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# Impact of the precise ephemeris on accuracy of GNSS baseline in relative positioning technique

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ABSTRACT

For advanced geodesy tasks that require high-accuracy, such as tectonics, surveying services usually use not only long-baselines but also the duration of tracking GNSS satellites in a long (e.g., 24/7). The accuracy of these baselines in baseline analysis is dominated by inaccuracy satellite positioning and orbit, leading to specified accuracy may not be adequate. One way to overcome this problem is to use the final precise ephemeris, provided by IGS. The objective of this study is to investigate the impact of precise ephemeris on the accuracy of GNSS baselines in relative positioning techniques in two aspects: baseline length and duration of tracking GNSS satellites. To this end, 197 baselines were generated from a total of 88 CORS stations in South Korea, and then thirteen testing cases were constructed by grouping baseline lengths from under 10 km to over 150 km. Besides, data for one day of each CORS was divided into the different duration, such as 1, 2, 3, 6, and 24 hours. The GNSS measurements have been processed by TBC software with an application of the broadcast and precise ephemerides. The precision of the baseline processing from two types of ephemeris was analyzed about baseline lengths and time of data. The obtained results showed that using precise ephemeris significantly improved the accuracy of baseline solutions when the length of the baseline larger than 50km. In addition, this accuracy is independent of the length of baselines in the case of the precise ephemeris. Finally, the result of the testing baselines was enhanced when the duration of tracking data increases.

*Keywords*: GNSS, precise ephemeris, broadcast ephemeris, GNSS baseline processing.

## 1. Introduction

Global Navigation Satellite System (GNSS) is now widely used as a multi-purpose survey technique applied in numerous applications, such as mapping, surveying, and monitoring deformation because the accuracy and efficiency of positioning have increased dramatically compared to the conventional surveying method (Tran Dinh Trong, 2013). This system can determine the precise location anywhere on the Earth using range from the orbit of satellite located about 20,000 km above the ground and the GNSS

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receiver via the electromagnetic signal. On the user's side, the GNSS receiver, which located in an open space, receivers at least four satellites simultaneously for positioning and navigation. To do this, the positions of these satellites in orbit are must be known that may be forecasted and broadcasted with the signal.

The GNSS positioning technique can be divided into absolute positioning and relative positioning according to the correction method of systematic errors included in the observation data. Absolute positioning is a method of estimating the position of a single receiver by removing or modeling errors. A representative of this positioning is Precise Point Positioning (PPP) that its solution delivers accuracy up to a centimeter by using precise ephemeris to get GNSS satellite clock and orbit corrections (Seeber, 2003; Rizos, 1997; NovaAtel Inc., 2015). Different from the absolute positing technique, the relative positioning operates on the basic principle of using two or more GNSS receivers to simultaneously observed GNSS satellites to determine coordinate differences between two stations. In this method, one receiver is selected as a reference, or control, which remains stationary at a site with more than a centimeter precisely known coordinate. The other receiver, known as the rover or remote receiver, has its coordinates unknown (Hofmann-Wellenhof, 2001; Rizos, 1997).

The calculation of performance by GNSS static consists of two steps: baseline processing and network adjustment. The former is aims to estimate the three-dimensional (3-D) components of unknown stations by least square estimation passing through the determination of integer ambiguity process after the application of mathematical double-difference data for the observed carrier phase (Rizos, 1997; Kwang-Ho, 2010). Then, as convenient, the difference between the two observation points is calculated, called the baseline vector. The latter uses the results of the baseline processing step (e.g., baseline vectors) and geodetic datum for finally estimating 3-D coordinates of unknown points in the network after checking for outliers, accuracy, and reliability.

For baseline processing, the broadcast ephemeris often uses to calculate the position of the satellite in the orbit. With the long-baseline, however, using the broadcast data may not ensure the required accuracy (e.g., float solution). As mentioned by Trimble company, the baseline exceeding 50 km is necessary to use precise ephemeris data (Department of Transport and Main Roads, 2019). In addition, it is highly recommended to process using precise ephemeris whenever possible. However, it should be noted that the precise ephemeris is only available after 12-18 days on IGS (International GNSS Service) website. In the study of Earth's crust displacement, the baselines of the GNSS networks are long and observed in long-duration; hence, the processing of these networks need to use the precise ephemeris to achieve the required accuracy.

In determining the user position, the orbit of GNSS satellites and correction of the satellite clock must be known. To investigate the ability of the broadcast and precise ephemerides for determining satellite's orbit and clock correction, the studies were conducted by Li (2013) and Murata (1995), aiming to compare with using the difference of these ephemerides in terms of accuracy. Accordingly, the user's positioning with precise orbits and clock correction instead of broadcast data can obtain significant improvement in its accuracy. Also, the IGS estimated and provide the accuracy of satellite orbit was around 1.6 m in the broadcast ephemeris case, while that of precise ephemeris can reach 5 cm (International GNSS Service, 2020). To investigate the impact of baseline length onto the baseline solution, the research of Chika Okorocha (2014) conducted a study to compare results of short, medium, and long baselines when using broadcast ephemeris only. The short baseline included 19 baselines smaller than 10 km, while the forming of the medium is over 10 km, and those of long baselines were larger than 100 km. All baselines were processed by using Trimble Business Center (TBC) software package. The accuracy of each baseline was expressed in terms of horizontal and vertical precisions. This study has shown that the accuracy of GNSS baseline processing is a function of the baseline length. The obtained precision decreased when the longer baseline was used in processing.

The company of Waypoint (Waypoint Consulting Inc., 2005) carried out experimental testing to compare the two approaches above in different groups of baseline length given specific observation time. In this study, three groups' lengths, such as short and medium, long, and very long basslines were generated from the data downloaded from the IGS network. However, each group was limited to four baselines and ignored the baseline with a range from 60 km to 200 km. Each baseline was processed using GrafNet version 7.60 in different times of data, such as 1 hour, 3 hours, 6 hours, 12 hours, and 24 hours using both the broadcast and precise ephemerides. The obtained result was expressed in terms of 3D errors. This study concluded that the accuracy of baseline processing is a function of both times of data and the length of the baseline. In particular, using precise ephemeris is no benefit for the baseline length of 200 km or less. Besides, the precision of the baseline was enhanced when the longer time of data obtained. The study also indicates that precise ephemeris should use for the short observation periods.

Like many countries in the world, CORS is developing in the whole of Vietnam's territories to meet the demanding advanced geodesy tasks in the future, such as tectonics, surveying services. A total of 65 CORS stations included the 24 geodetic CORSs and 41 stations for Network Real-Time Kinematic (NRTK) (Phan Duc Hieu & Tran Bach Giang, 2019). It is noted that the spatial density of the geodetic network is from 150 km to 200 km. In the tectonic mission survey, the networks require high-accuracy in which uses not only long baseline length but also the duration of tracking GNSS satellite in a long (e.g., 24/7) that are dominated by distance-dependent errors, leading to specified accuracy may not be adequate. To deal with this problem is to use the final precise ephemeris provided by IGS. However, so far, the static data of these CORSs in Vietnam have never been provided to users yet due to it is in processing tests.

Therefore, this study has used the GNSS data from 88 CORS stations provided by Integrated data Center Korea (IGCK) for testing experiments. The objective of this study is to investigate the impact of precise ephemeris on the accuracy of GNSS baselines in relative positioning techniques in two aspects: baseline length and duration of tracking GNSS satellites. To this end, 197 baselines were generated from a total of 88 CORS stations in South Korea, and then thirteen testing cases were constructed by grouping baseline lengths from under 10 km to over 150 km. Besides, data for one day of each CORS was divided into the different duration, such as 1, 2, 3, 6, and 24 hours. The GNSS measurements have been processed by TBC with an application of the broadcast and precise ephemerides. The precision of the estimated coordinates from two types of ephemeris was analyzed about both baseline lengths and time of data. These results are hopefully providing the recommendations of a suitable selection of the ephemerides concerning processing conditions, such as the baseline length and the time of obtaining data.

## 2. Broadcast and Precise Ephemerides

### *2.1. Broadcast Ephemeris*

The broadcast ephemeris is available as a set of modified elements of Kepler to predict and calculate the position of the satellites at the observation of each epoch. Those of the Keplerian parameter are listed in Table 1. The parameters are given in terms of the center of the ephemeris reference time; for example, it is measured in seconds from the start of the GPS week (e.g., at Sunday midnight) (Rizos, 1997). This ephemeris data computation takes place at the Master Control Station by using tracking data acquired from the monitor stations of the Control Segments.

```
NAVIGATION DATA                      RINEX VERSION / TYPE
CCRINEXN V1.6.0 UX CDDIS              16-JAN-17 17:31     PGM / RUN BY / DATE
IGS BROADCAST EPHEMERIS FILE                             COMMENT
0.7451D-08 -0.1490D-07 -0.5960D-07 0.1192D-06            ION ALPHA
0.8806D+05 -0.4915D+05 -0.1966D+06 0.3277D+06              ION BETA
0.931322574616D-09 0.000000000000D+00   233472     1932 DELTA-UTC: A0, A1, T, W
18                                          LEAP SECONDS
END OF HEADER
PRN     Date of clock            a0 (µ second)           a1 (µ second/day)        a2 (µ second/day^2)
1        17 1 15  0  0        0.0 0.468431971967D-04     0.113686837722D-11       0.000000000000D+00
    Age of ephemeris (sec)             Crs (m)                Δn (rad/sec)              Mo (rads)
     0.390000000000D+02    -0.123031250000D+03         0.414481560185D-08       -0.230187955448D+01
          Cuc (rads)                     e                     Cus (rads)                √a (m^0.5)
    -0.633858144283D-05      0.614144210704D-02          0.827573239803D-05        0.515370075035D+04
        toe (secs in GPS wk)          Cic (rads)                Ωo (rads)                 Cis (rads)
     3.190400000000D+04    -0.353902578354D-07        -0.133744633127D+00       -0.633299350738D-07
       io (rads)                      Crc (m)                  ω (rads)                Ω (rad/sec)
     0.966717087030D+00     0.223156250000D+03         0.549710553514D+00      -0.787711407213D-08
        i (rad/sec)                                       b GPS week number
    -0.173221506583D-09      0.100000000000D+01         0.193200000000D+04       0.000000000000D+00
```

Broadcast ephemeris can be obtained by extract the navigation message, as part of the GNSS navigational message, in the output ofthe processed GNSS receiver data or directly downloaded on the IGS website. It is noted that the ephemeris data are normally uploaded daily and are valid for two hours in advance of the epoch for which they were calculated. Besides, the position of each satellite was determined using the broadcast ephemeris at each 15 min interval which coincides with the orbit epochs. The accuracies are about 100 cm and 5ns for the orbit and the satellite clock, respectively (International GNSS Service, 2020). Therefore, the accuracy of the broadcast ephemeris is expected on average better than 10 m (Rizos, 1997).

A sample of the broadcast ephemeris data for GPS satellite 1 (i.e., PRN01) for a day of 15th January 2017 is illustrated below and the broadcast ephemeris parameters are explained in Table 1.

*Table 1.* Broadcast ephemeris representation parameters (Hofmann-Wellenhof, 2001; Rizos, 1997)

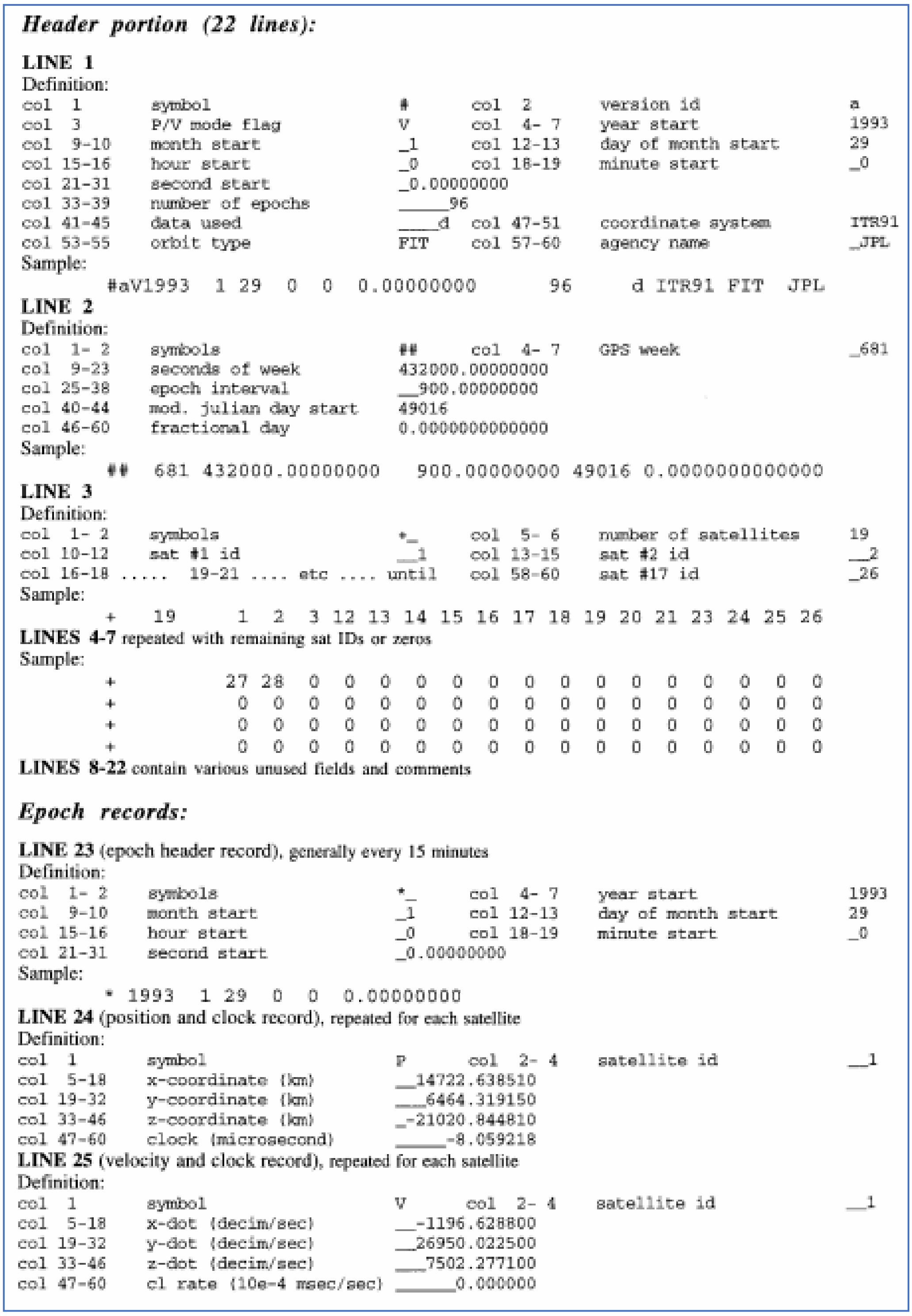
| Parameter | Description |
|---|---|
| Mo | Mean anomaly at the reference epoch |
| $\omega_0$ | Argument of perigee |
| io | Inclination |
| $l_0$ | Longitude of the node at weekly epoch |
| $\Delta n$ | Mean of motion difference |
| i | Rate of an inclination angle |
| $t_e$ | Ephemerides reference epoch |
| $\Omega$ | Rate of node's right ascension |
| a | Semimajor axis |
| e | Eccentricity |
| Cuc, Cus | Amplitude of the cosine and sine harmonic correction terms to the argument of latitude |
| Crc, Crs | Amplitude of the cosine and sine harmonic correction terms to the orbit radius |
| Cic, Cis | Amplitude of the cosine and sine harmonic correction terms to the argument of inclination |
| $t_c$ | Satellite clock reference epoch |
| a0 | Satellite clock offset |
| a1 | Satellite clock drift |
| a2 | Satellite clock frequency drift |

### 2.2. Precise Ephemeris

Different from the broadcast ephemeris, the precise ephemeris provides more accurate satellite orbit and clock through the IGS website managed by the Jet Propulsion Laboratory, USA, and is stored in the so-called SP3 ephemeris format. The formatted SP3 is igswwwwd.sp3 in which wwww is expressed the GPS week, and d shows the day of the week (e.g., n = 0, 1,…, 6). Unlike the broadcast, the precise orbit was estimated by loading all available ephemeris records, which provided epochs every 15 minutes. Consequently, it provides the orbit and clock accuracy on the order of smaller than 5 cm; for instance, 2.5 cm for final precise ephemeris, as detailed in Table 2. The construction of the formatted precise ephemeris is, a sample, shown in Fig. 1.

*Table 2.* List of ephemerides and their information for GPS satellite (International GNSS Service, 2020)

| Type of ephemeris | Accuracy | | Latency | Sample interval |
|---|---|---|---|---|
| | Orbit (cm) | Satellite clocks | | |
| Broadcast | 100 | 5 ns | Real-time | Daily |
| Ultra-Rapid (predicted half) | 5 | 3 ns | Real-time | 15 min |
| Ultra-Rapid (observed half) | 3 | 150 ps | 3-9 hours | 15 min |
| Rapid | 2.5 | 75 ps | 17-41 hours | 15 min |
| Final (Precise) | 2.5 | 75 ps | 12-18 days | 15 min |



***Header portion (22 lines):***

**LINE 1**

Definition:

```
col  1       symbol                 #      col  2      version id              a
col  3       P/V mode flag          V      col  4- 7   year start              1993
col  9-10    month start            _1     col 12-13   day of month start      29
col 15-16    hour start             _0     col 18-19   minute start            _0
col 21-31    second start           _0.00000000
col 33-39    number of epochs       ______96
col 41-45    data used              ____d  col 47-51   coordinate system       ITR91
col 53-55    orbit type             FIT    col 57-60   agency name             _JPL
```

Sample:

```
#aV1993  1 29  0  0  0.00000000      96     d ITR91 FIT  JPL
```

**LINE 2**

Definition:

```
col  1- 2    symbols                ##     col  4- 7   GPS week                _681
col  9-23    seconds of week        432000.00000000
col 25-38    epoch interval         __900.00000000
col 40-44    mod. julian day start  49016
col 46-60    fractional day         0.0000000000000
```

Sample:

```
##  681 432000.00000000   900.00000000 49016 0.0000000000000
```

**LINE 3**

Definition:

```
col  1- 2    symbols                *_     col  5- 6   number of satellites    19
col 10-12    sat #1 id              __1    col 13-15   sat #2 id               __2
col 16-18 .....  19-21 .... etc .... until col 58-60   sat #17 id              _26
```

Sample:

```
+   19      1  2  3 12 13 14 15 16 17 18 19 20 21 23 24 25 26
```

**LINES 4-7** repeated with remaining sat IDs or zeros

Sample:

```
+          27 28  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

**LINES 8-22** contain various unused fields and comments

***Epoch records:***

**LINE 23** (epoch header record), generally every 15 minutes

Definition:

```
col  1- 2    symbols                *_     col  4- 7   year start              1993
col  9-10    month start            _1     col 12-13   day of month start      29
col 15-16    hour start             _0     col 18-19   minute start            _0
col 21-31    second start           _0.0000000
```

Sample:

```
* 1993  1 29  0  0  0.00000000
```

**LINE 24** (position and clock record), repeated for each satellite

Definition:

```
col  1       symbol                 P      col  2- 4   satellite id            __1
col  5-18    x-coordinate (km)      __14722.638510
col 19-32    y-coordinate (km)      ___6464.319150
col 33-46    z-coordinate (km)      _-21020.844810
col 47-60    clock (microsecond)    ______-8.059218
```

**LINE 25** (velocity and clock record), repeated for each satellite

Definition:

```
col  1       symbol                 V      col  2- 4   satellite id            __1
col  5-18    x-dot (decim/sec)      __-1196.628800
col 19-32    y-dot (decim/sec)      __26950.022500
col 33-46    z-dot (decim/sec)      ___7502.277100
col 47-60    cl rate (10e-4 msec/sec) ______0.000000
```

*Figure 1.* A sample of IGS GPS satellite ephemeris SP3 file  (Rizos, 1997)

## 3. Data and Methodology

### 3.*1. GNSS Data*

In Korea, CORS networks have been independently operated and provided by eight governmental agencies, institutes, and corporations for their own purposes. Since 2016, the Korean government implemented the so-called Integrated GNSS Data Center (IGDC) which provided users with GNSS data of near 200 CORS, via the internet for real-time and post-processing applications. Hence, the GNSS users are free able to obtain the CORS data wherever they are in the country if they are connected to the internet. However, the number of stations considered in this study is limited to 88 CORSs, as shown in Fig. 2. Besides, the receiver independent exchange (RINEX) formatted data of these target stations for a day of 15th January 2018 were obtained through the webpage of the IGCK (http://gnssdata.or.kr) for post-processing application. Note that all GNSS data was processed at a 30 second interval. The quality of the data is expectedly high, with a located station at low multipath conditions and excellent views of all available satellites.

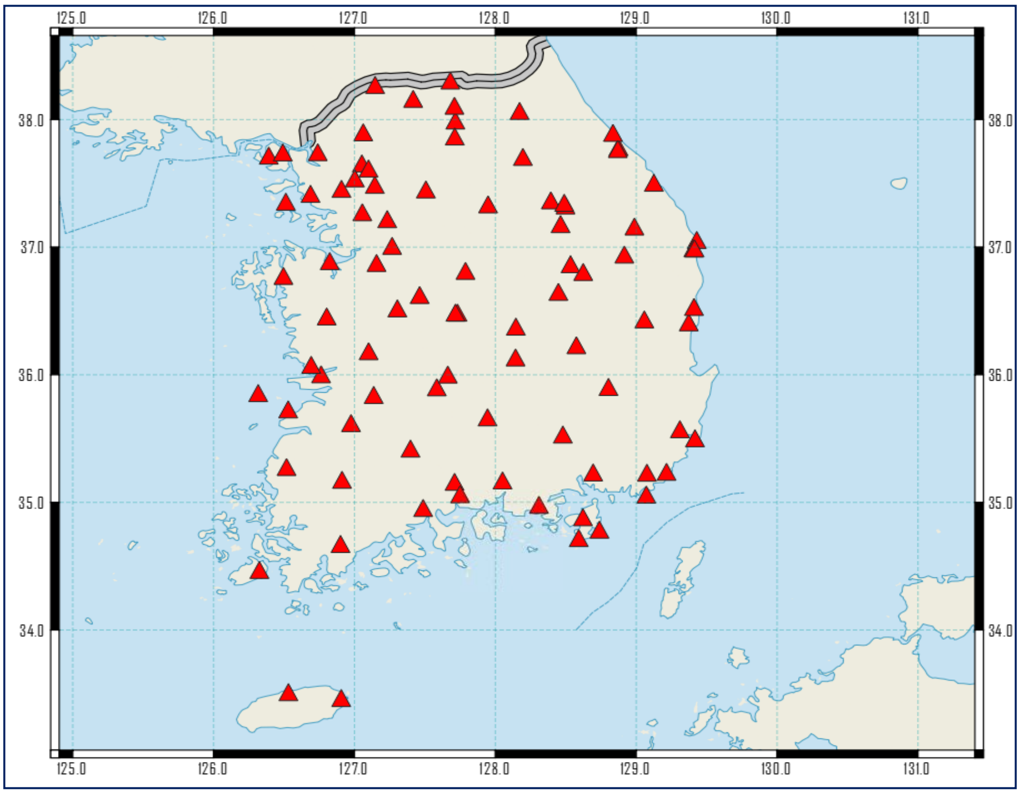


*Figure 2.* Configuration of CORS stations used in the study

The type of antenna with their radome used to process the data acquired of these CORS stations was summarized in Table 3. Among them, the Trimble antenna was, for instance, set up for 63 stations and with radome types of NONE, SCIS, or TZGD. Besides, although all receivers have different capabilities to track multi-GNSS signals, such as GPS, GLONASS, Galileo, BeiDou, only GPS measurement has been considered in this study.

*Table 3.* List of antennas and their information used to obtain CORS data

| No. | Antenna | Radome | No. of CORSs |
|---|---|---|---|
| 1 | JAVRINGANT | SCIS | 10 |
| 2 | LEIAR25 | LEIT/SCIS | 7 |
| 3 | TRM55971.00 | NONE/TZGD | 36 |
| 4 | TRM57971.00 | NONE | 3 |
| 5 | TRM59800.00 | SCIS | 17 |
| 6 | TRM59800.80 | NONE | 15 |

To investigate the impact of precise ephemeris on the accuracy of baseline processing, a total of 197 baselines with a range from 0.8 km to 161 km were generated from 88 CORS stations. After that, thirteen testing cases were constructed by grouping baseline lengths from under 10 km to over 150 km, as shown in Table 4. For example, CASE 1 consisted of 14 baselines that their lengths are about 10km, while those of CASE 6, which is composed of 23 baselines around 50 km with their average of 49.7 km. On the other hand, each baseline was processed with five different durations of tracking satellite, such as 1 hour, 2 hours, 3 hours, 6 hours, and 24 hours to exam the effect of time of data on the baseline solution. It is well known that both length and duration impact the GNSS baseline solution.

*Table 4.* Testing case used in this study

| CASEs | Group of Baseline Length (km) | No. of Baselines | Baseline Length (km) | | | Duration |
|---|---|---|---|---|---|---|
| | | | Aver. | Max. | Min. | |
| 1 | 10 | 14 | 7.2 | 12.4 | 0.8 | - 1 hour<br>- 2 hours<br>- 3 hours<br>- 6 hours<br>- 24 hours |
| 2 | 15 | 12 | 13.6 | 15.3 | 12.4 | |
| 3 | 20 | 12 | 19.2 | 23.9 | 16.5 | |
| 4 | 30 | 13 | 31.0 | 34.8 | 26.6 | |
| 5 | 40 | 20 | 39.8 | 44.7 | 35.5 | |
| 6 | 50 | 23 | 49.7 | 54.6 | 45.0 | |
| 7 | 60 | 22 | 59.5 | 64.8 | 55.1 | |
| 8 | 70 | 19 | 69.8 | 74.6 | 65.2 | |
| 9 | 80 | 13 | 78.8 | 84.5 | 75.1 | |
| 10 | 90 | 13 | 90.5 | 94.5 | 85.1 | |
| 11 | 100 | 13 | 102.2 | 112.0 | 95.0 | |
| 12 | 120 | 11 | 120.1 | 125.6 | 115.5 | |
| 13 | 150 | 11 | 151.2 | 161.2 | 145.3 | |
| Total | | 197 | | | | |

### *3.2. Methodology*

A data processing adopted in this study for evaluating the benefit of precise ephemeris on the accuracy of GNSS baseline in relative positioning was illustrated in Fig. 3. After obtaining GNSS data from IGCK, thirteen testing cases were generated for preparing baseline processing. Besides, data of each CORS station was divided into the time of data, such as 1 hour, 2 hours, 3 hours, 6 hours, and 24 hours. The precise ephemeris data for a day of 15th January 2018 was downloaded from IGS (http://gnssdata.or.kr) and stored in the standard SP3 files. To this end, the baselines were intensively processed in both using broadcast and precise ephemeris TBC version 3.5. The TBC is a commercial software provided by a Trimble Geospatial company that can estimate 3D coordinates through the static mode of GNSS data (Department of Transport and Main Roads, 2019). In this study, the options for baseline processing by TBC were indicated in Table 5. All data were processed using the default options in TBC, excepting the type of satellite ephemeris: broadcast or precise. These options included an elevation mask of 10 degrees and multiple frequencies were applied for solving ambiguity solutions that cause a fixed or a float solution. As noted above, only GPS measurement has been used in this study. After data processing, the obtained results of horizontal and vertical components have been assessed in terms of precision.

*Table 5.* Options used in baseline processing

| Options | Used in processing |
|---|---|
| GNSS used | GPS only |
| Elevation mask | 10 degree |
| Satellite ephemeris | Broadcast/Precise Ephemeris |
| Frequency | Multiple |
| Ionosphere effect | Automatic |

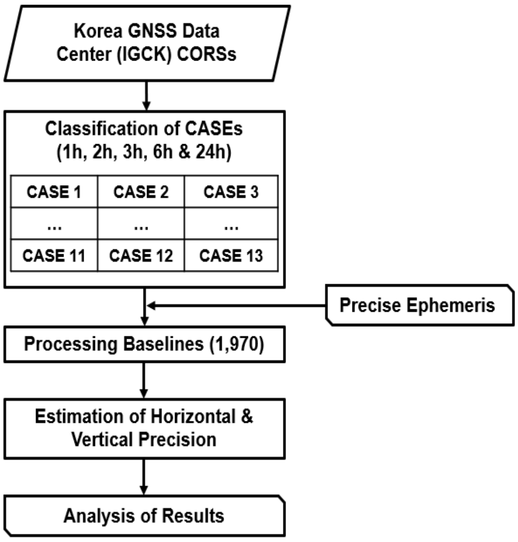


*Figure 3.* A procedure of GNSS data processing and analysis

## 4. Results

It is well known that both the length and the duration impact the quality of the baseline processing by the relative positioning technique. To investigate the performance of baseline processing using broadcast and precise ephemeris, the precision of horizontal and vertical components for all baselines are evaluated. Fig. 4 to 8 presented the precision of the baseline component of all baseline following the time of data, while these averages are shown in Fig. 9 to 13 for the solution using both broadcast and precise ephemerids. It is noted that the horizontal and vertical precision is a measure of accuracy in calculating the position of the observed stations. Overall, the results are shown in Fig. 4 to 8 that there is no difference in precision between broadcast and precise ephemerides in case of bassline length smaller than 50 km. This result is also clearly illustrated in Fig. 9 to 13. Besides, the averages precision of using broadcast becomes larger in proportion to the baseline lengths, while those of using precise is almost similar (e.g., see Fig. 9 to 13). On the other hand, the results also have shown that the precision of the solution is dependent on the time of data. These results will be discussed below.

To look into the impact of the length in more detail, the thirteen cases were re-divided into three groups based on the length of the baseline. Group 1 consisted of a length smaller than 50 km, while those of Group 2 between 50 km and 100 km. Group 3 included the baselines that have length larger than100 km. The average and their standard deviation of horizontal and vertical precision of each group were summarized in Table 6 and Fig. 14.

The results showed that the precision of horizontal using broadcast is about 4 mm, 9 mm, and 16 mm of Group 1, 2, and 3, respectively. While those values using precise are 4 mm, 5 mm, and 5 mm. For the vertical component, the precision of groups 1, 2, 3 are 15 mm, 26 mm, 42 mm in the broadcast case, and 15 mm, 15 mm, 15 mm in the precise case. As a result, there is no difference in using precise compared with broadcast in Group 1 (e.g., length < 50 km). Therefore, it is not beneficial to use the precise in this group. However, using the precise ephemeris significantly improved the accuracy of both horizontal and vertical components of baseline length is larger than 50 km (e.g., Group 2 & 3); for example, reducing from 9 mm to 5 mm and 26 mm to 15 mm in horizontal and vertical components in Group 2. Therefore, it can be concluded that the precise ephemeris would use in baseline processing when the length of baselines is over 50 km to obtain the highest precision in the results.

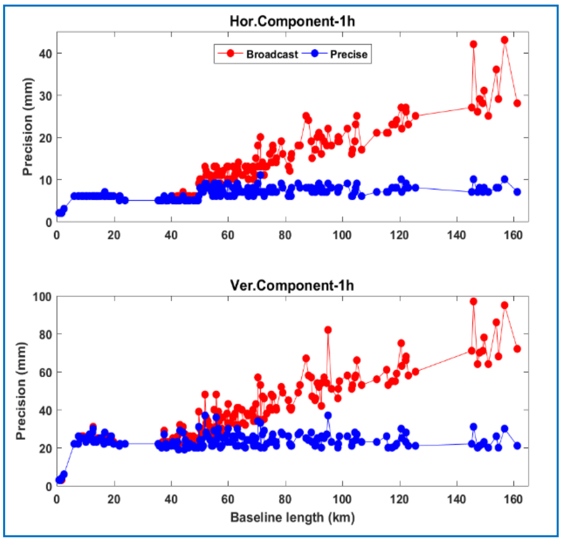


*Figure 4.* Estimated precision of horizontal and vertical components of all baselines (1-hour)

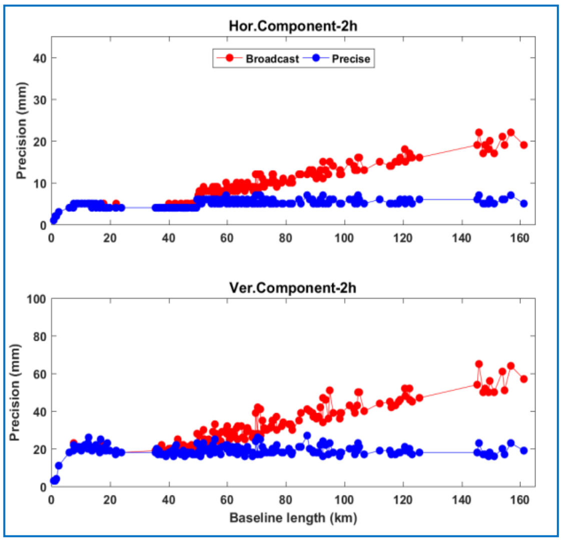


*Figure 5.* Estimated precision of horizontal and vertical components of all baselines (2-hours)

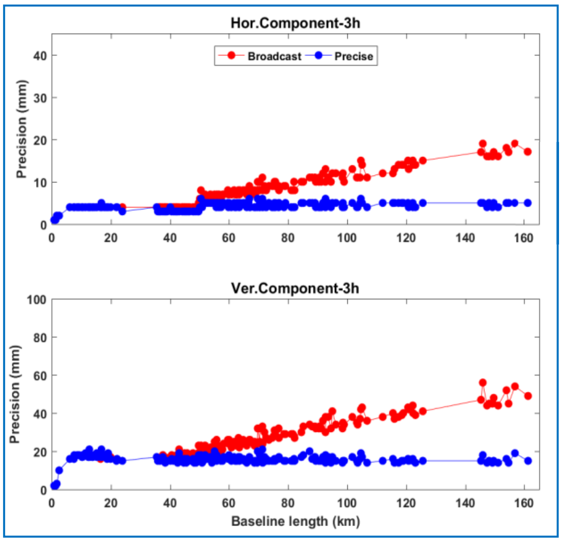


*Figure 6.* Estimated precision of horizontal and vertical components of all baselines (3-hours)

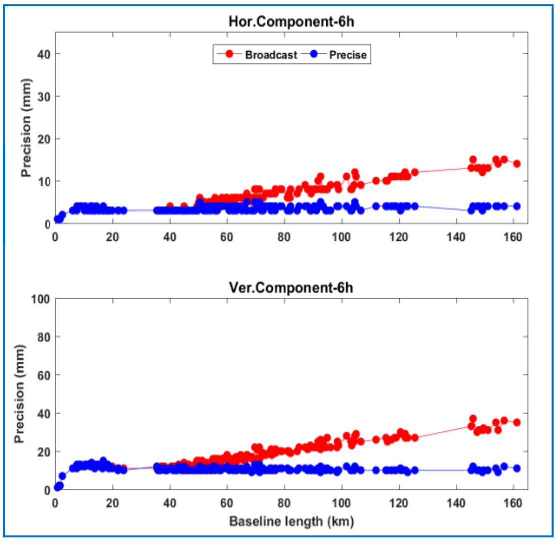


*Figure 7.* Estimated precision of horizontal and vertical components of all baselines (6-hours)

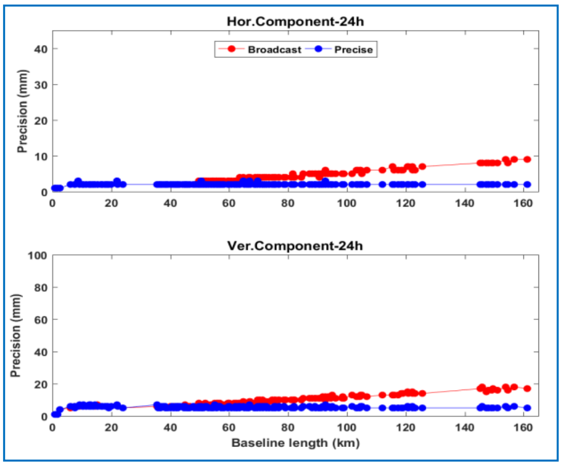


*Figure 8.* Estimated precision of horizontal and vertical components of all baselines (24-hours)

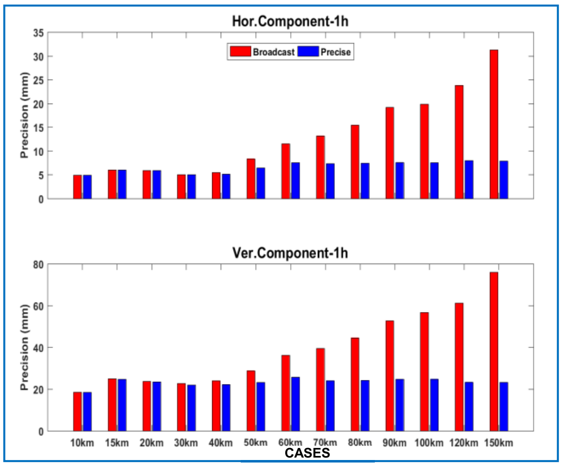


*Figure 9.* Averaged precision of horizontal and vertical components of all cases (1-hour)

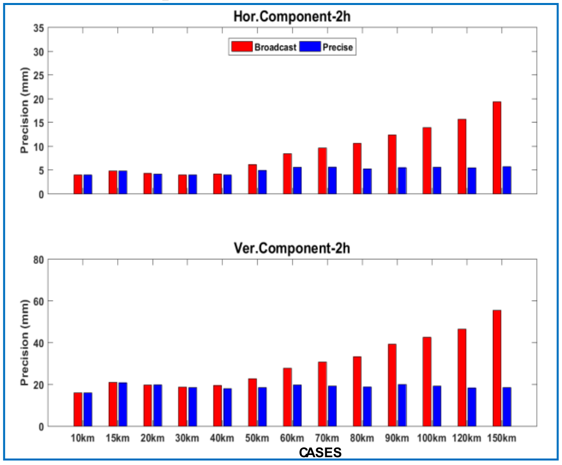


*Figure 10.* Averaged precision of horizontal and vertical components of all cases (2-hours)

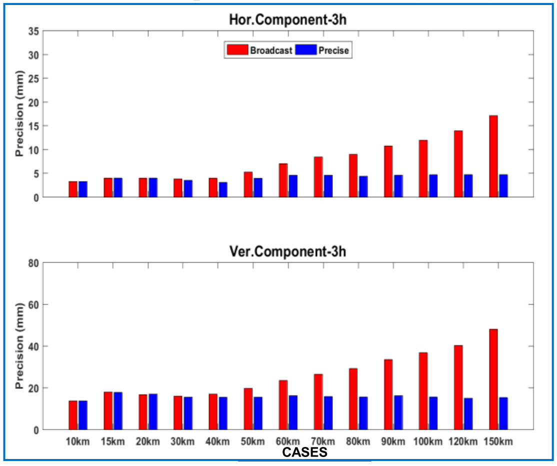


*Figure 11.* Averaged precision of horizontal and vertical components of all cases (3-hours)

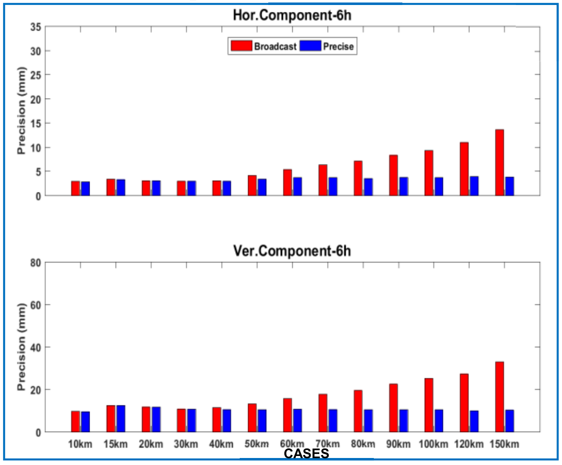


*Figure 12.* Averaged precision of horizontal and vertical components of all cases (6-hours)

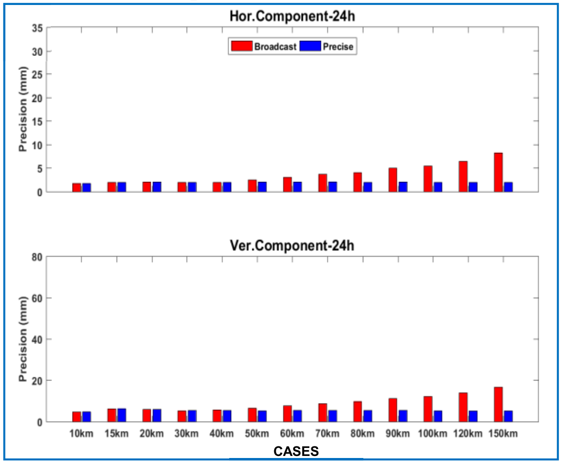


*Figure 13.* Averaged precision of horizontal and vertical components of all cases (24-hours)

On the other hand, Table 6 and Fig. 14 also indicated that the accuracy of Group 1, 2, 3 are 5 mm, 5 mm, 5 mm for the horizontal component and 15 mm, 15 mm, 15 mm for the vertical component if the precise ephemeris is used. It is interesting that although the length of the baseline increases, the result of baseline processing (e.g., precise) are almost similar. Therefore, the solution is independent of the length of the baseline if precise ephemeris is used in the baseline processing.

*Table 6.* Results of precision of re-grouping baseline length

| Group | Baseline length | Horizontal component (m) | | | | Vertical component (m) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Broadcast | | Precise | | Broadcast | | Precise | |
| | | Aver. | Std. | Aver. | Std. | Aver. | Std. | Aver. | Std. |
| 1 | < 50 km | 0.004 | 0.001 | 0.005 | 0.001 | 0.015 | 0.007 | 0.015 | 0.006 |
| 2 | 50 km -100 km | 0.009 | 0.004 | 0.005 | 0.002 | 0.026 | 0.013 | 0.015 | 0.007 |
| 3 | > 100 km | 0.016 | 0.007 | 0.005 | 0.002 | 0.042 | 0.020 | 0.015 | 0.007 |

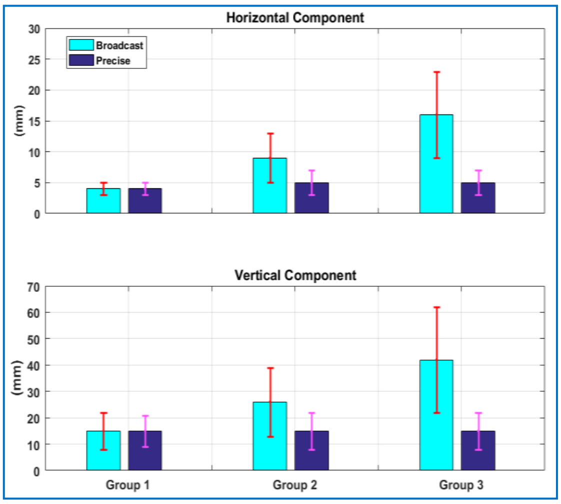


*Figure 14.* Average and their standard deviation of horizontal and vertical components.

For example, the impact of duration of tracking GNSS satellites on the accuracy of the baseline processing solution using both broadcast and precise ephemeris, the averaged precision, and their standard deviation of each component of each duration was summarized in Tables 7, 8 for the horizontal and vertical, respectively. Besides, these results are plotted in Fig. 15 and 16. The obtained results in Table 7 show that using broadcast ephemeris (Br.) for only 1 hour of data, the average precision of horizontal is about 13 mm, but this value decreases to 9 mm, 8 mm, 6 mm and 4 mm in order case of 2 hours, 3 hours, 6 hours, and 24 hours, respectively. For the precise ephemeris (Pr.), the precision of the average is 7 mm, 5 mm, 4 mm, 3 mm, and 2 mm when using duration increase. Therefore, it is clear that increasing the time of data would enhance the precision of baseline processing.

*Table 7.* Horizontal precision statistics of each duration: 1 hour, 2 hours, 3 hours, 6 hours, and 24 hours

| Class. | 1h | | 2h | | 3h | | 6h | | 24h | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. |
| Aver. (m) | 0.013 | 0.007 | 0.009 | 0.005 | 0.008 | 0.004 | 0.006 | 0.003 | 0.004 | 0.002 |
| Std. (m) | 0.008 | 0.001 | 0.005 | 0.001 | 0.004 | 0.001 | 0.003 | 0.001 | 0.002 | 0.001 |

*Table 8.* Vertical precision statistics of each duration: 1 hour, 2 hours, 3 hours, 6 hours, and 24 hours

| Class. | 1h | | 2h | | 3h | | 6h | | 24h | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. |
| Aver. (m) | 0.039 | 0.024 | 0.030 | 0.019 | 0.026 | 0.016 | 0.018 | 0.011 | 0.009 | 0.005 |
| Std. (m) | 0.018 | 0.002 | 0.012 | 0.001 | 0.011 | 0.001 | 0.007 | 0.001 | 0.004 | 0.001 |

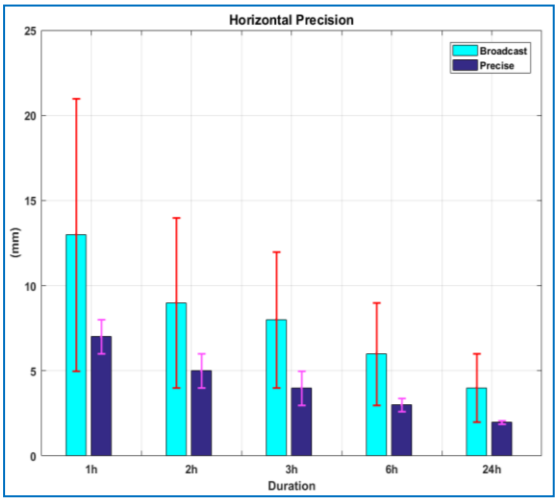


*Figure 15.* Horizontal precision of all baseline as a function of time

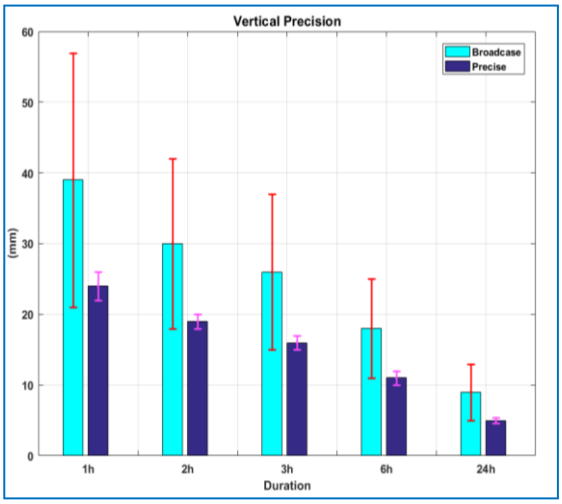


*Figure 16.* Vertical precision of all baseline as a function of time

For the vertical component, the result was indicated in Table 8 and Fig. 16. the precision of the vertical component is 39mm, 30mm, 26mm, 18mm, and 9mm in cases of 1hours, 2 hours, 3 hours, 6 hours, and 24 hours, respectively. While those of 24mm, 19mm, 16mm, 11mm, and 5mm when applying the precise ephemeris. Similar to the horizontal component, it is indicated that the baseline precision is a function of the duration of tracking GNSS satellite. It is mean that when using more time of data, the more improvement of the solution of baseline processing.

As the analysis above, it is thus evident that in practice both baseline distance and the duration of satellite data collection are two factors that impact the precision of baseline solution when it is beneficial to use the precise ephemeris in baseline processing. To find the case which obtains the highest precision, the solution of horizontal and vertical components using precise ephemeris based on two aspects: length of baseline and time of data were summarized in Table 9 that expressed in 3D error for combined horizontal and vertical components. Besides, the graph quantifies of difference in the solution obtained using both precise and broadcast gave an amount of observation time and variable baseline distance group was indicated in Fig. 17. The 3D precision is calculated as follows equation:

$$3D-\text{Precision}=\sqrt{(\text{Horizontal Precision})^2+(\text{Vertical Precision})^2} \quad (1)$$

As shown in Table 9, the different result of broadcast and precise ephemerides was not found in Group 1 case with baseline length smaller than 50 km. In contrast, there is a clear benefit when using precise ephemeris for the baseline of 50 km or larger. In these cases, the precision of orbit position and clock corrections helps for obtaining more accuracy of baseline solution compared with those of broadcast ephemeris. Besides, the 3D error significantly increased when the length of the baseline increases. On the other hand, the precise baseline solution was enhanced when increasing the time of data. For example, a 3D error improvement of approximately 17 mm, 36 mm, and 57 mm in Group 1 is seen in the solution that used the precise ephemeris when using 1 hour and 24 hours of data, respectively. The best level of observed 3D error was 6 mm for all three groups using 24 hours of data and the precise ephemeris.

*Table 9.* Observed 3D precision of grouping as a function of baseline length and observation time

| Group | 1h (m) | | 2h (m) | | 3h (m) | | 6h (m) | | 24h (m) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. | Br. | Pr. |
| 1 | 0.023 | 0.023 | 0.019 | 0.019 | 0.017 | 0.016 | 0.012 | 0.011 | 0.006 | 0.006 |
| 2 | 0.046 | 0.026 | 0.034 | 0.020 | 0.030 | 0.016 | 0.020 | 0.011 | 0.010 | 0.006 |
| 3 | 0.074 | 0.025 | 0.054 | 0.019 | 0.047 | 0.016 | 0.033 | 0.011 | 0.017 | 0.006 |

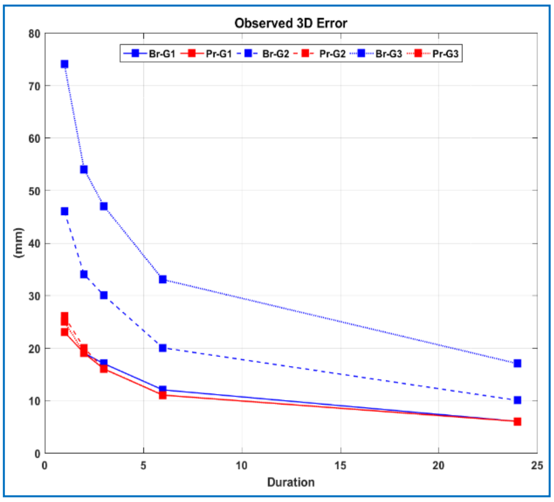


*Figure 17.* Observed 3D Error as a Function of Baseline Length and Time of Data

## 5. Conclusions

Through baseline processing and analysis of its results, it is evident that GNSS baseline processing is dependent on both the baseline length and duration of data. The precise ephemeris does not affect baseline solution compared with broadcast ephemeris when the length of the baseline smaller than 50 km. In contrast, the accuracy of the baseline significantly improved for the length of the processing baseline exceeding 50 km. Therefore, the precise ephemeris suggested using these lengths of baselines for obtaining the highest solution.

This study also has shown that the longer baseline length the lower precision in using the broadcast case, while it is independent of the precise ephemeris was used. Meaning that the baseline length does not impact the baseline solution in the case of using the precession ephemeris in baseline processing.

The result indicated that the obtained precision of the baseline solution is also a function of the time of data. The solution improves if the duration of tracking satellite increases whether using broadcast or precise ephemeris. The combination of both 24 hours of data and the precise ephemeris is given the highest accuracy of the baseline solution.

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