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IMPROVING THE ACCURACY IN PROCESSING GNSS DATA BASED ON PRECISE EPHEMERIS

Bui Thi Hong Tham, Trinh Thi Hoai Thu
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

This paper presents for using precise ephemeris to improve point positioning accuracy when processing GNSS data. The experimental GNSS network locates in Dak Nong province. It consists of 13 points, of which 3 points are control points for coordinates and height. The shortest baseline of the GNSS network is 2.5 km, the longest is 68.5 km and the average is 34.3 km. The data of the GNSS network is processed in two ways: Option one is to use broadcast ephemeris; Option two is to use precise ephemeris. Research results show that the error of point positioning of option two is smaller than option one, respectively. The minimum value of this error is 0 mm, the maximum is 3 mm and the average is 1 mm. There is not much difference in the height error of the points when adjusting according to the two options. The biggest difference is 2 mm, the smallest is 0 mm and the average is 1 mm. The accuracy of the GNSS point positioning depends on how the data is processed. The accuracy of point positioning when using a precise ephemeris is higher than that of using a broadcast ephemeris. Currently, exacting precise ephemeris from the internet is easy. Precise ephemeris is updated quickly in the software. The accuracy and reliability of the adjustment results are high. Therefore, precise ephemeris should be used during GNSS data processing.

Keywords: Ephemeris; Precise ephemeris; Broadcast ephemeris; GNSS; Adjustment.

Corresponding author. Email: bththam@hunre.edu.vn

1. Introduction

The process of processing Global Navigation Satellite System (GNSS) data follows the principle: Determine the satellite orbit from the ephemeris, then combine with the measured values to calculate the coordinates, the height of the points, the distance between points and their accuracy.

An ephemeris is a set of data that represents a satellite's position as a function of time. There are three types of satellite calendars: Almanac ephemeris, broadcast ephemeris and precise ephemeris. These satellite calendars have different accuracy, so the satellite calendar chosen while processing GNSS data will affect the coordinates as well as the accuracy of the factors after network adjustment [7, 8, 9, 10].

In normal GNSS data processing, broadcast ephemerises are used in the calculation. Precise ephemerises are interested in processing GNSS data with high accuracy requirements (for researching the modern movement of the Earth's crust, studying changes in sea level and building national frame geodesy) by scientific software such as Bernese, Gamit/Globk.

In this paper, for improving the accuracy of point positions, precise ephemerises will be used to process GNSS data by commercial software. The study not only shows the role of precise ephemeris in processing GNSS data but also suggests for GNSS data handlers in using precise ephemeris.

2. Theoretical basis

2.1. Broadcast ephemeris

GNSS broadcast ephemerides are forecasted, predicted or extrapolated satellite orbits data which are transmitted from the satellite to the receiver in the navigation message. Because of the nature of the extrapolation, broadcast ephemerides do not have enough high qualities for precise applications. The predicted orbits are curve fitted to a set of relatively simple disturbed Keplerian elements and transmitted to the users.

a_0, a_1, a_2: Polynomial coefficients of the clock error.

t_{oe}: Reference epoch of the ephemerides

$\sqrt{a}$: Square root of the semimajor axis of the orbital ellipse.

e: Numerical eccentricity of the ellipse.

M_0: Mean anomaly at the reference epoch t_{oe}.

ϖ_0 : Argument of perigee.

i_0: Inclination of the orbital plane.

Ω_0: Right ascension of ascending node.

Δn: Mean motion difference.

idot: Rate of inclination angle.

$\dot{\Omega}$: Rate of node's right ascension.

C_{UC}, C_{US}: Correction coefficients (of argument of latitude).

C_{rC}, C_{rS}: Correction coefficients (of geocentric distance).

C_{iC}, C_{iS}: Correction coefficients (of inclination).

2.2. Precise ephemeris

Since the 1980s, due to the importance of precise ephemeris, international professional organizations have been interested and cooperated in promoting the establishment of its. Not only that, this product has been unified and standardized. From the beginning, precise ephemeris was designated the standard product (SP). As with many other GNSS products and metrics, the standardization is brought many benefits to the user community [2, 3].

In 1982, the organizations agreed to develop precise ephemeris.

In 1985, the first generation of precise ephemeris was announced: SP1 and ECF1, SP2 and ECF2. The SP1 ephemeris in ASCII includes the coordinate component and the velocity component of the satellite at a given time. Not all GNSS applications require high accuracy so that SP2 calendar is also published. The SP2 ephemeris is also in ASCII, but only includes the coordinates of the satellites. ECF1, ECF2 is the binary form corresponding to SP1 and SP2. EF13 is the compressed form of ECF2.

In 1989, the 2nd generation precise ephemeris was published. In addition to the same parameters as in the 1st

generation, the 2nd generation precision satellite calendar adds clock correction to improve the accuracy of positioning applications. Standardized orbit offer many advantages, especially in ephemeris conversion. ASCII and binary both serve this function, but binary is simpler because it is independent of the computer's operating system.

IGS operates the publication of the precise ephemeris. Monitoring data from IGS sites are transferred to the following centres: Jet Propulsion Laboratory (JPL); Scripps Institution of Oceanography; National Geodetic Survey (NGS); GeoForschungsZentrum (Berlin); Center for Orbit Determination in Europe (University of Berne, Switzerland); European Space Agency; Canada (EMR) processing. The final accurate satellite calendar is the combined solution of the solutions received from the centres.

The precise ephemeris is determined based on: The accurate model for transition of reference systems; The accurate model represents the effects of anomalies on satellites and measuring points; The precise coordinates of points in the ITRF which these poitns are observation of the satellite; Processing software; Atmospheric delay error model; Model of solar storm pressure; System of continuous monitoring points in the world with high quality data. The database for processing data (real - time) is strong enough [4, 6].

Each data processing software uses a type of ephemeris. When processing GNSS data using precise ephemeris, it is necessary to understand their structure, quantities and meanings. In general, the structure of each type of precise ephemeris can be divided into two parts [5]: The header and the body. The file header contains information about the ephemeris type, issuing agency, time, satellite type,... The body of the file is the quantities directly related to the ephemeris. The quantities, their characteristics and their meanings are different depending on the type of ephemeris. In principle, all ephemeris issuers have a notice explaining the structure of the ephemeris in detail. From time to time, versions of the satellite calendar have been published in the formats SP3a, SP3c and SP3d. The SP3d format adds three extensions to the previous SP3c format as the maximum number of satellites is increased from 85 to 999, the unlimited number of comment records allowed in the header and the maximum length of each track comment recording has been increased from 60 characters to 80 characters.

Table 1. Part of an ephemeris file in SP3d format

```
#dP2013 4 3 0 0 0.00000000 96 ORBIT WGS84 BCT MGEX
## 1734 259200.00000000 900.00000000 56385 0.0000000000000
+ 140 G01G02G03G04G05G06G07G08G09G10G11G12G13G14G15G16G17
+ G18G19G20G21G22G23G24G25G26G27G28G29G30G31G32R01R02
+ R03R04R05R06R07R08R09R10R11R12R13R14R15R16R17R18R19
+ R20R21R22R23R24E01E02E03E04E05E06E07E08E09E10E11E12
+ E13E14E15E16E17E18E19E20E21E22E23E24E25E26E27E28E29
+ E30C01C02C03C04C05C06C07C08C09C10C11C12C13C14C15C16
+ C17C18C19C20C21C22C23C24C25C26C27C28C29C30C31C32C33
```

```
+ C34C35J01J02J03I01I02I03I04I05I06I07S20S24S27S28S29
+ S33S35S37S38 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 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 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
%c M cc GPS ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%f 1.2500000 1.025000000 0.00000000000 0.000000000000000
%f 0.0000000 0.000000000 0.00000000000 0.000000000000000
%i 0 0 0 0 0 0 0 0 0
%i 0 0 0 0 0 0 0 0 0
/* Note: This is a simulated file, meant to illustrate what an SP3-d header
/* might look like with more than 85 satellites. Source for GPS and SBAS satel29
/* lite positions: BRDM0930.13N. G=GPS, R=GLONASS, E=Galileo, C=BeiDou,J=QZSS,
/* I=IRNSS,S=SBAS. For definitions of SBAS satellites, refer to the website:
/* http://igs.org/mgex/status-SBAS
* 2013 4 3 0 0 0.00000000
PG01 5783.206741 -18133.044484 -18510.756016 12.734450
PG02 -22412.401440 13712.162332 528.367722 425.364822
PG03 10114.112309 -17446.189044 16665.051308 189.049475
PG04 -24002.325710 4250.313148 -11163.577756 179.333612
PG05 -15087.153141 8034.886396 20331.626539 -390.251167
PG06 13855.140409 -11053.269706 19768.346019 289.556712
……………………………………………………………………………………………………………………
PS28 5169.591020 41849.037979 17.421140 0.170452
PS29 -32240.432088 27155.480094 -12.156456 0.101500
PS33 -5555.490565 -41739.269117 2093.250932 -0.199099
PS35 -28749.533445 -30836.454809 -4.729472 -0.008333
PS37 -34534.904566 24164.610955 29.812840 0.299420
PS38 -12548.655240 -40249.910397 -3.521920 -0.027787
```

```
* 2013 4 3 0 15 0.00000000
………………………………………………………………………………………………………………………………
* 2013 4 3 23 45 0.00000000
PG01 4340.761149 -17469.395805 -19521.652181 13.021579
PG02 -22187.015530 13877.264416 2583.141886 425.527461
PG03 9785.535610 -18824.396329 15333.698561 189.465625
PG04 -24642.374460 4816.578416 -9365.337848 180.261632
PG05 -13667.233808 8977.038381 20922.734874 -390.371011
PG06 13696.828033 -12657.020030 18869.219517 288.240920
………………………………………………………………………………………………………………………………
```

Table 1 is part of the SP3d ephemeris, on which the most basic features can be explained and summarized in Table 2.

Table 2. Basic features of an ephemeris file in SP3d format

Row	Description
1	Ephemeris version (d), ephemeris type (P: Position or V: Velocity), time, number of records (96), description of data used (ORBIT: Mixed data from multiple agencies), coordinate system (IGS05), orbital type (HLM: FIT form after applying the Helmert transform), issuing agency (IGS).
2	the GPS week; The seconds of the GPS Week elapsed at the start of the orbit (0.0 <= seconds of week < 604800.0); The epoch interval (0.0 < epoch interval < 100000.0) in seconds; The modified Julian Day Start (where 44244 represents GPS zero time - January 6, 1980) and fractional part of the day (0.0 <= fractional < 1.0) at the start of the orbit.
3 - 11	Indicates the number of satellites followed by their respective identifiers. For the SP3d format, the maximum number of satellites has been increased from 85 to 999. Hence there can now actually be more than five "+" lines if there are more than 85 satellites. For the sake of backwards compatibility, if an SP3d file has less than 85 satellites, it must still have five satellite ID ("+") lines. The identifiers must use consecutive slots and continue as many lines as required. The value 0 should only appear after all the identifiers are listed (see Example 1). Satellite identifiers may be listed in any order. However, for ease in reviewing satellites included in the orbit file it is recommended that numerical order be used. Each identifier will consist of a letter followed by a 2 - digit integer between 01 and 99. For example, "Gnn" for GPS satellites, "Rnn" for GLONASS satellites, "Lnn" for Low - Earth Orbiting (LEO) satellites, "Snn" for Satellite - Based Augmentation System (SBAS) satellites, "Enn" for Galileo satellites, "Cnn" for BeiDou Navigation Satellite System (BDS) satellites, "Inn" for the Indian Regional Navigation Satellite System (IRNSS) satellites and "Jnn" for the Japanese Quasi - Zenith Satellite System (QZSS) satellites. For QZSS the nn = PRN - 192 rule is applied, for example QZS - 1 (PRN = 193) is expressed by "J01". Other letters will be allowed for other types of satellites. Lower numbered satellites must always have a preceding zero (e.g., "G09" not "G9"). The letter, which represents the Satellite System Indicator, must always be present (i.e., "09" is no longer a valid satellite identifier). This is a significant change from SP3 - a and needs to be noted when software is updated to read the new SP3c or SP3d format.

Row	Description
12 - 20	The twelfth to the twentieth lines hold the orbit accuracy exponents. The value 0 is interpreted as accuracy unknown. A satellite's accuracy exponent appears in the same columns within these lines as the identifier on the satellite ID lines. The accuracy is computed from the exponent as in the following example. If the accuracy exponent is 13, the accuracy is 2**13 mm or ~ 8 m. The quoted orbital error should represent one standard deviation and be based on the orbital error in the entire file for the respective satellite. This may lead to some distortion when orbit files are joined together, or when a file contains both observed and predicted data.
21 - 22	On the twenty - first line, columns 4 - 5 hold the File Type descriptor. This is a single character left-justified in the two-character field. The currently defined values are: "G" for GPS only files, "M" for mixed files, "R" for GLONASS only files, "L" for LEO only files, "S" for SBAS only files, "I" for IRNSS only files, "E" for Galileo only files, "C" for BeiDou only files and "J" for QZSS only files. No default values are implied; Either "G", "M", "R", "L", "S", "I", "E", "C", or "J" is required. On this same line, columns 10 - 12 hold the Time System Indicator. In order to remove any ambiguity with respect to which time system is being used in mixed files, this field specifies the time system used in each SP3d file: Use "GPS" to identify GPS Time, "GLO" to identify the GLONASS UTC time system, "GAL" to identify Galileo system time, "BDT" to identify BeiDou system time, "TAI" to identify International Atomic Time, "UTC" to identify Coordinated Universal Time, "IRN" to identify IRNSS Time, or "QZS" to identify QZSS Time. No default value is implied; either "GPS", "GLO", "GAL", "BDT", "TAI", "UTC", "IRN", or "QZS" must be specified.
23 - 24	On Line twenty - three, columns 4 - 13 would hold the floating - point base number used for computing the standard deviations for the components of the satellite position and velocity. Instead of using 2**nn as is done in the orbit accuracy lines 12 - 20 in the header, better resolution can be attained using a number like 1.25**nn. The units for position and velocity are mm and 10**-4 mm/sec, respectively. Likewise, columns 15 - 26 would hold the floating - point base number for computing the standard deviations for the clock correction and the rate-of-change of the clock correction. Again, instead of using 2**nnn, one might use a number like 1.025**nnn (see also Example 2). The units for the clock correction and the rate-of-change of the clock correction are picosec and 10**-4 picosec/sec, respectively.
21 - 26	The six lines that begin with the character "%" have been designed so that additional parameters may be added to the SP3 format.
27 - 31	There are free form comments (comments go in columns 4 - 80). For backwards compatibility, there will always be at least 4 comment lines. These can be filled with "/* CCCCC…CCC" or with "/*". The comment lines should be read in until the first Epoch Header Record (i.e. the first time tag line) is encountered.
32	It is the first epoch header record, showing the epoch date/time.
33	It is the first Position and Clock Record; The first character is always 'P'. The positional values are in kilometers and are precise to 1 mm. A precision of 0.5 mm can be accommodated if rounding is used, i.e., the value shown is never more than 0.5 mm from the computed value. The clock values are in microseconds and are precise to 1 picosecond. Bad or absent positional values are to be set to 0.000000. Bad or absent clock values are to be set to _999999.999999. The six integer nines are required, whereas the fractional part nines are optional.

The above are the most important features to be able to identify the quantities, parameters and meanings in the ephemeris file. It is necessary to find out in detail from the accompanying documents of the ephemeris issuing authorities for specific applications.

2.3. GNSS data processing

The principle of processing GNSS measurement data is to determine the satellite orbit from ephemerises and then combine it with the measured values to calculate the coordinates of the points, the distance between the points and their accuracy. Basically, the processing of GNSS data includes the following main steps: Extracting data from the receiver to the computer; Processing baselines; Checking the network; Adjusting the network [1].

The calculation of adjustment is done after the results of the baseline resolution meet the requirements. It means that the error of characteristic elements of the GNSS network is within the allowed error limit. The GNSS network needs to be adjusted in the 3D coordinate system. Similar to other geodetic networks, the GNSS network is also adjusted according to the principle of least squares, the condition [PVV] = min. The GNSS network is presented in the X, Y and Z geocentric space perpendicular coordinate system or in the B, L and H geodetic coordinate system.

3. Experimental data

The GNSS network in Dak Nong province is built for the establishment of topographic maps of bauxite mines in this province. The network consists of 13 points of which 3 points play role in coordinate and height controls.

3.1. Control points

Table 3. Control points of GNSS network in bauxite mine area of Dak Nong province

N^{o}	Point	X (m)	Y (m)	H (m)
1	I(BMT-APD)15	461039.9274	1342762.8218	813.3559
2	I(BMT-APD)28	424699.2050	1312862.8638	432.5320
3	II(DN-DL)12-1	498296.9474	1291083.3910	1051.0290

Coordinates of points in Table 3 at axis meridian 108^{o}, projection zone 3^{o}, Hon Dau height system.

3.2. Measurement data

Measurement data files include: 12-13411.dat, I-153411.dat, I-283411.dat, IV553411.dat, IV613412.dat, IV693412.dat, IV703412.dat, KN663411.dat, N0623412.dat, N0693412.dat, N0703411.dat, N0743411.dat, N0773411.dat and N0793411.dat.

3.3. Precise ephemerises

The precise ephemeris files include: igs14043.sp3 and igs14044.sp3.

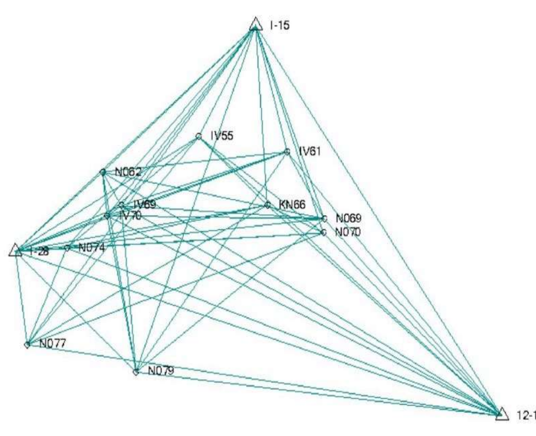

Figure 1: Diagram of GNSS network

Part of the Rinex file will be shown in the following table:

Table 4. Part of file 12-13411.06O

```
     2.11        OBSERVATION DATA    G (GPS)          RINEX VERSION / TYPE
HuaceNav                                      PGM / RUN BY / DATE
12-1                                          MARKER NAME
                                              OBSERVER / AGENCY
Trimble Dat File                              REC # / TYPE / VERS
                                              ANT # / TYPE
 -1929326.4597  5942739.4120  1282395.5678              APPROX POSITION XYZ
        1.5000        0.0000        0.0000              ANTENNA: DELTA H/E/N
     1     1                                  WAVELENGTH FACT L1/2
     2    C1    L1                            # / TYPES OF OBSERV
    15.000                                    INTERVAL
  2006    12     6    23    56   15.000000      GPS       TIME OF FIRST OBS
                                              END OF HEADER
 06 12  6 23 56 15.0000000  0  8G 1G 3G16G20G23G25G31G19
  20658371.719     -280294.4695
  20135761.039     -652812.5945
  21677376.141     -151053.3485
  22919110.727     -359949.3835
  22462978.102     -899525.4775
  22434918.109     -472439.0125
  23036374.383     -408703.5005
  21763240.398     -244259.7075
 06 12  6 23 56 30.0000000  0  8G 1G 3G16G20G23G25G31G19
  20653035.484     -308333.6254
  20123118.031     -719253.1604
  21674456.000     -166399.2624
  22912066.031     -396967.3714
  22445254.484     -992660.9964
  22425640.445     -521193.5274
  23028351.063     -450867.9534
  21746273.852     -333420.4924
 06 12  6 23 56 45.0000000  0  8G 1G 3G16G20G23G25G31G19
  20647732.383     -336201.6804
  20110506.930     -785523.6454
  21671546.984     -181685.3714
```

22905044.828	-433866.8554
22427550.313	-1085700.6374
22416373.492	-569893.4614
23020337.367	-492978.8794
21729326.414	-422478.2504

From this Rinex file, it is shown that the experimental network only receives the signal of the GPS system (G).

The experimental GNSS network is processed in two ways:

- Option 1: Using broadcast ephemeris in the process of processing experimental network data.

- Option 2: Using precise ephemeris in the process of processing experimental network data.

From the results obtained according to the above two data processing options, compare, analyze and evaluate the results.

4. Result and discussion

The data of the experimental GNSS network are processed by Trimble Business Center 5.0 (TBC) software in the sequence of the data processing steps mentioned above. After adjusting, the coordinates, height and typical errors for the accuracy of the network are determined.

Table 5. Comparative table of coordinates and heights of the points after adjustment

Point	Broadcast ephemeris			Precise ephemeris			ΔX (m)	ΔY (m)	Δh (m)
	X (m)	Y (m)	h (m)	X (m)	Y (m)	h (m)			
IV55	1328049.392	452422.036	704.65	1328049.392	452422.036	704.653	0.000	0.000	-0.003
IV61	1326064.069	465829.141	635.246	1326064.068	465829.139	635.246	0.001	0.002	0.000
IV69	1318932.208	440717.316	592.74	1318932.210	440717.316	592.737	-0.002	0.000	0.003
IV70	1317591.890	438574.006	524.078	1317591.893	438574.004	524.067	-0.003	0.002	0.011
KN66	1319000.890	462799.096	608.98	1319000.889	462799.095	608.978	0.001	0.001	0.002
N062	1323385.715	437868.342	481.844	1323385.715	437868.343	481.837	0.000	-0.001	0.007
N069	1317202.136	471383.423	572.823	1317202.136	471383.418	572.822	0.000	0.005	0.001
N070	1315324.111	471267.457	657.477	1315324.110	471267.455	657.473	0.001	0.002	0.004
N074	1313335.764	432450.537	553.715	1313335.764	432450.536	553.714	0.000	0.001	0.001
N077	1300535.752	426496.767	432.508	1300535.752	426496.768	432.501	0.000	-0.001	0.007
N079	1296925.272	442952.585	528.331	1296925.275	442952.583	528.326	-0.003	0.002	0.005

It can be seen that:

- The maximum value of the deviation in coordinates between option one and option two in the X direction is 3 mm, in the Y direction is 5 mm and in height is 11 mm.

- The maximum value of the difference in coordinates between option one and option two in the X direction, Y direction and the height is 0 mm.

- The average value of the difference in coordinates between option one and option two in the X direction is 1 mm, in the Y direction is 1 mm and in height is 4 mm.

Table 6. The error in point positioning and point height

Nº	Point	Broadcast ephemeris (m)		Precise ephemeris (m)		Δmp (m)	Δmh (m)
		m_p (m)	m_h (m)	m_p (m)	m_h (m)		
1	IV55	0.013	0.028	0.013	0.029	0	-0.001
2	IV61	0.014	0.031	0.013	0.030	0.001	0.001
3	IV69	0.011	0.024	0.009	0.023	0.002	0.001
4	IV70	0.011	0.024	0.009	0.023	0.002	0.001
5	KN66	0.014	0.029	0.014	0.030	0	-0.001
6	N062	0.011	0.024	0.009	0.023	0.002	0.001
7	N069	0.015	0.036	0.013	0.034	0.002	0.002
8	N070	0.015	0.033	0.015	0.033	0	0
9	N074	0.009	0.018	0.009	0.019	0	-0.001
10	N077	0.011	0.027	0.011	0.027	0	0
11	N079	0.018	0.042	0.015	0.040	0.003	0.002

It can be seen that:

- The error of point positioning when adjusting the network using precise ephemeris is smaller than that of when adjusting the network using broadcast ephemeris. The minimum value is 0 mm, the maximum is 3 mm and the average is 1 mm. Thus, it shows that the deviation value of the position error between the two options is not large.

- There is not much difference in the height error of the point when adjusting according to the two options. The maximum difference in height error difference between the two options is 2 mm, the minimum is 0 mm and the average is 1 mm.

Table 7. Baseline error and baseline relative square error

Point	Point	Distance S (m)	Broadcast ephemeris		Precise ephemeris		ΔS (m)	$Δm_s$ (m)
			m_s	m_s/s	m_s	m_s/s		
12-1	IV55	58915.131	0.01	1/5654003	0.01	1/5632804	0	0
12-1	IV61	47726.369	0.01	1/4665855	0.009	1/5152880	0	0.001
12-1	IV69	63960.695	0.009	1/7428949	0.007	1/8947910	-0.001	0.002
12-1	IV70	65341.642	0.009	1/7497832	0.007	1/9122391	-0.003	0.002
12-1	KN66	45160.649	0.011	1/4201545	0.011	1/4271746	0	0
12-1	N062	68520.482	0.009	1/7929044	0.007	1/9512853	0.001	0.002
12-1	N069	37503.688	0.012	1/3237227	0.01	1/3763007	-0.004	0.002
12-1	N070	36307.104	0.012	1/3109387	0.011	1/3193691	-0.001	0.001
12-1	N074	69504.804	0.007	1/9931255	0.007	1/9654496	-0.001	0
12-1	N077	72419.700	0.009	1/7934892	0.009	1/7990754	0.001	0
12-1	N079	55651.828	0.014	1/3980023	0.011	1/4903223	-0.002	0.003
I-15	IV55	17051.483	0.007	1/2275698	0.007	1/2292931	0	0
I-15	IV61	17371.958	0.009	1/1964413	0.008	1/2073530	0	0.001
I-15	IV69	31319.430	0.007	1/4477996	0.006	1/5012540	0.002	0.001
I-15	IV70	33738.604	0.007	1/4702042	0.006	1/5347185	0.001	0.001
I-15	KN66	23826.961	0.008	1/2935721	0.008	1/2942626	-0.001	0

Point	Point	Distance S (m)	Broadcast ephemeris		Precise ephemeris		ΔS (m)	Δm_s (m)
			m_s	m_s/s	m_s	m_s/s		
I-15	N062	30205.871	0.007	1/4048107	0.007	1/4580714	0.001	0
I-15	N069	27574.201	0.01	1/2676735	0.009	1/2992595	0.002	0.001
I-15	N070	29282.849	0.01	1/2915564	0.01	1/2970758	0	0
I-15	N074	41028.100	0.006	1/7317910	0.006	1/7185364	0	0
I-15	N077	54555.984	0.007	1/7446284	0.007	1/7498914	0.001	0
I-15	N079	49277.104	0.011	1/4387345	0.01	1/4966039	0.003	0.001
I-28	IV55	31609.903	0.009	1/3373420	0.009	1/3403956	0	0
I-28	IV61	43196.568	0.011	1/3981574	0.009	1/4673482	0.003	0.002
I-28	IV69	17129.414	0.008	1/2149408	0.007	1/2514725	0	0.001
I-28	IV70	14658.574	0.008	1/1790269	0.007	1/2126259	0.001	0.001
I-28	KN66	38591.153	0.011	1/3620845	0.01	1/3719597	0.002	0.001
I-28	N062	16856.944	0.008	1/2244587	0.007	1/2545421	-0.001	0.001
I-28	N069	46885.451	0.012	1/3841918	0.01	1/4611810	0.005	0.002
I-28	N070	46633.248	0.012	1/3892069	0.012	1/4034687	0.002	0
I-28	N074	7765.744	0.007	1/1125436	0.007	1/1095935	0.001	0
I-28	N077	12457.484	0.007	1/1758661	0.007	1/1759669	-0.001	0
I-28	N079	24232.06	0.014	1/1741518	0.011	1/2160003	0.004	0.003
IV55	KN66	13768.034	0.01	1/1340506	0.01	1/1312647	0	0
IV55	N070	22739.452	0.012	1/1899663	0.012	1/1887694	0.001	0
IV55	N074	24806.282	0.01	1/2567349	0.01	1/2568428	-0.001	0
IV55	N077	37803.703	0.01	1/3616612	0.01	1/3666533	0.001	0
IV61	IV69	26104.927	0.011	1/2291979	0.01	1/2697556	0.003	0.001
IV61	IV70	28541.552	0.012	1/2466578	0.01	1/2914965	0.001	0.002
IV61	N062	28088.785	0.012	1/2357011	0.01	1/2769739	0.003	0.002
IV61	N069	10458.676	0.009	1/1143776	0.009	1/1211284	0.002	0
IV61	N079	37046.003	0.013	1/2815703	0.012	1/3170879	0.004	0.001
IV69	IV70	2527.890	0.005	1/ 460861	0.005	1/ 524115	-0.002	0
IV69	N062	5286.812	0.006	1/ 891308	0.005	1/1025074	0.003	0.001
IV69	N069	30714.870	0.013	1/2440751	0.01	1/2941662	0.004	0.003
IV69	N079	22120.164	0.012	1/1910194	0.01	1/2234236	0.001	0.002
IV70	N062	5836.640	0.006	1/1035701	0.005	1/1152714	0.003	0.001
IV70	N069	32811.732	0.013	1/2569922	0.011	1/3108986	0.003	0.002
IV70	N079	21125.365	0.012	1/1785635	0.01	1/2119262	0	0.002
KN66	N070	9232.109	0.009	1/1076748	0.009	1/1061955	0.001	0
KN66	N074	30872.782	0.011	1/2699801	0.011	1/2736490	0	0
KN66	N077	40728.619	0.012	1/3434249	0.012	1/3515961	0.002	0
N062	N069	34080.747	0.013	1/2633226	0.011	1/3159791	0.006	0.002
N062	N079	26944.472	0.012	1/2199363	0.01	1/2584055	0.004	0.002
N069	N079	34920.821	0.014	1/2481295	0.012	1/2880953	0.004	0.002
N070	N074	38867.812	0.013	1/3047599	0.012	1/3114344	0.001	0.001
N070	N077	47149.870	0.013	1/3545024	0.013	1/3655136	0.003	0
N074	N077	14116.929	0.007	1/1972554	0.007	1/1965417	0.001	0

The difference in distance and baseline error when adjusting the two options is not much. However, these values represent the accuracy of the baseline after adjustment. Of the total 61 baselines, there are 49 baselines when adjusted according to option 2 have a relative square error of the baseline smaller than that of option 1. It is an equation of about 80 % of the total number of baselines in the network when adjusted according to the method option 2 has higher accuracy than option 1. This proves that the variance according to option 2 gives higher accuracy.

5. Conclusion

From the above research results, we have:

- The process of calculating the GNSS network adjustment when using the precise ephemeris and the broadcast ephemeris is done according to a strict process. Because of different satellite ephemeris, the coordinates and the height of the points received after adjusting by the two methods are different.

- The experimental GNSS network has the shortest baseline of about 2.5 km, the longest of about 68.5 km and an average of 34.3 km. Therefore, the difference in position error of the GNSS points when adjusted according to the two options is not much. However, research results have also shown that using precise ephemeris while adjusting will give higher accuracy and reliability than that using broadcast ephemeris.

- Precise ephemeris plays an important role in the processing of GNSS data. Currently, the exploitation of precise ephemeris is easy and the process of updating them into the software is quick. Therefore, precise ephemeris should be used during GNSS data processing.

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