An Investigation of the Effect of Ionospheric Models on Performance of Network-Based RTK GPS in Thailand

Charoenkalunyuta, T.,[1] Satirapod, C.,[1] Li, Y.[2] and Rizos, C.[2]
[1]Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330 Thailand, E-mail: teeratat.c@student.chula.ac.th, chalermchon.s@chula.ac.th
[2]School of Surveying & Geospatial Engineering, UNSW, Sydney, Australia
E-mail: yong.li@unsw.edu.au, c.rizos@unsw.edu.au
Corresponding author: Chalermchon Satirapod

Abstract
Thailand established a Network-based Real Time Kinematic (NRTK) GPS system using the Virtual Reference Station (VRS) concept in 2008. Currently the Thai NRTK consists of 11 reference stations located in the central part of Thailand with average reference station spacing of about 60 km. (Charoenkalunyuta et al., 2012) suggested that the ionospheric bias is the main error source which degrades NRTK performance in Thailand since the rate of ambiguity-fixing is significantly decreased when an irregular ionospheric variation occurs. In this paper, the position performance of NRTK is tested with a large number of GPS observations (31 consecutive days) and different reference receiver spacing, 10-20, 30-50, 50-60 and 60-80 km, with the use of final Global Ionospheric Maps (GIM) from the Center for Orbit Determination in Europe (CODE) and all available Continuous GPS (CGPS) stations in the central part of Thailand. Test results indicate that the NRTK positioning performance is improved when the final GIM was used, especially in the case of large reference receiver spacing. Thus it is concluded that the final GIM can mitigate the ionospheric bias in the NRTK mode.

1. Introduction

Nowadays, the Network-RTK GPS (NRTK) is widely used in many countries. The main idea of this technique is to estimate distance-dependent errors (ionospheric delay, tropospheric delay and orbit biases) for each reference station, then generate the network corrections within the network coverage and transmit these directly to users. These corrections can be separated into dispersive (ionospheric-related) and non-dispersive (tropospheric and orbit-related) components (Lim et al., 2008). Dispersive component typically exhibit rapid changes with high variations due to the effect of free electrons in the ionosphere (Hernandes, 1999, Odijk, 2002 and Memarzadeh, 2009). On the other hand, the non-dispersive component changes slowly and smoothly over time due to the characteristic behavior of the tropospheric and orbit biases (Lim et al., 2008). In Thailand, the Department of Lands (DOL) has established since 2008 the Virtual Reference Station (VRS) - NRTK system mainly to support cadastral surveying applications. Currently, the DOL NRTK system comprises 11 reference stations located in the Central Plain region with spacing ranging from 27.8 to 125.6 km, and average spacing of around 60 km. Charoenkalunyuta et al., (2012) stated that the performance of NRTK in Thailand is highly dependent on the reference station spacing. Shorter reference station spacing yields better performance. To ensure the high performance, it is recommended that the reference station spacing should be kept less than 30 km. Previous studies (Satirapod et al., 2008 and Charoenkalunyuta et al., 2012) also suggested that the ionospheric bias is the main error source which degrades NRTK performance in Thailand. Since Thailand is in a low-latitude region, the ionospheric bias is highly problematic. This is due to the fact that, in a low-latitude region, the ionospheric activity is much higher than in mid-latitude regions (Musa, 2007 and Lim et al., 2008). Previous studies (Attaviriyasuwon et al., 2005, Gwal et al., 2004 and SEALION, 2012) have shown the high variation of ionospheric activity in Thailand region and confirmed that ionospheric irregularities usually occur at night time. There are several ionospheric models such as Klobuchar model, NeQuick, and the Global Ionosphere Maps (GIM). The Klobuchar model is broadcasted by the GPS navigation message. While, NeQuick is a real-time ionospheric correction model for the future

European Galileo navigation system and the GIM is the Global Ionospheric VTEC Maps that are produced routinely (Memarzadeh, 2009). Memarzadeh. (2009) investigated the performance of Klobuchar, NeQuick and GIM models under different ionospheric condition in the mid-latitude region. It was found that the best accuracy could be obtained with the GIM model under both quiet and severe ionospheric conditions. Moreover, Wienia (2008) studied the use of GIM for Precise Point Positioning. The results revealed that the horizontal position precision in the European region is at the three decimeter level. The vertical precision is about half a meter. Considering the ionospheric effect in this region, mitigating ionospheric bias through the using of GIM from the Center for Orbit Determination in Europe (CODE) may improve reliable and accurate positioning solutions of the NRTK especially because of the long average reference station spacing. This paper aims to test the performance of NRTK in the Thai region by incorporating the available Continuous GPS (CGPS) stations in the central part of Thailand with the aid of the final GIM. In the following sections, the final GIM are described, followed by the GPS data and software used. The data processing is then explained. Next, discussion of the test results is given. Finally, some concluding remarks are made.

2. Final Global Ionospheric Models (GIM)

The final Global Ionosphere Maps (GIM) are generated on a daily basis at The Center for Orbit Determination in Europe (CODE) using data from about 150 GPS sites of the International GNSS Service (IGS – http://igs.org) and other institutions. A value for the Vertical Total Electron Content (VTEC) is generated every two hours starting from 0 to 24 UTC time at the grid points in the IONEX (IONosphere map EXchange) format (Schaer, 1999). The resolution of the maps is 5° in longitude and 2.5° in latitude. The VTEC is modeled in a solar-geomagnetic reference frame using a spherical harmonics expansion up to degree and order 15. Piece-wise linear functions are used for representation in the time domain. To convert line-of-sight TEC into vertical TEC, a modified single-layer model mapping function approximating the Jet Propulsion Laboratory (JPL) extended slab model mapping function is adopted. The mapping function is evaluated at geodetic satellite elevation angles. For the computation of the ionospheric pierce points, a spherical layer with a radius of 6821 km is assumed, implying geocentric, not geodetic IONEX latitudes. The final GIM are made available with a delay of approximately 3 days. The VTEC provided by final GIM has a standard deviation of 2-8 TEC units (TECU) depending on the epoch in the solar cycle, season, and location. (CODE, 2012)

3. GPS Data and Software used

This research focuses on the benefit of final GIM on performance of NRTK in Thailand with different reference receiver spacing distances. The GPS datasets were those used as in the previous study (Charoenkalunyuta et al., 2012), i.e. datasets from the Department of Lands (DOL), the Department of Public Works and Town and Country Planning (DPT), the Royal Thai Survey Department (RTSD), the Thai Meteorological Department (TMD), S.D.M. Company Limited (SDM), and Chulalongkorn University (Figure 1). All stations operated dual-frequency geodetic-grade GPS receivers. For a reliable statistical analysis, common GPS observation periods for all CGPS stations between February 1^{st}, 2010 and March 3^{rd}, 2010 (31 days) were selected. The GPS data were sampled at a 30-second rate giving rise to a total of 89,280 epochs. Trimble Total Control (TTC) version 2.73, commercial post-processing software, was used to compute the coordinate solutions for roving receivers.

4. Data Processing

All test data were processed in an off-line mode. Although the rover stations are stationary, the processing is performed in kinematic mode. The processing consisted of three main steps. The first step was to establish the reference stations' coordinates using the BERNESE software, while the second step dealt with the generation of the VRS observations for different reference receiver spacing distances nearby each roving station (Figure 2). The final step was the post-processing of NRTK solutions between VRS observations (generated from the previous step) and the real observation of the stationary rover stations. The details of each step can be found in Charoenkalunyuta et al., (2012). However, in this study we introduce the final GIM to account for the ionospheric bias in the second step.

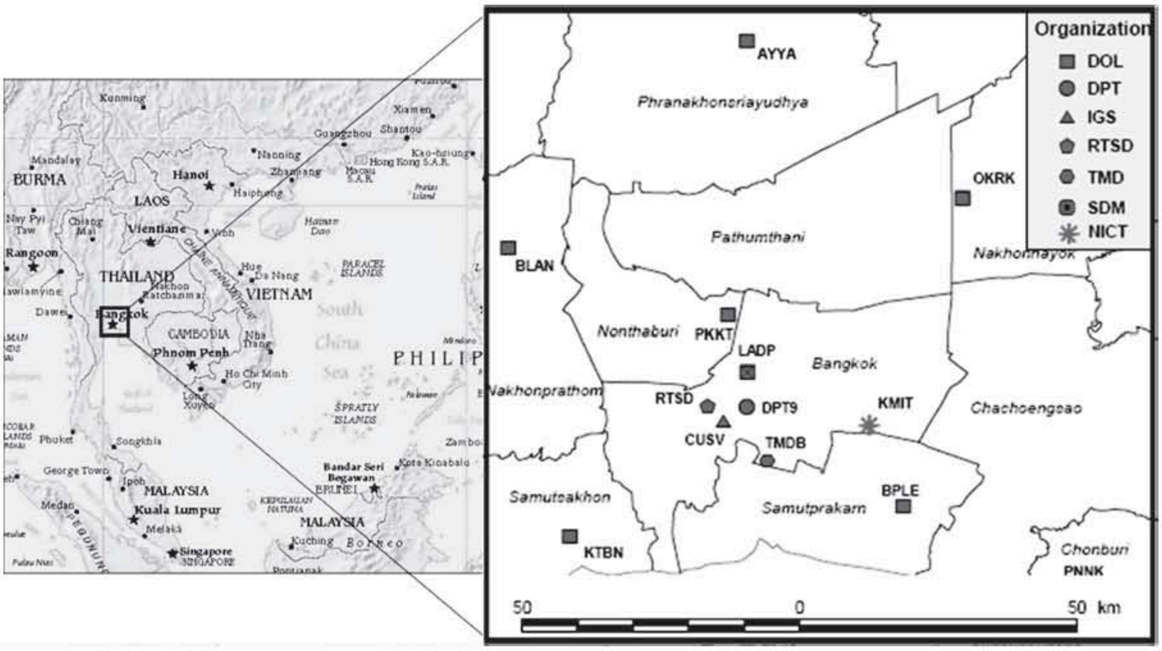

Figure 1: The location of CGPS stations used in this research (Charoenkalunyuta et al., 2012)

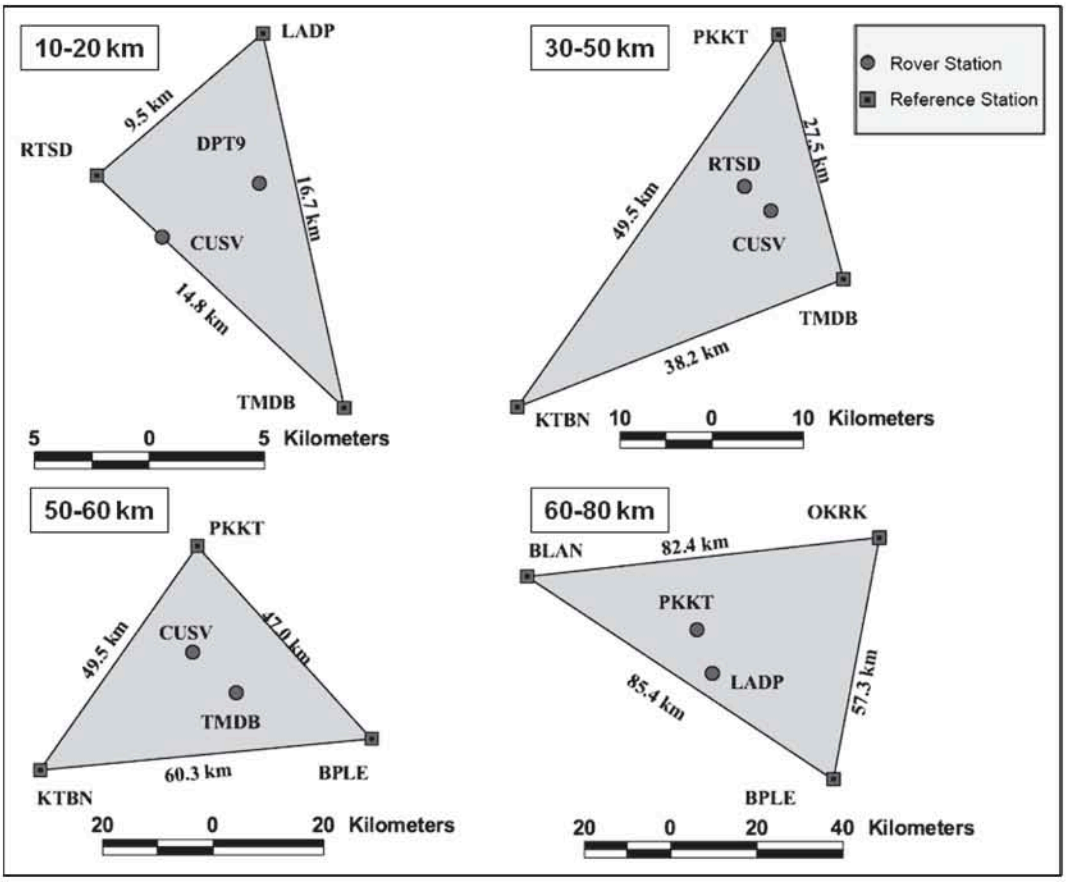

Figure 2: Four different reference station spacing and roving receivers (Charoenkalunyuta et al., 2012)

5. Test Results and Discussion

After all data were processed, the final coordinates were compared with the reference coordinates in both cases, i.e. with the use of the final GIM and without the use of the final GIM. The performance of the NRTK technique can be characterised by two main indicators: namely the rate of ambiguity-fixing and Root Mean Square Error (RMSE). The rate of ambiguity-fixing is the percentage of ratio between the ambiguity-fixed solutions and all data (89,280 epochs) used in processing. In this investigation, the RMSE in both cases (with and without the final GIM) is calculated separately for horizontal and vertical components. It should be noted that all indicators are the averaged values of the solutions obtained from two roving stations in each VRS triangle (Figure 2). These quality indicators are shown in Table 1. Further test comparisons are plotted in Figures 3 and 4.

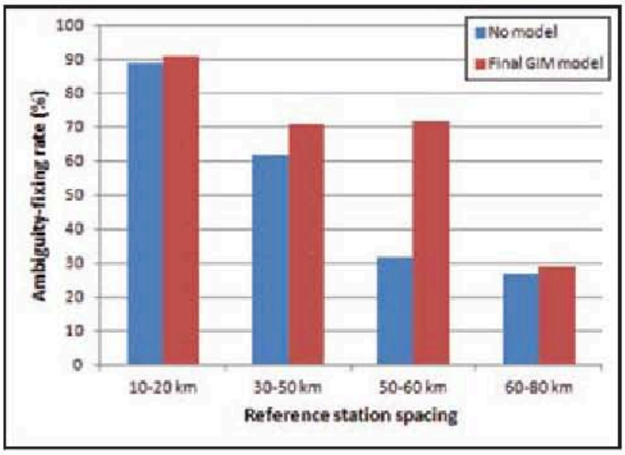

Figure 3: Ambiguity-fixing rate with and without GIM for different reference station spacing

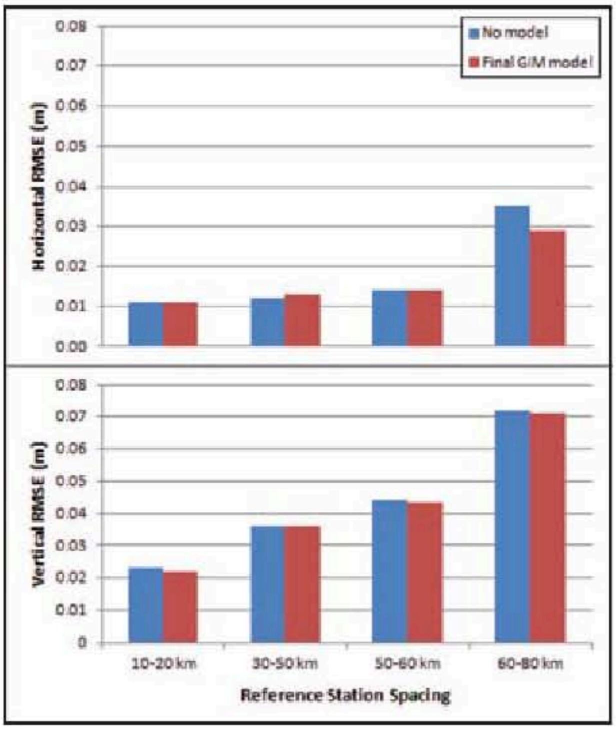

Figure 4: RMSE values obtained from different reference station spacing with and without GIM (Top: Horizontal RMSE. Bottom: Vertical RMSE)

Table 1: Summary of the performance of NRTK with and without final GIM for different reference station spacing

Reference receiver spacing	Amb.-fixing rate (%)		RMSE (m)			
	No model	GIM	No model		GIM	
			Hor.	Vert.	Hor.	Vert.
10-20 km	89	91	0.011	0.023	0.011	0.022
30-50 km	62	71	0.012	0.036	0.013	0.036
50-60 km	32	72	0.014	0.044	0.014	0.043
60-80 km	27	29	0.035	0.072	0.029	0.071

Table 1 shows that the performance of NRTK has been improved when the final GIM is used in all reference station spacing. Considering the rate of ambiguity-fixing (as illustrated in Figure 3), the use of the final GIM can significantly improve the NRTK performance in the middle reference station spacing (i.e. 30-50 km and 50-60 km) especially in the 50-60 km spacing the ambiguity-fixing was improved by the used of the final GIM from 32% to 72%. While, the 30-50 km spacing, it was improved from 62% to 71%. However, there is only a slight improvement for the case of the shortest (10-20 km) and the longest (60-80 km) reference spacing distances. This is due to the fact that the final GIM is the global model which may not be fitted to the small area. Therefore, the local ionospheric model is needed. In the case of RMSE values, the use of the final GIM can slightly reduce the RMSE values, as illustrated in Figure 4.

6. Concluding Remarks

In this paper the performance of NRTK in Thailand was tested using real GPS observations collected for 31 consecutive days. Based on the available GPS observations, four different reference station spacings of 10-20 km, 30-50 km, 50-60 km, and 60-80 km have been tested with and without the introduction of the final Global Ionosphere Maps derived from IGS data. Test results show that the performance of the NRTK is improved when the final GIM are introduced into the data processing step. This investigation confirms that the ionospheric error is the main error source which degrades the NRTK performance in Thailand since the rate of ambiguity-fixing is significantly improved when the final GIM is applied. Since the final GIM is a global ionospheric model, our future work will focus on the generation of the local ionospheric models to further improve the performance of NRTK in the Thai region.

Acknowledgements

This paper is based on a paper presented at the 33rd Asian Conference on Remote Sensing (ACRS2012), Chonburi, Thailand, 26-30 November 2012. This research is supported by the Graduate school and department of Survey Engineering, Chulalongkorn University Endowment Fund. The authors would like to thank the Department of Lands (DOL), Department of Public Works and Town and Country Planning (DPT), Royal Thai Survey Department (RTSD), Thai Meteorological Department (TMD) and S.D.M. Company Limited (SDM) for providing the CGPS data used in this study.

References

Attaviriyasuwon, R., Boonchuk, T., Leelaruji, N. and Hemmakorn, N., 2005, Observation of Ionospheric Height Changes at Chumphon near the Magnetic Equator. *The 5th Int. Conf. on Information Communications and Signal Processing (ICICS 2005)*, Bangkok, Thailand, 6-9 December, 1169-1172.

Charoenkalunyuta, T., Satirapod, C., Lee, H. K. and Choi, Y.-S., 2012, Performance of Network-Based RTK GPS in Low-Latitude Region: A Case Study in Thailand. *Engineering Journal*, 16(5), 9.

CODE, 2012, Center for Orbit Determination in Europe, Astronomy Institute University of Berne (AIUB). Website: http://aiuws.unibe.ch/ionosphere/

Gwal, A., Feliziani, A., Dubey, S., Wahi, R. and Gwal, A., 2004, Amplitude and Phase Scintillation Study at Chiang Rai, Thailand. *Advances in Space Research*. 38(2006), 2361-2365.

Hernandes, P. M., Juan, J. M. and Colombo, O. L., 1999, "Precise Ionospheric Determination and its Application to real-time GPS Ambiguity Resolution, *The 12th Int. Tech. Meeting of the Satellite Division of the ION, Nashville*, Tennessee, 14-17 September, 1409-1417.

Lim, S., Rizos, C. and Musa, T., 2008, Application of Running Average Function to Non-Dispersive Errors of Network-Based Real-Time Kinematic Positioning. *Journal of Global Positioning Systems*, 7(2), 148-155.

Memarzadeh, Y., 2009, Ionospheric Modeling for Precise GNSS Applications.", PhD Thesis, Delft Institute of Earth Observation and Space systems (DEOS). *Delft University of Technology*, The Netherlands, 208pp.

Musa, T., 2007, Residual Analysis of Atmospheric Delay in Low Latitude Region using Network-Based GPS Positioning", PhD. Thesis, School of Surveying & Spatial Information Systems. The University of New South Wales, Australia, 243.

Odijk, D., 2002, Fast Precise GPS Positioning in the Presence of Ionospheric Delays", PhD Thesis, Delft University of Technology, Delft, The Netherlands, 242.

Satirapod C., Chen, H. Y. and Prakhammintara, P., 2008, First Experiences of Automated Processing of Thai Permanent GPS Observations for Ground Deformation Monitoring and Earthquake Studies. *International Journal of Geoinformatics*, 4(4), 33-38.

Schaer, S., 1999, Mapping and Predicting the Earth's Ionosphere using the Global Positioning System. *Geod.-Geophys. Arb. Schweiz*, Vol. 59. PhD Thesis.

SEALION, 2012, The SouthEast Asia Low-latitude IOnospheric Network (SEALION) project. Website: http://wdc.nict.go.jp/IONO2/THAI-GPS/KMI/ROTI/

Wienia, R. J., 2008, Use of Global Ionospheric Maps for Precise Point Positioning. M.Sc Thesis., Delft Institute of Earth Observation and Space Systems (DEOS),Faculty of Aerospace Engineering. Delft University of Technology, the Netherlands. 132.