An Evaluation of Tropospheric Delay on GNSS Observations

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Abstract: *The Global Navigation Satellite System is used to find point locations in latitude, longitude, and altitude which are involved among the satellites and receivers through electromagnetic signals. Due to the refraction of the electromagnetic signals, the signals are delayed than the actual propagation time. In this study, the effect of tropospheric delay on GNSS observations is considered by single-point observation on a primary control point of the Sri Lanka Datum 99 network. The study aims to investigate the total tropospheric delay of GNSS observations affected at different times of the day without considering dry and wet components of the delay. The 24 hours of dual-frequency row data were collected and processed separately on the morning, afternoon, and evening observations using Leica Geo Office 8.4 software applying Hopfield, Simplified Hopfield, and Saastamoinen models to correct the tropospheric delay. Then fulfill the purpose to identify the variation of GNSS observations affected at different times of the day due to the tropospheric delay, determine the best tropospheric model which can be used to minimize tropospheric delay, and define the best time for getting Global Navigation Satellite System observations. The Saastamoinen model shows the minimum variation toward the original values of the A166 primary control point. The morning was the best time for collecting data for Global Navigation Satellite System purposes according to this study.*

Keywords: Hopfield Model, Saastamoinen Model**,** Primary Control Point, Tropospheric Delay**,** Dual Frequency

I.INTRODUCTION

Global Navigation Satellite System (GNSS) was established by the US Department of Defense after starting Global Positioning System (GPS) in the 1970s. People use satellites to collect independent geospatial data for different purposes. It determines point locations with latitudes, longitudes, and altitudes of each position. High-accurate time signals are transmitted from satellites to receivers to determine locations. Electromagnetic waves are used to transmit signals. The signals are reached fromorbital satellites, which are located at 20000 km above the Earth's surface. GNSS errors are implemented according to three different error foundations. Errors should affect other factors at the space control level, during the way from the satellite to receive, and at the receiver's level.

While satellite signals were transmitted through the satellite to the receiver, signals are travelling in the Earth's atmosphere. The satellite signals were affected by different atmospheric layers. Ionospheric effects and tropospheric effects are errors, which are, arise on the way from the satellite to the receiver. Tropospheric delay is smaller than ionospheric delay but measuring tropospheric effect is very difficult because of ground meteorological data (Povero,2019). The troposphere's main characteristic is that it is a non-diffusive medium for electromagnetic waves up to 15GHz, which means that the tropospheric impacts on GNSS signals are not frequency-determined (Opaluwa, et al,2013)

Tropospheric delay is typically rectified using the ray tracing method, parameter estimate method, model approach, and external correction method (Wang, et al, 2014). This study used the model method to correct the tropospheric delay.

A. Objectives of the Study

- To determine tropospheric delay on the GNSS observations at different times of the day.
- To determine the best tropospheric model which can be used to minimize tropospheric delay.
- To determine the best time for getting GNSS observations

II. METHODOLOGY AND EXPERIMENTAL DESIGN

A. Study Area

This study is based on single-point observation. The selected station was A166 station situated in the Wariyapola Survey Department office which was included in Sri Lanka WGS 84 coordinate system for this study. It is a primary GPS station (A Point) that was established by the GNSS unit of the Survey Department of Sri Lanka. Figure 1 shows the study location which was used to collect row data.

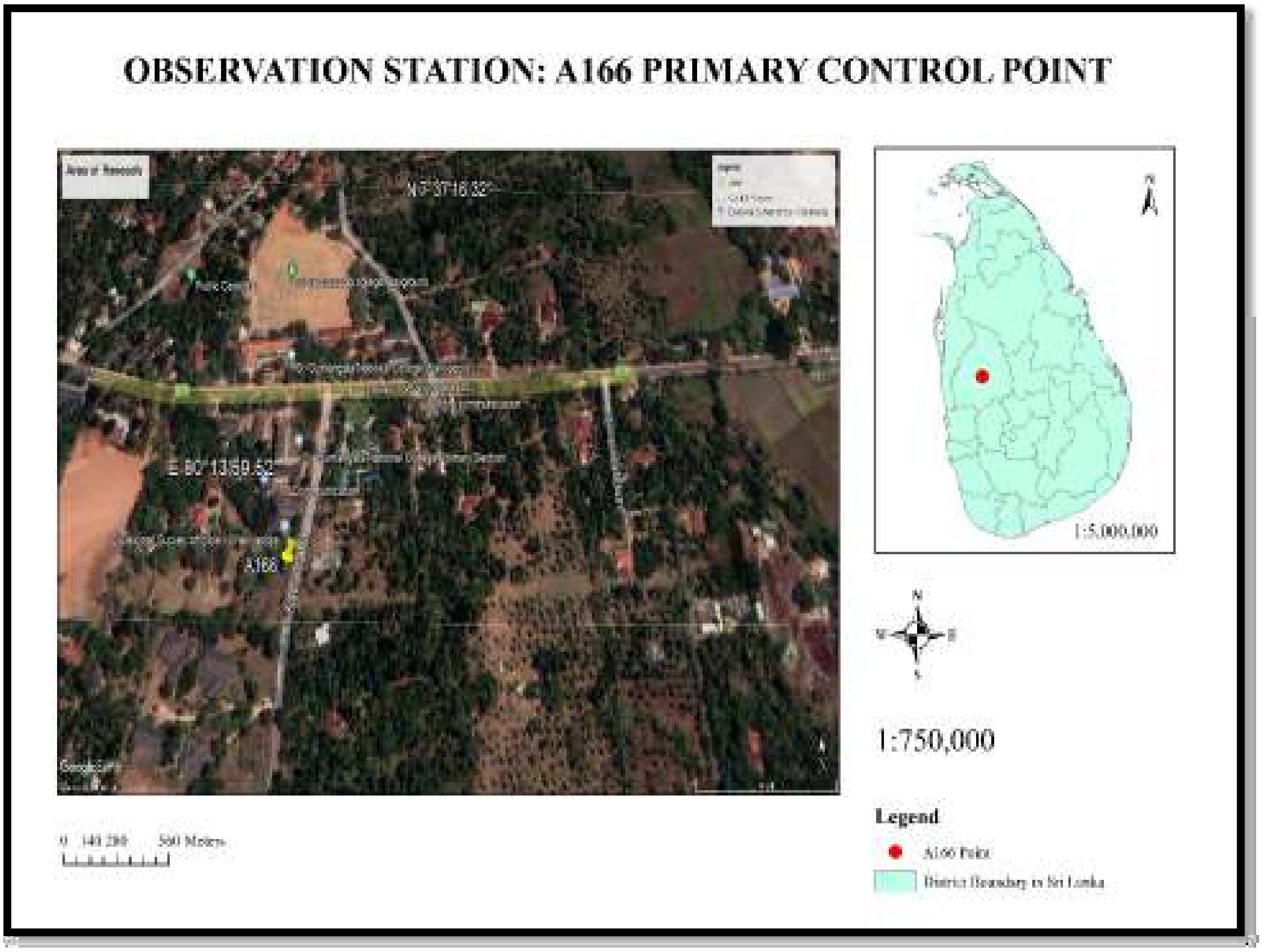

Figure 1. Location of selected control point

B. Data Used

For this study, gather 24 hours of raw GNSS observation in static mode (Mohamad, et al., 2021). The E-Survey, E-600 GNSS receiver was used for data observations. The following settings were used while collecting data. The observed data were downloaded in ".dat "data format. The below table shows the data-acquiring parameters.

Table 1: Data collecting parameters

Instrument	Mask Angle (Degree)	Sampling Rate	Frequency
E-600 & P8II handheld Android Data Controller	15^0	5 seconds	Dual frequency

The following table shows the approximate coordinates of selected primary control point. The coordinates were extracted from the report on Sri Lanka Datum 1999 (Geodetic Survey Unit,2000) on the WGS 84 coordinate system.

Table 2: Approximate coordinates of the A166 primary control point

Latitude (N)	Longitude (E)	Latitude (N) (Decimal Degree)	Longitude (E) (Decimal Degree)
7^0 37' 4.52416"	80^0 14' 1.89558"	7.617923369	80.23385989

The study was comparing using those original coordinates which are provided by GNSS unit of Survey Department in Sri Lanka. According to the survey department website A166 is in 7.617923369N, 80.23385989E in Kurunegala district. The morning observations obtained from 3 hours observation period started at 06.00 am to 09.00 am on 18/03/2022. The afternoon observations were obtained from 12.00 noon to 03.00 pm at the A166 station. The evening observations were obtained from 06.00 pm to 09.00 pm at the A166 station.

C. Workflow of the study

Select a Primary Reference point for collect GNSS row data

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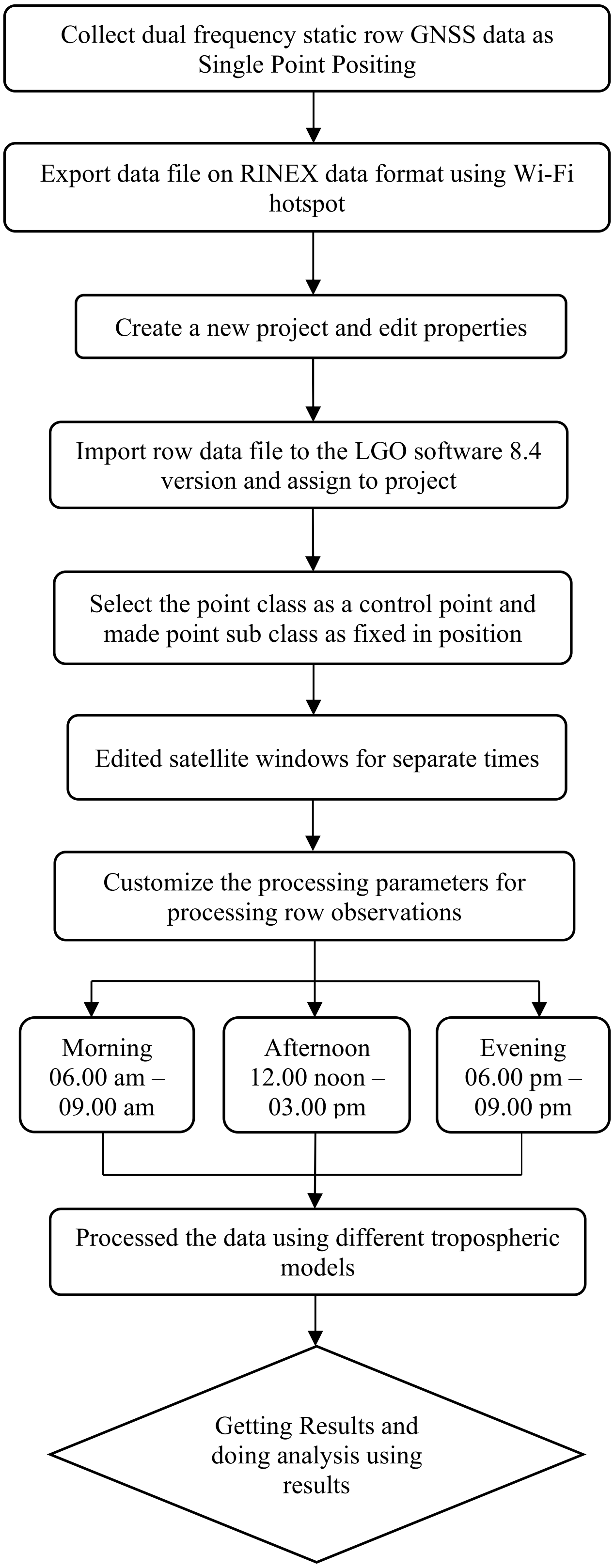

Figure 2: Workflow of the study

1) Field Data Collection

The field data collection was carried out on 18th March 2022. There were three sessions of a three-hour period. Each field observation was conducted over the course of a day which included a total of 9 hours (Dodo, et al., 2008). Used the Surpad 4.2 software for point observations. Used 150 mask angle for collecting observations and 1Hz data collection interval for getting accurate row observations.

2) Data Processing

For processing the data, used Leica Geo Office 8.4 application. Single point processing mode was applied to proceeds row data. Below table shows the processing parameters used to row data processing.

Table 3: Processing Parameters of the LGO 8.4 software

General Parameters	Processing on LGO 8.4
Cut-off angle	15^0
Ephemeris type	Broadcast
Processing mode	Manual
Solution type	Automatic
GNSS type	Automatic
Frequency	L1 and L2
Fix ambiguities up to	20km
Sampling rate	5 sec
Tropospheric model	Hopfield, Simplified Hopfield, Saastamoinen
Ionospheric Model	Automatic

After modifying the processing parameters of the manual processing mode. The table revealed the processing parameters that were applied. The ephemeris type was broadcast for most applications across short baselines, its impact will be minor since quality remains as strong as in recent times (Higgins,1999). The solution type was automatic due to resolving the ambiguities of used codes and phase observations. Used dual frequencies to mitigate ionospheric errors (Danasabe, et al., 2015). Automatically applied L3 solutions for baselines up to 15km which helped to minimize multipath error. Excluded window mode is used to cut down unnecessary satellite windows. After processing the data under morning, afternoon, and evening applying Hopfield, simplified Hopfield, and Saastaminan all the outputs were saved.

After that, converted those coordinates from DMS form to Decimal degrees values using 3.1 formula according to different times and the different tropospheric models.

$$DD=Degree+\left(\frac{Minutes}{60}\right)+\left(\frac{Seconds}{3600}\right) \quad (3.1)$$

From this formula, giving conversion of coordinates in Degrees, Minutes, and Seconds to decimal degree format of the WGS 84 coordinate system.

III.RESULTS

After processing row data using LGO 8.4 software got the coordinates in DMS format in the WGS84 coordinate system. The following tables represent processed coordinates with latitude and longitudes of the Wariyapola A166 point station during morning, afternoon, and evening observations.

Table 4: Coordintes of occupied station in Morning

Tropospheric model	Latitude	Longitude
Hopfield	07^{0} 37' 4.59339"	80^{0} 14' 1.89391"
Simplified Hopfield	07^{0} 37' 4.59567"	80^{0} 14' 1.89028"
Saastamoinen	07^{0} 37' 4.57416"	80^{0} 14' 1.90344"

Table 5: Coordintes of occupied station in Afternoon

Tropospheric model	Latitude	Longitude
Hopfield	07^{0} 37' 5.02252"	80^{0} 14' 2.36910"
Simplified Hopfield	07^{0} 37' 5.02590"	80^{0} 14' 2.37496"
Saastamoinen	07^{0} 37' 5.00846"	80^{0} 14' 2.35875"

Table 6: Coordintes of occupied station in Evening

Tropospheric model	Latitude	Longitude
Hopfield	07^{0} 37' 4.49248"	80^{0} 14' 2.15924"
Simplified Hopfield	07^{0} 37' 4.40477"	80^{0} 14' 2.12509"
Saastamoinen	07^{0} 37' 4.48535"	80^{0} 14' 2.09049"

In decimal degree values occupy the degree and minute values must not be changed but the second values must be switched on the first decimal value. Two decimal values are occupied in seconds for a 1m accuracy level (Anom, 2014).

Table 7: Processed coordinates in DD at Morning

Tropospheric model	Latitude (DD)	Longitude (DD)
Hopfield	7.617942608	80.23385942
Simplified Hopfield	7.617943242	80.23385841
Saastamoinen	7.617937267	80.23386207

Lowest variation along the latitudinal direction at the morning session was showed by the Saastamoinen model. But the highest variation along the latitudinal direction is occupied by the Simplified Hopfield model. In the longitudinal direction highest variation was occupied by the Saastamoinen model and the lowest deviation is derived from the Hopfield model.

Table 8: Processed coordinates in DD at Afternoon

Tropospheric model	Latitude (DD)	Longitude (DD)
Hopfield	7.618061811	80.23399142
Simplified Hopfield	7.61806275	80.23399304
Saastamoinen	7.618057906	80.23398854

At the afternoon observations, the lowest deviation along the latitudinal direction was prepared by the Saatamoinen model, and the highest variation was derived from the Hopfield model. From the longitudinal direction, the lowest variation was occupied by the Saastaminen model, and the highest deviation was occupied by the Simplified Hopfield model corresponding to afternoon observations.

Table 9: Processed coordinates in DD at Evening

Tropospheric model	Latitude (DD)	Longitude (DD)
Hopfield	7.617914578	80.23393312
Simplified Hopfield	7.617890214	80.23392364
Saastamoinen	7.617912597	80.23391403

Along the latitudinal direction, the Saastamoinen model derived the lowest fluctuation towards approximate values of the A166 primary control point at evening observations. The simplified Hopfield model occupied the highest variation for original values. From the longitudinal direction, the lowest variation occupied the Saastaminen model as well as latitude. Not only the lowest but also the highest variation occupied by the Hopfield model.

The following four figures show those colors and numbers as this. Point B represents the original coordinates of the A166 primary control point established by the GNSS unit of the Sri Lanka Survey Department in red color.

Color	Correction Filter	Numbers	Time Of the Day
	Hopfield	1	Morning
	Simplified Hopfield	2	Evening
	Saastamoinen	3	Afternoon

Figure 3: Colors and Numbers of Figures

The M1 is coordinates processed using the Hopfield model in morning observation. The Simplified Hopfield was used to correct the tropospheric delay in the M2 point. Point M3 represents the Saastamoinen model. The minimum variation from the original coordinates of the station shown by the M1 point used Hopfield model for correct tropospheric delay. The coordinates proceed according to Saastamoinen make maximum variation from the original coordinates on following Figure 4.

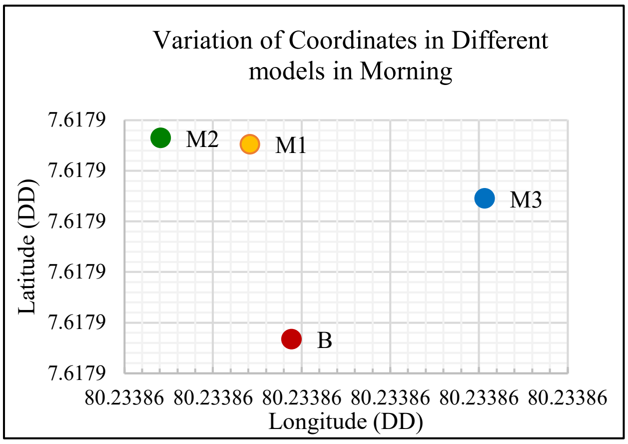

Figure 4: Variation of coordinates in different models in Morning observations

Below Figure 5 shows the variation of coordinates in afternoon observations using different tropospheric models. A1 coordinates were processed using the Hopfield model in afternoon observation. The Simplified Hopfield was used to correct the tropospheric delay in the A2 point. Point A3 represents the Saastamoinen model. Minimum variation included in coordinates which processed applying Saastamoinen model from original coordinates. Coordinate using Simplified Hopfield model to tropospheric delay correction had maximum variation.

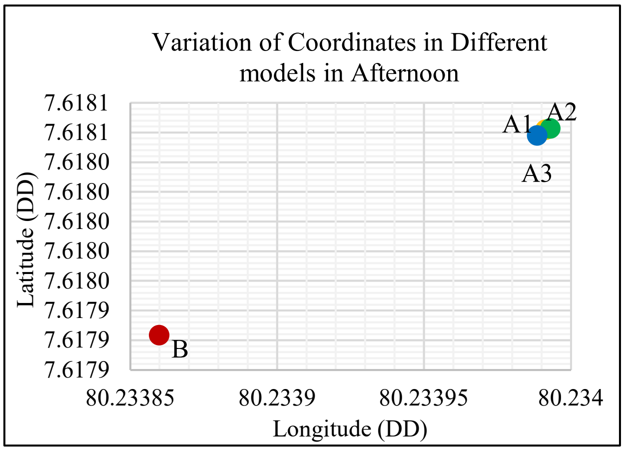

Figure 5: Variation of coordinates in different models in Afternoon observations

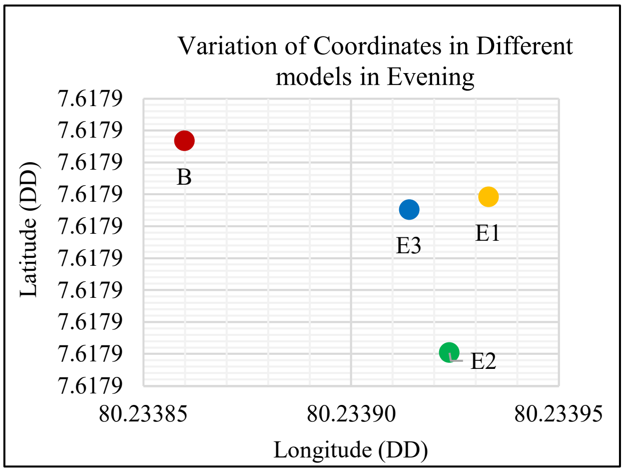

Figure 6: Variation of coordinates in different models in Evening observations

There is a significant difference in point E2, which used the Simplified Hopfield model. Coordinates E1 from evening observation were analyzed using the Hopfield model. The tropospheric delay was adjusted in the E2 point using the Simplified Hopfield. The Saastamoinen model is represented by Point E3 in above figure 6.

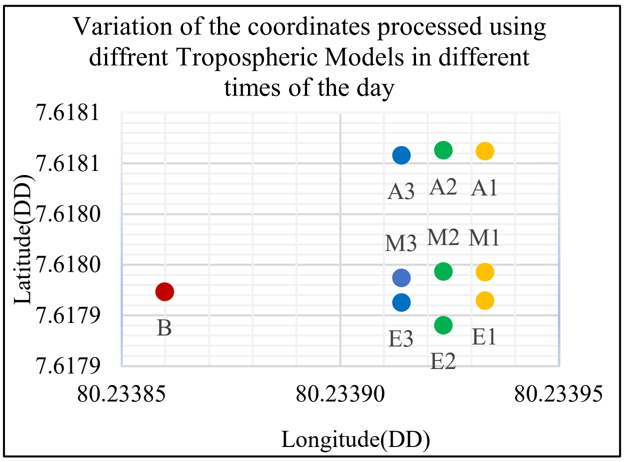

Figure 7: Deviation of the Coordinates Processed using Different Tropospheric Models

Figure 7 represents points M1, M2, and M3 were morning observations processed which were used in order Hopfield model, Simplified Hopfield, and Saastamoinen model. The afternoon observations were A1, A2, and A3 in order as previously. Not only that but also evening observations represent in order as well as previously at E1, E2, and E3. According to the figure, Hopfield models varied without much change in morning, afternoon, and evening. This figure shows the minimum deviation shows the Saastamoinen model at morning observations for A166 Primary control point.

IV.DISCUSSION AND CONCLUSION

This study analyses the effect of tropospheric delay on GNSS observations. Therefore, in this study, investigate GNSS row data that were gathered using static mode at three different times of the day (Opaluwa, et al., 2013). The morning, afternoon, and evening observations were processed including tropospheric corrections using Hopfield, Simplified Hopfield, and Saastamoinen models. Single Point Positioning was used to obtain row data at a primary control point on the SLD99 network. Leica Geo Office 8.4 application was used to process row data. Sri Lanka was a tropical country, and the temperature was higher than polar countries. According to this study, the Saastamoinen model and Hopfield model gave the minimum variation from the original coordinates of the A166 primary control point. The Hopfield model occupies not only the lowest but also the maximum variation. Finally, the Saastamoinen model makes the smallest variations towards the original coordinates through this study (Opaluwa, et al., 2013).

Then according to the results, the morning which had time 06.00 am to 09.00am was the most suitable time for obtaining GNSS observations. The atmospheric conditions were controlled at those times in the country.

The temperature must not high, the pressure should be low, etc. While using GNSS, the time from 12 noon to 03.00 pm was not suitable for gathering row data. Afternoon observations have more variation rather than morning and evening observations. The Atmospheric parameters should affect refractions of the signals highly at this time. (Opaluwa, et al., 2013; Dodo, et al., 2008)

1)Further Improvements

The study can be improved for multiple control points spread throughout the country. This study considers the overall total tropospheric delay of GNSS observations. It can be improved evaluate the dry and wet tropospheric delay. While using different modeling can be considered meteorological parameters of the different stations. Row data can be processed using different software packages like TBC, LGO, Bernese, etc. And can get observations throughout long periods of time even for a week. Anyone can modify or make a new model by getting long-time row data observations. Further developments could be an investigation of tropospheric delay over the altitude variations examined. RMSE calculations can be applied as further developments also. Not only is the observation time increasing but also can use different mask angles for observations. Not only that anyone also can expand this study and apply different data collection methods according to the availability of resources.

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ABBRIVIATIONS

DD- Decimal Degree
GNSS – Global Navigation Satellite system
GPS – Global Positioning System
LGO -Leica Geo Office
RINEX – Receiver Independent Exchange Format
RTK – Real Time Kinematic

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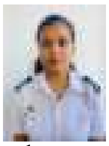
AUTHOR BIOGRAPHY



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