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The Performance of GPS Baseline Solution during Northeast Monsoon Season in Malaysia

Mohd Hafiz Yahya and Md Nor Kamarudin

***Abstract*— Bringing heavy rainfall particularly to the east coast states of Peninsular Malaysia and western Sarawak, Northeast Monsoon occurs from November to March each year. Variability of tropospheric refractive indices caused by the inhomogeneity of dry gases and water vapour throughout this seasonal weather period induces latency in the satellite-to-receiver radiowave signal transmission. To date, Global Positioning System (GPS) has been responsible much of the local fast growing infrastructures, covering from the low cost and recreational uses to highly accurate and professional applications. As proper functioning of this space-based radio navigation satellites system receiver requires uninterrupted signal reception from at least four simultaneously available satellites, this paper examines the performance of GPS baseline solutions associated with relative positioning during the Northeast Monsoon period. Result shows that discrepancies on the computed three dimensional vectors can be expected during the Northeast Monsoon season. Better result in the GPS positioning can be expected based from the relatively short baseline compared to the long baseline. By examining the effect of the Saastamoinen model and the Hopfield model in data processing, these global tropospheric models tend to improve the ratio, reference variance and root mean square (RMS) in GPS baseline solutions. Nevertheless, no statistical differences can be seen based on the comparative analysis between these models on the result.**

***Keywords*:** GPS, Northeast Monsoon, tropospheric refractive indices

I. INTRODUCTION

Global Positioning System (GPS) is a satellite-based positioning system that nominally consists of 32 satellites, arranged in nearly circular orbital planes at altitudes of about 22,000 km above the ground. This all-weather multi-satellites system provides real time three-dimensional positioning (X, Y, Z or latitude, longitude and height), velocity information and time in common reference system 24-hour a day. To date, GPS has been widely used by most professionals and practitioners around the globe to support various applications such as navigation, surveying, mapping and engineering. For highly precise applications (i.e. landslide detection, petrology and deformation monitoring), the accuracy of the GPS measurement is however, often complicated by the variability of the refractive indices within the troposphere. The troposphere is the first layer of the Earth atmosphere where most of the world's weather takes place. In addition to the tropical storms and the El-Nino and La Nina phenomenon, monsoon is one of the anticipated and inevitable weather events which influence not only the agricultural cycle and human well-being, but also many economic and societal activities. Malaysia is mainly characterized by two monsoon regimes: the Southwest Monsoon and the Northeast Monsoon. As it relatively signifies drier weather with most states experience minimum monthly rainfall, the Southwest Monsoon normally occurs from late May to September. Bringing heavy rainfall particularly to the east coast states of Peninsular Malaysia and western Sarawak, the Northeast Monsoon on the other hand occurs from November to March each year.

Spatial and temporal variability of refractive indices due to the presence of dry gases and water vapour during these seasonal weather periods induces latency in the propagation of the radiowave transmission. The effect is significantly strong especially within the equatorial region (e.g. Malaysia) where the troposphere is notably thicker compared to any other regions. The high and variable water vapour content, particularly within the equatorial troposphere may exacerbate the effect even further [1]. Positioning error due to improper modelling of the tropospheric effect itself can range from 2 m at zenith to over 20 m at lower elevation angles [2]. Careful modelling of the effect therefore should be carried out to achive high accuracy positioning especially in a condition where the relative height differences (between base and rover receivers) are excessively high [3], [4]. Several attempts have been made to model the troposphere for atmospheric and signal propagation studies. These models were experimentally derived with correspond to radiosonde data and water vapour radiometers, observed mostly on the European and the North American continents. Divided into hydrostatic and wet components,

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examples of the tropospheric delay models include Hopfield (1969), Davis et al. (1985), Baby et al. (1988), Saastamoinen (1973), Ifadis (1986) and Mendes & Langley (1998). Detail expressions of the models can be referred in [5].

The tropospheric effect is a distance-dependent error that increases when the baseline length between two GPS stations increases [6]-[8]. It is noted that a large height difference can introduce a bias of the order of 2 to 5 mm per 100 m height difference [9]. Changes up to 1 cm in range of signal propagation delay can been expected if differences in station height range up to at least 50 m above the mean sea level [7], [8]. This paper examines the performance and the variations of the GPS baseline solutions associated with relative positioning during the Northeast Monsoon period. Discussions were made on the computed three-dimensional vectors i.e. ratio, reference variance and root mean square (RMS), based on series of Malaysian Real Time Kinematic Network (MyRTKnet) data over the year of 2006.

II. THE EXPERIMENT

A. DATA ACQUISITION

To study the influence of the seasonal Northeast Monsoon event towards the performance of GPS positioning, two sets of RINEX data retrieved from five MyRTKnet reference stations namely Johor Jaya (JHJY), Kluang (KLUG), Mersing (MERS), Melaka (JUML) and Meru (MERU) were used (see figure 1). As one set represents twelve days of RINEX data during Northeast Monsoon of 2006, another set represents twelve days of RINEX data during Inter Monsoon period over the same year. The Inter Monsoon in general occurs during the two transition periods; April to early May and September to October. As all selected MyRTKnet stations are well-equipped with 5700 Trimble dual frequency geodetic GPS receivers with Zephyr Geodetic type antennas, the quality of data retrieved from these stations is expectedly high. Located at the southern part of the Peninsula Malaysia, JHJY was selected as a reference in relative to other corresponding stations. The distance between KLUG, MERS, JUML and MERU stations in relative to JHJY are respectively sufficient to signify short baseline (76 km), medium baseline (101 km), long baseline (187 km), and very long baseline (319 km).

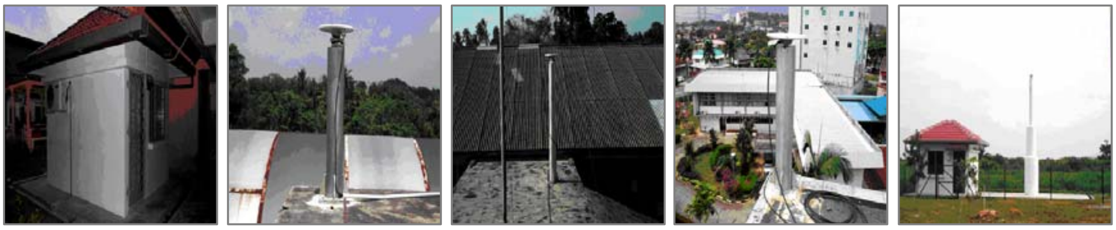

Figure 1: Overviews of the MyRTKnet Stations.

B. MULTI-STATION ANALYSIS

Even under the full constellation of the GPS satellites, there are some periods where the visibility of the GPS satellites is limited for extended periods or simply unavailable throughout an observation campaign. Fortunately, due to the nature of the GPS constellation, it is suggested that problem in satellite visibility is most likely to be detected at high latitudes region compared to the equatorial region [10]. Signal outages situation however can also happen within the dense canopy area or in the inner city streets of urban areas line with huge buildings and skyscrapers. Similarly, as far as the satellite-receiver geometry is concerned, good geometry is obtained when the satellites are well-distributed (spread out) within all receiver observational quadrants. Commonly measured using a single dimensionless number namely the geometry dilution of precision (GDOP), less number of GDOP provides better result in the positioning accuracy. GDOP that is fewer than six is often considered as within an excellent geometry. Figure 2 depicts the multi-station analysis based on the satellite visibility and the GDOP values over aforementioned MyRTKnet stations at an elevation angle of 20˚ during the Northeast Monsoon and the Inter Monsoon of 2006. Based on the result, it is noted that the number of satellites visibility ranges from at least 8 to 12 satellites per day; that is more than enough as proper functioning of a GPS receiver only requires uninterrupted signal reception from at least four simultaneous satellites. Ranging from 2.0 to 3.8 per day, GDOP values are also within an acceptable limit in which considerably sufficient to examine the performance of GPS during the monsoons period.

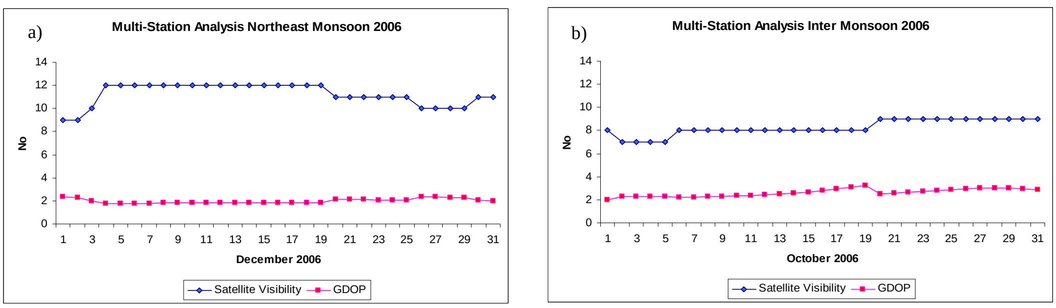

Figure 2: Satellite Visibility and GDOP during (a) Northeast Monsoon 2006 (b) Inter Monsoon 2006.

C. PROCESSING STRATEGIES

All baselines were processed at 24-hour batch processing intervals. As far as the ionospheric effect is concerned, ionosphere-free double difference solution were applied throughout the process. IGS earth rotation parameters (ERP) were used to mitigate the effect of the pole tides. Multipath effects on the other hand, were mitigated by excluding low elevation satellites during data processing. It is suggested that 20˚ of satellite elevation (cut-off angle) is sufficient as low elevation signals are more susceptible to the multipath and receiving antenna gain roll-off effects [11]. In place of the broadcast orbits, IGS precise orbits were used to mitigate the effect of the orbital errors (as well as other associated GPS errors).

III. ANALYSIS OF RESULTS

A. GPS BASELINE SOLUTION

To gauge the performance of GPS baseline solution, the quality of each data is estimated in term of ratio, reference variance and root mean square (RMS). Ratio is a measure of how well the processing software is able to determine fixed-integer solutions. A fixed-integer solution is obtained when the processor is able to find a set of integer values for the ambiguity. Reference variance on the other hand is a measure as to how well the baseline processor estimates the expected error. RMS values entails the degree to which the baseline residuals tend to spread about its average values. As higher number of ratio is considered better, smaller values for the reference variance and the RMS in the baseline solution tend to produce better results in GPS positioning. JHJY-JUML baseline was used to indicate the influence of seasonal monsoon towards the estimated three dimensional vectors. Without applying tropospheric model during data processing, figure 3 illustrates the computed ratio, the reference variance and the RMS during Northeast Monsoon and Inter Monsoon periods of 2006.

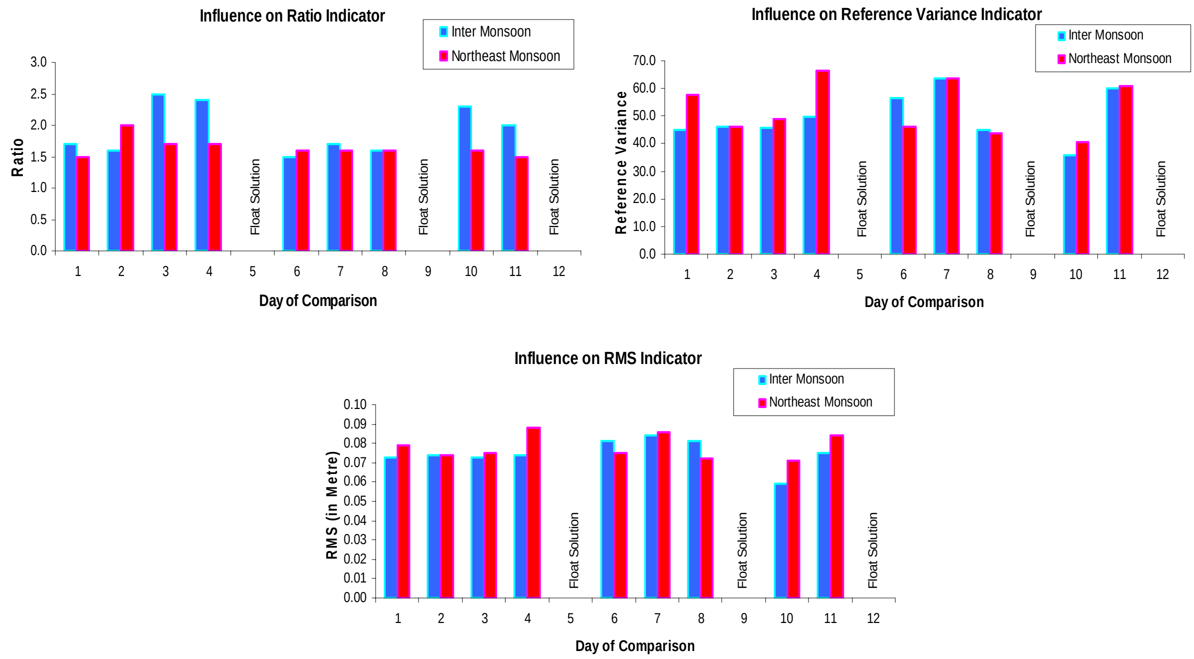

Figure 3: The Influence of Northeast Monsoon and Inter Monsoon Period on GPS Baseline Solution Indicator (a) Ratio (b) Reference Variance (c) RMS.

It is noted that on Day 5, Day 9 and Day 12; only float solution can be produced using this baseline. Float solutions in general are weaker than fixed-integer solutions. In contrast to the fixed-integer solution, a float solution is obtained when the baseline processor cannot compute a definitive integer value for the ambiguity terms. As far as the three dimensional vectors are concerned, in most cases, the ratio indicator for Northeast Monsoon is lower compared to during the Inter Monsoon season. Similarly, the baseline solutions for Northeast Monsoon tend to produce larger amount of reference variance and RMS. With an approximate of 0.09 m, the highest RMS is detected on Day 4 during Northeast Monsoon. Based on the results, it is apparent that Northeast Monsoon tends to produce larger amount of discrepancies on the performance of the GPS baseline solution compared to during the Inter Monsoon season. This might be due to the signal bending and refraction caused by the variability of atmospheric refractive indices during heavy rainfalls throughout Northeast Monsoon over JHJY and JUML stations. Proper attention therefore should be given when dealing with GPS data observed during Northeast Monsoon period.

B. BASELINE LENGTH FACTOR

To examine the effect of baseline length towards variations on the estimated three dimensional vectors during Northeast Monsoon, four baselines in reference to JHJY station were used. As mentioned earlier, these baselines signify short baseline (JHJY-KLUG), medium baseline (JHJY-MERS), long baseline (JHJY-JUML), and very long baseline (JHJY-MERU). The importance of this study is to evaluate the significant of proper selection of GPS baseline length in data processing during this seasonal monsoon. Without applying tropospheric model during data processing, figure 4 illustrates the computed ratio, the reference variance and the RMS during Northeast Monsoon of 2006.

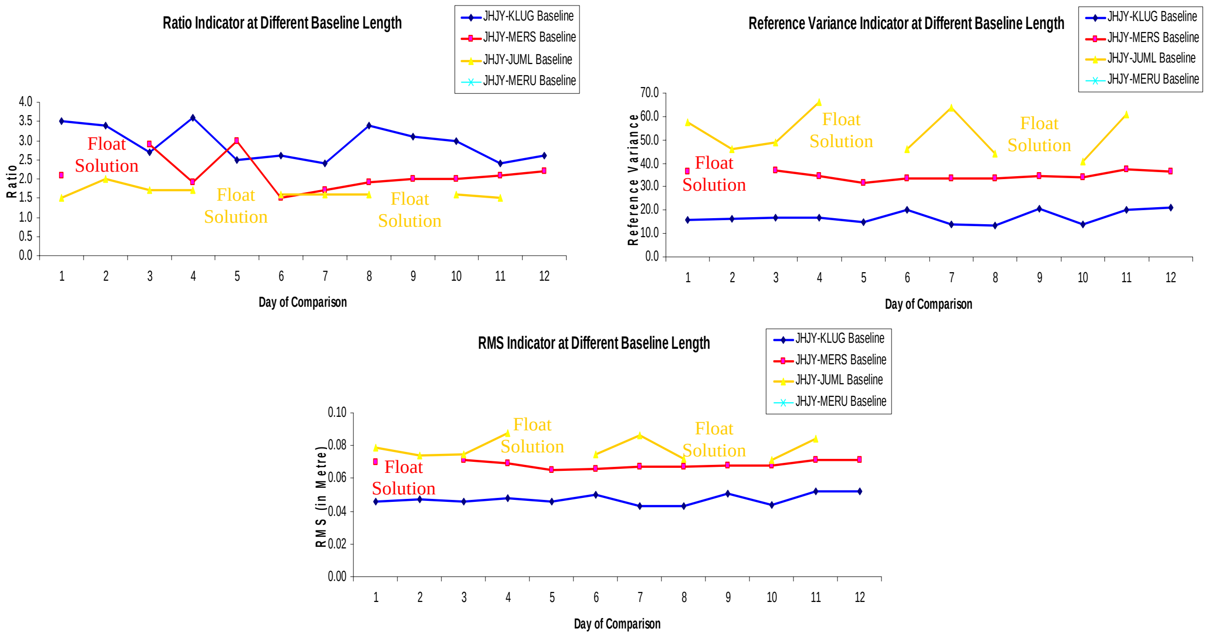

Figure 4: The Influence of Different Baseline Length on GPS Baseline Solution Indicator
(a) Ratio (b) Reference Variance (c) RMS.

Although it was mentioned that JHJY-MERU baseline was included during data processing, it is apparent that only float solution can be produced using this baseline. However, as illustrated by other fixed-solution baselines, it is noted that the discrepancies in GPS baseline solutions are much more pronounced on the longer distance baselines. Consistently providing fixed-solution baselines throughout the observation campaigns, JHJY-KLUG baseline tends to produce better result in all estimated three dimensional vectors followed by the JHJY-MERS baseline and the JHJY-JUML baseline respectively. Better result in the GPS derived position is therefore can be expected based from short baseline compared to long baseline.

C. TROPOSPHERIC MODEL FACTOR

Further analyses were made to examine the effect of applying currently available global tropospheric models towards variations on the estimated three dimensional vectors of the GPS baseline solution. The aim of this study is to evaluate the role of two global tropospheric models: the Saastamoinen model and the Hopfield model on enhancing JHJY-JUML baseline solution during Northeast Monsoon of 2006. Result of the study is as shown in figure 5.

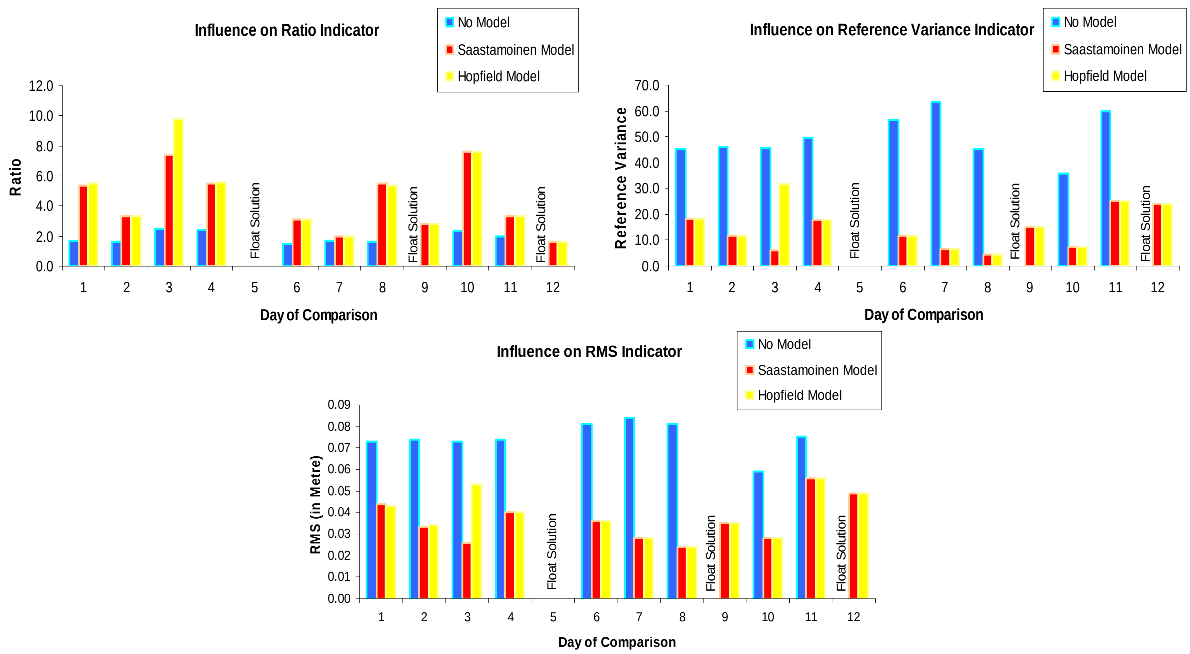

Figure 5: The Influence of Tropospheric Model on GPS Baseline Solution Indicator
(a) Ratio (b) Reference Variance (c) RMS.

Based on the result, it is obvious that global tropospheric models tend to improve the performance of GPS baseline solutions in all aspects including ratio, reference variance and RMS. As seen on Day 9 and Day 12, float solution can also be avoided just by applying these models in data processing. The ratio value tends to improve up to 235 % after applying the tropospheric models. The reference variance value on the other hand tends to improve up to 95 % after applying the tropospheric models. As far as the RMS is concerned, the improvement ranges from 0.016 m to 0.068 m; that is around 19 % to 77 %. Comparative analysis between the Saastamoinen model and the Hopfield model however shows that no statistical or significant differences can be clearly seen on the result. Both models tend to produce similar three dimensional vectors in which after all are merely significant in improving the GPS baseline solution during the Northeast Monsoon in Malaysia.

IV. CONCLUDING REMARKS

This paper examines the performance of GPS baseline solutions associated with relative positioning during the Northeast Monsoon period. Based on series of Malaysian Real Time Kinematic Network (MyRTKnet) data over the year of 2006, result shows that discrepancies on the computed three dimensional vectors can be expected during the Northeast Monsoon season. As far as the baseline length factor is concerned, the discrepancies in GPS baseline solutions are much more pronounced on the longer distance baselines. Better result in the GPS derived position is therefore can be expected based from the relatively short baseline compared to the long baseline. By examining the effect of applying two currently available global tropospheric models: the Saastamoinen model and the Hopfield model towards variations on the estimated three dimensional vectors of the GPS baseline solution, it is noted that the global tropospheric models tend to improve the performance of GPS baseline solutions in all aspects including ratio, reference variance and RMS. Comparative analysis between the Saastamoinen model and the Hopfield model however shows that no statistical differences can be clearly seen on the result.

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