GIM VTEC, whereas they overestimate those of GIM VTEC between 17:00 UT and 23:00 UT (00:00–06:00 LT). These results are good agreements with the results of Jongsintawee et al. [8].

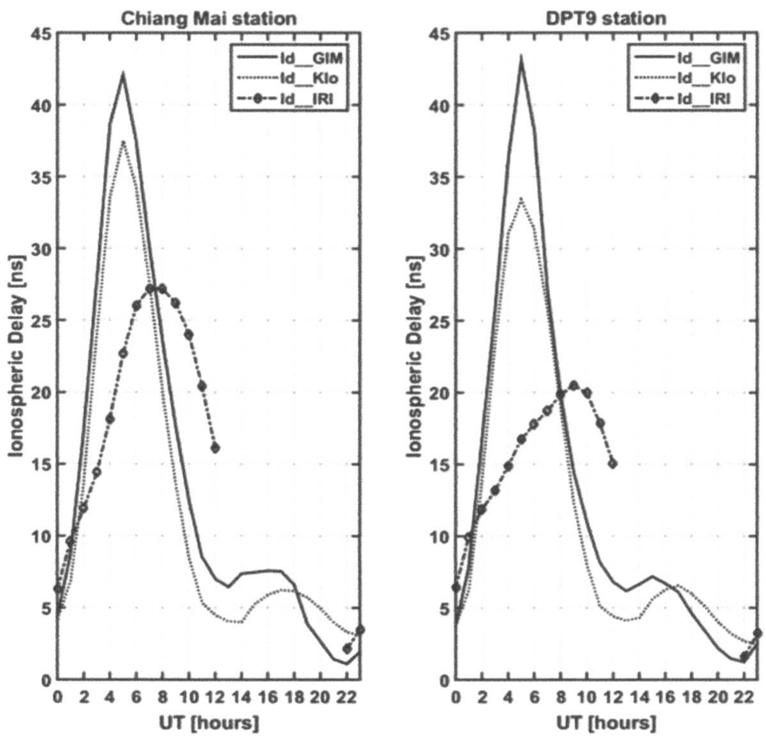

Fig. 2 The studied ionospheric delays for CHMA and DPT9 stations on May 12, 2021

Table 2 The ionospheric delays (unit: ns) of the GIM VTEC, Klobuchar model, and IRI-2016 models at Chiang Mai and DPT9 stations on May 12, 2021

Periods	Ionospheric delay statistics (Id)	Chiang Mai station		
		observed GIM	Klobuchar	IRI-2016
Daytime	Max. Id	42.08	37.50	27.22
	Min. Id	4.42	4.18	6.28
	Mean Id	22.41	19.11	19.50
Nighttime	Max. Id	7.58	6.22	–
	Min. Id	1.10	3.10	–
	Mean Id	5.09	4.76	–
		DPT9 station		
Daytime	Max. Id	43.11	33.41	20.51
	Min. Id	3.73	3.73	6.39
	Mean Id	21.02	17.78	15.64
Nighttime	Max. Id	7.20	6.55	–
	Min. Id	1.22	2.51	–
	Mean Id	4.59	4.57	–

As for the ionospheric range delays, the studied results are similar to the results of the ionospheric delays shown in Fig. 3 and Table 3. During daytime, the averaged range delays of the GIM VTEC are highest at both stations, while the averaged range delays of the IRI-2016 model are largest during nighttime period at both stations. Moreover, during daytime, the I_{r_GIM}, I_{r_KLO} and I_{r_IRI} at both stations behave the decreasing trend, respectively, as a result of the orderly lower VTEC values. Meanwhile, during night time period, the I_{r_IRI} values seem to be highest as compared to I_{r_GIM} and I_{r_KLO}, although the IRI-2016 data are not available on this geomagnetic storm. It can be seen clearly that the positioning errors at higher latitude (CHMA station) are larger than those at lower latitude (DPT9 station) as reported in Jongsintawee et al. [8].

6 Conclusion

This paper compares the positioning accuracy obtained from the GIM VTEC, Klobuchar model, and the IRI-2016 model at Chiang Mai and DPT9 stations over Thailand region during an intense storm on May 12, 2021. The VTEC variations of

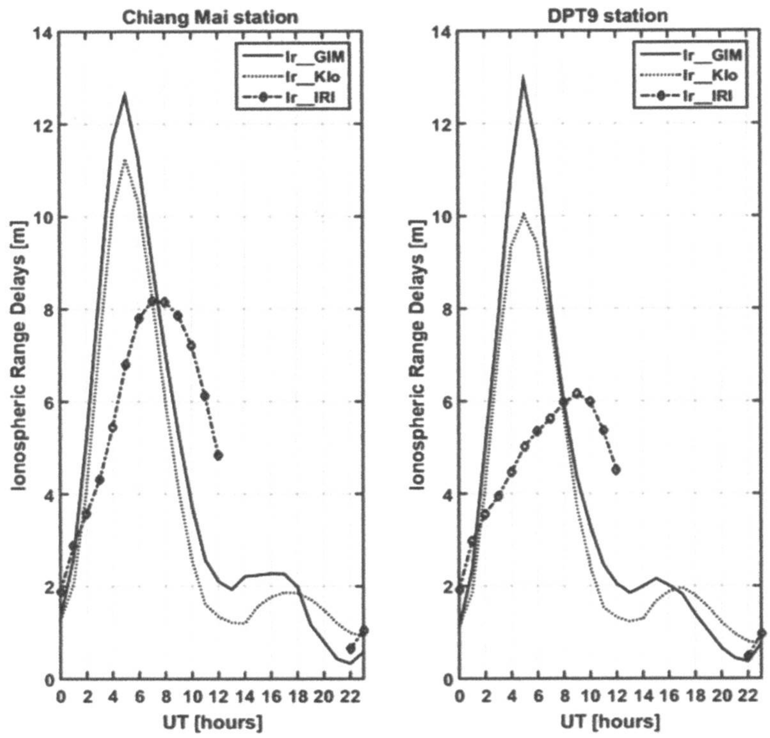

Fig. 3 The studied ionospheric range delays for CHMA and DPT9 stations on May 12, 2021

GIM map behave the same trend as those of the Klobuchar model, so the ionospheric delays and the ionospheric range delays behave the same trends as the VTECs. The results show that the Klobuchar model is suitably employed for compensating the ionospheric delays during 07:00–23:00 LT, whereas it should be improved during 00:00–06:00 LT due to the estimation beyond the GIM VTEC. Moreover, the IRI2016-predicted VTECs should be improved to be higher during daytime period and be more robust during the intense geomagnetic storm.

Table 3 The ionospheric range delays (unit: m) of the GIM VTEC, Klobuchar model, and IRI-2016 models at Chiang Mai and DPT9 stations on May 12, 2021

Periods	Ionospheric range delay statistics (Ir)	Chiang Mai station		
		observed GIM	Klobuchar	IRI-2016
Daytime	Max. Ir	12.62	11.25	8.17
	Min. Ir	1.32	1.26	1.88
	Mean Ir	6.72	5.73	5.85
Nighttime	Max. Ir	2.27	1.87	–
	Min. Ir	0.33	0.93	–
	Mean Ir	1.53	1.43	–
		DPT9 station		
Daytime	Max. Ir	12.93	10.02	6.15
	Min. Ir	1.12	1.12	1.92
	Mean Ir	6.31	5.33	4.69
Nighttime	Max. Ir	2.16	1.97	–
	Min. Ir	0.37	0.75	–
	Mean Ir	1.38	1.37	–

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