Performance of Ionospheric Error Mitigation Techniques for Single-Frequency GNSS Positioning in the South East Asian Region

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Key words: GNSS, ionosphere, single-frequency positioning

SUMMARY

The ionosphere layer of the Earth contributes a significant amount of error in GNSS positioning. The severity of ionospheric effects depends on time and location of GNSS receivers. Generally, ionospheric error ranges from 5 m to 15 m during noon time under high solar activities, especially in equatorial region, e.g. South East Asia. Users with dual-frequency L1 and L2 GNSS receivers can take the advantage of measurements from both frequencies to remove the effect but single-frequency receivers have to apply an ionosphere model for error mitigation. In this study, the performance of single-frequency GNSS positioning (relative and precise point positioning) in terms of positioning accuracy during low and high solar activity periods in South East Asia, is investigated. The investigation is conducted by exploiting different strategies for ionospheric modelling in Leica Geo Office software.

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1. INTRODUCTION

The ionosphere of the Earth is that band of atmosphere extending from about 50 to 1000 km above the Earth's surface in which the sun's Extreme Ultra-Violet (EUV) radiation and X-ray emission ionises gas molecules which then produces free electrons and ions (Klobuchar, 1996). The ionosphere layer contributes a significant amount of error in Global Navigation Satellite Systems (GNSS) positioning. The severity of ionospheric effects depends on time and location of GNSS receivers. Generally, ionospheric error ranges from 5 m to 15 m during noontime but it can exceed over 100 m under high solar activities, especially in equatorial region.

Users with dual-frequency L1 and L2 GNSS receivers can take the advantage of measurements from both frequencies to remove the effect but single-frequency (SF) receivers have to apply an ionosphere model for error mitigation. Empirical ionosphere models, for example, Klobuchar model (Klobuchar, 1987) is estimated to reduce about the 50% Root Mean Square (RMS) ionospheric range error worldwide. Alternatively, SF GNSS users can obtain ionospheric corrections from an external source such as Centre for Orbit Determination in Europe (CODE) Global Ionosphere Maps (GIM).

The performance of these models has been investigated in other regions under different solar activity conditions (Abdel Mageed, 2014; Adekunle, 2014). Hence, the focus of this paper is to examine the ionospheric modelling strategies in Leica Geo Office (LGO) software for SF GNSS pseudo- Precise Point Positioning (PPP) during low and high solar activity periods in South East Asia (SEA).

2. DATA AND METHOD OF ANALYSIS

2.1 Data and Area of Study

This study concentrates on South East Asia and adjacent area, which is located under low-latitude region as shown in Figure 1. The daily RINEX data from IGS stations in this region for the year 2015 day of year (DoY) 045 and DoY 067, which correspond to a day with low solar activity (K_p = 1) and the St. Patrick's Day 2015 geomagnetic storm (G4-class; K_p = 8), respectively, have been used in this study.

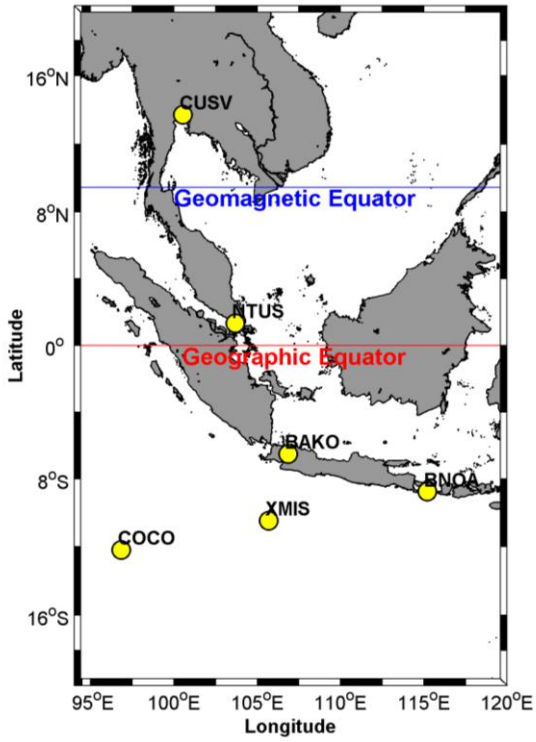

Figure 1. The location of IGS stations in South East Asian region.

2.2 Method of Analysis

For both days, SF GNSS pseudo-PPP solutions with different ionosphere modelling were obtained for each IGS stations using the processing parameters and strategy as shown in Table 1. Results were compared against its known ITRF coordinates for performance assessment.

Table 1. Processing parameters and strategy for SF GNSS solutions

Processing parameters	Processing strategy
Software	Leica Geo Office 8.4
Positioning mode	Static pseudo-PPP
Satellite system	GPS+GLONASS
Frequency	L1 only
Solution type	Smoothed pseudorange
Elevation cut-off angle	10 degrees
Sampling rate	30 seconds
Satellite ephemeris	IGS precise final orbit (SP3)
Tropospheric correction	Hopfield model
Ionospheric correction	Broadcast Klobuchar model, Computed model (Single-layer model), CODE Global Ionosphere Maps (GIM)

3. RESULTS AND DISCUSSIONS

3.1 Accuracy of SF GNSS Pseudo-PPP

The positional accuracy of SF GNSS pseudo-PPP is expressed in 3D position error. The results for DoY045 and DoY067 are tabulated in Table 2 and 3, respectively.

Table 2. 3D position error with different ionospheric models for DoY045

2015 DoY045	**3D Position Error [m]**			
	Ionosphere Modelling			
	None	**Klobuchar**	**Computed**	**CODE GIM**
CUSV	13.076	4.907	1.275	1.492
NTUS	13.392	5.213	0.933	2.307
BAKO	9.184	1.863	4.470	2.360
BNOA	8.654	0.554	4.298	2.235
COCO	11.633	4.438	1.729	1.438
XMIS	8.446	2.151	0.935	1.963
Average	10.731	3.188	2.273	1.966

Table 3. 3D position error with different ionospheric models for DoY076

2015 DoY076	**3D Position Error [m]**			
	Ionosphere Modelling			
	None	**Klobuchar**	**Computed**	**CODE GIM**
CUSV	13.329	4.106	1.931	1.313
NTUS	13.162	4.473	1.073	1.331
BAKO	9.877	1.591	3.311	1.917
BNOA	10.060	2.479	3.433	1.652
COCO	11.454	4.342	3.378	1.024
XMIS	11.664	4.180	2.562	0.834
Average	11.591	3.528	2.615	1.345

The largest error of 13.4 m was recorded for positioning without applying ionosphere model. All stations showed higher position error on DoY076 than DoY045 due to disturbed ionosphere condition. Similar trend can be observed for results with ionospheric modelling (Klobuchar and computed) except CODE GIM. Applying CODE GIM gave the lowest error about 1.3 m regardless of solar activity level. Local computed ionosphere model outperformed Klobuchar model as the model computed is in accordance with conditions prevalent at the time and position of observation. For better perspective, Figure 2 illustrates comparison between two selected days for each IGS stations. The accuracy of SF GNSS Pseudo-PPP in SEA region by averaging results from chosen IGS station is shown in Figure 3.

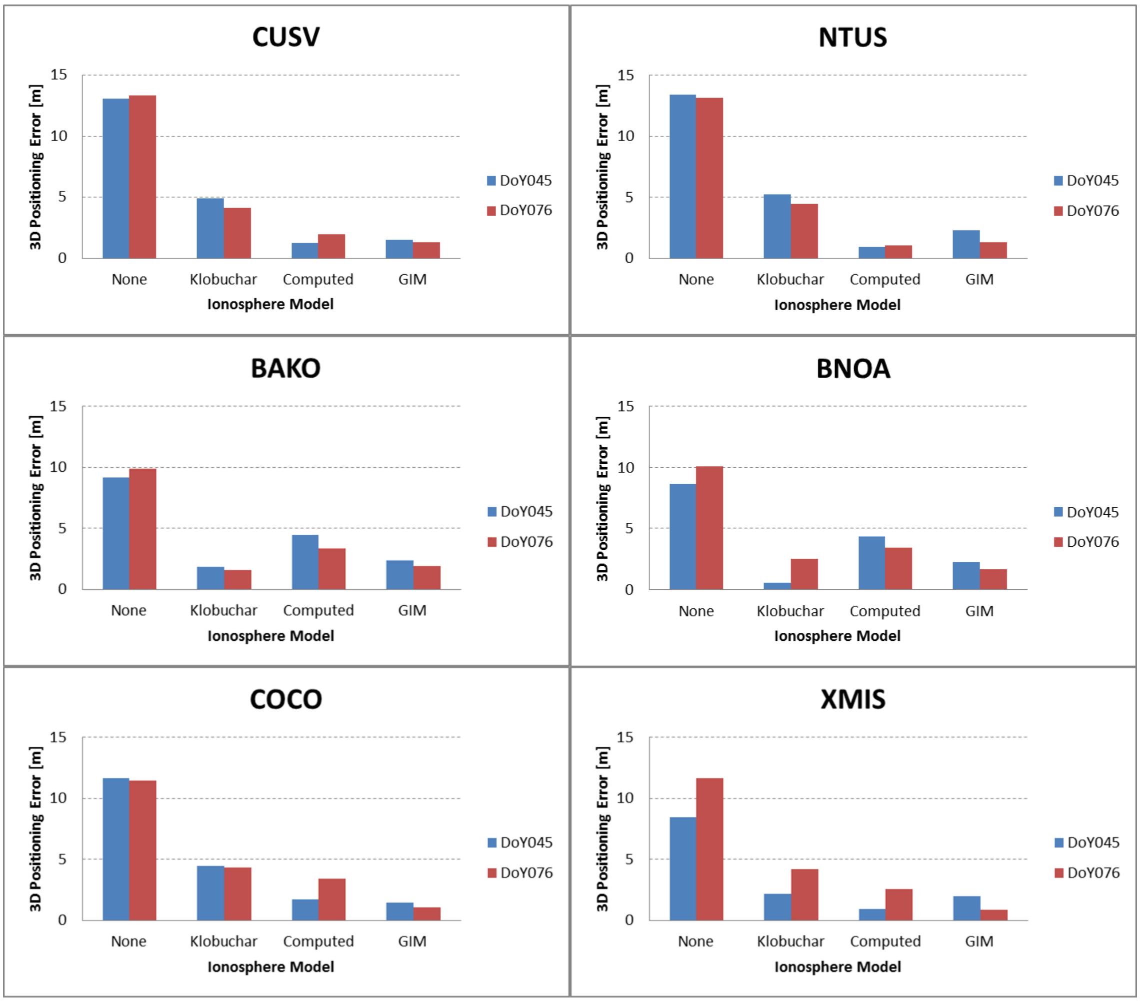

Figure 2. Accuracy of SF GNSS pseudo-PPP with different ionospheric modelling strategy during low (DoY045) and high (DoY076) solar activity periods for each IGS stations.

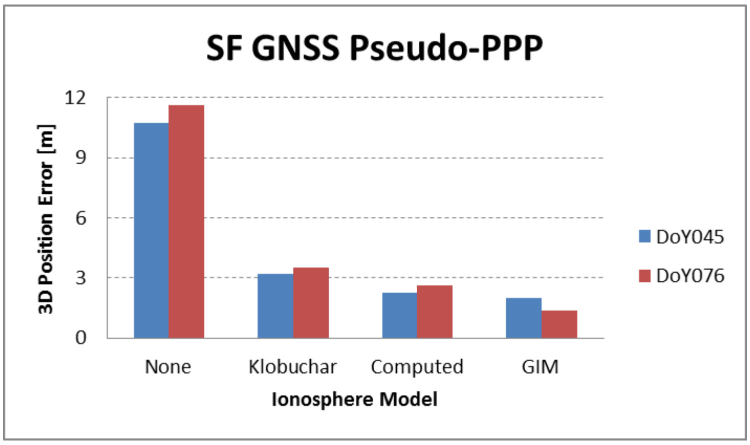

Figure 3. Mean accuracy of SF GNSS pseudo-PPP with different ionospheric modelling strategy during low (DoY045) and high (DoY076) solar activity periods.

3.2 Performance of Ionospheric Modelling in LGO

The percentage of improvement over solution without ionosphere correction for DoY045 and DoY067 are listed in Table 4 and 5, respectively.

Table 4. Improvement with different ionospheric models for DoY045

2015 DoY045	Improvement [%]		
	Ionosphere Modelling		
	Klobuchar	Computed	CODE GIM
CUSV	62	90	89
NTUS	61	93	83
BAKO	80	51	74
BNOA	94	50	74
COCO	62	85	88
XMIS	75	89	77
Average	72	77	81

Table 5. Improvement with different ionospheric models for DoY076

2015 DoY045	Improvement [%]		
	Ionosphere Modelling		
	Klobuchar	Computed	CODE GIM
CUSV	69	86	90
NTUS	66	92	90
BAKO	84	66	81
BNOA	75	66	84
COCO	62	71	91
XMIS	64	78	93
Average	70	76	88

Figure 4 gives an overview picture of improvement exhibited by applying respective ionosphere models for each IGS stations, whereas the mean percentage of improvement in SEA is shown in Figure 5. The improvement of about 70% in Klobuchar model, which is considerably low compared with other models, suggests that the simplicity of Klobuchar model did not capture the variation of equatorial ionosphere in this region, even during quiet condition. On the other hand, same level of improvement for local computed model was observed during both quiet and disturbed days. CODE GIM, which is generated on a daily basis at CODE using data from about 200 GPS/GLONASS sites of the IGS and other institutions, proves itself as a reliable source for ionospheric modelling as it consistently elevates positioning results with over 80% improvement despite severe geomagnetic storm.

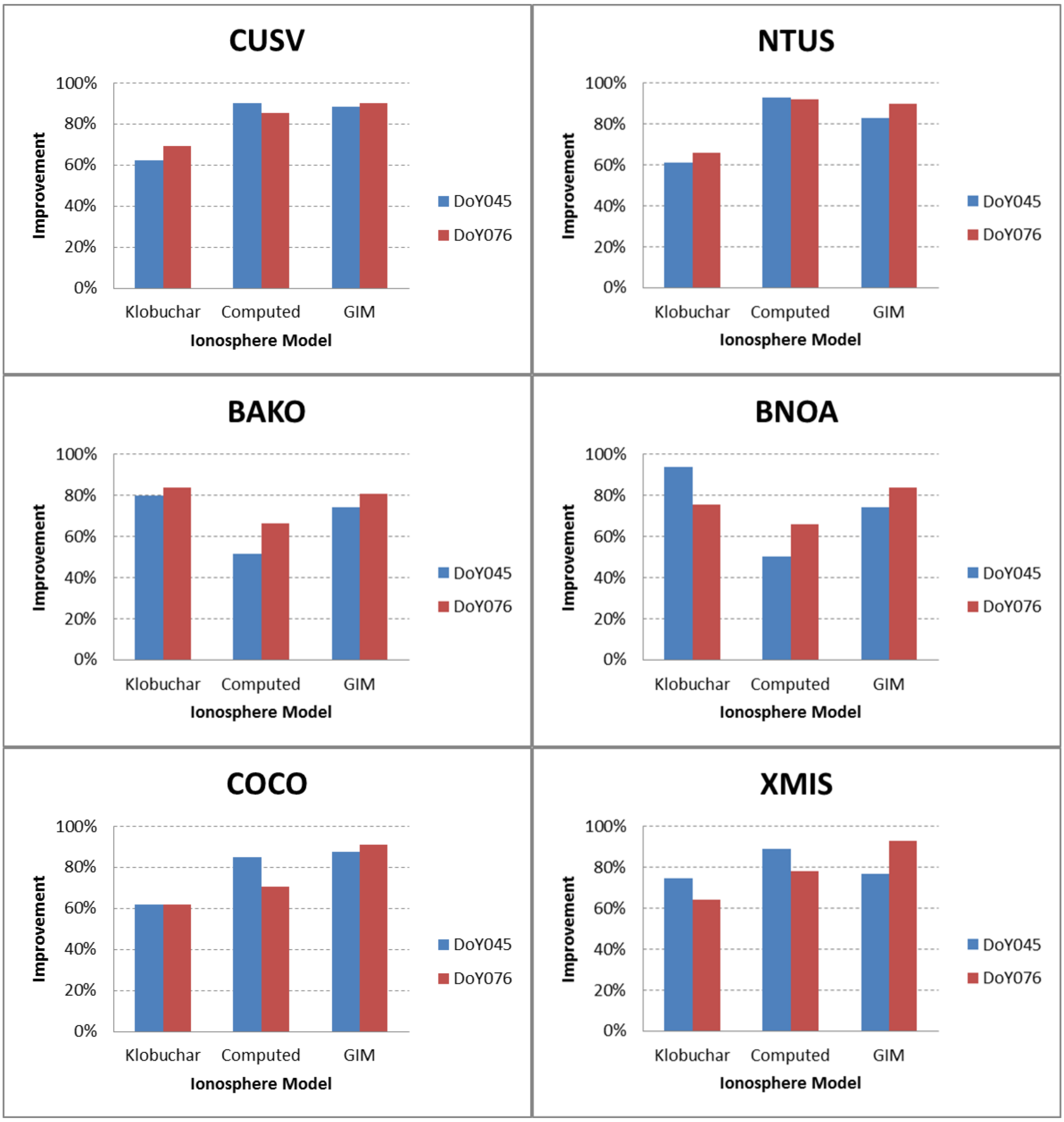

Figure 4. Improvement of positioning error exhibited by respective ionosphere models during low (DoY045) and high (DoY076) solar activity periods for each IGS stations.

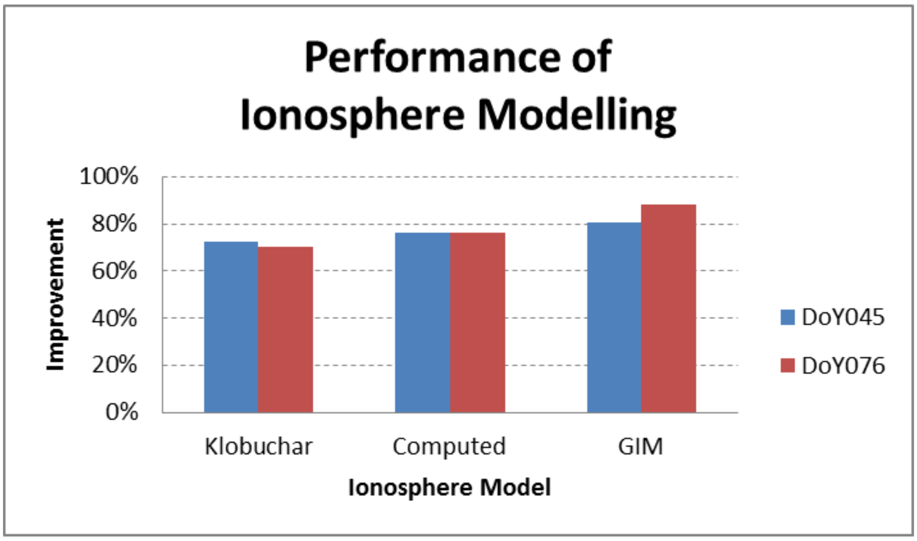

Figure 5. Mean improvement of positioning error exhibited by respective ionosphere models during low (DoY045) and high (DoY076) solar activity periods.

4. CONCLUDING REMARK

This paper presents the comparative study of SF GNSS pseudo-PPP solutions as estimated by applying three ionospheric models, i.e. Klobuchar model, local computed model and CODE GIM. Additionally, the performance in terms of percentage of improvement over solution without ionospheric correction demonstrated by these models was analysed. CODE GIM, which is generated on a daily basis at CODE using data from about 200 GPS/GLONASS sites of the IGS and other institutions, can be considered as a robust ionosphere model as it outperformed computed model that contains local information of ionosphere condition, and consistently elevates positioning results with over 80% improvement despite severe geomagnetic storm. With further enhancement, SF GNSS positioning with GIM shall stands out to be very advantageous, especially for user in sparse networks.

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BIOGRAPHICAL NOTES

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