

Contribution of BeiDou satellite system for long baseline GNSS measurement in Indonesia

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Abstract. The demand for more precise positioning method using GNSS (Global Navigation Satellite System) in Indonesia continue to rise. The accuracy of GNSS positioning depends on the length of baseline and the distribution of observed satellites. BeiDou Navigation Satellite System (BDS) is a positioning system owned by China that operating in Asia-Pacific region, including Indonesia. This research aims to find out the contribution of BDS in increasing the accuracy of long baseline static positioning in Indonesia. The contributions are assessed by comparing the accuracy of measurement using only GPS (Global Positioning System) and measurement using the combination of GPS and BDS. The data used is 5 days of GPS and BDS measurement data for baseline with 120 km in length. The software used is open-source RTKLIB and commercial software Compass Solution. This research will explain in detail the contribution of BDS to the accuracy of position in long baseline static GNSS measurement.

1. Introduction

Global Navigation Satellite System (GNSS) has been widely used for positioning application, such as infrastructure, deformation monitoring and atmospheric monitoring. Currently, GNSS is consist more than one satellite constellations. There are three global satellite constellation (GPS, GLONASS and Galileo) and there is one regional satellite constellation which rapidly developing, BeiDou Navigation Satellite System (BDS). By combining GPS and BDS constellation, the number of observed satellites has increased in conjunction with the accuracy and precision of the estimated position for short baseline GNSS data processing [1, 2]. In General, with the addition of frequencies and GNSS constellation satellites, it is possible to improve the reliable ambiguity resolution, reduce the various of error sources and improve the positioning accuracy and precision [3, 4, 5, 6, 7].

In Indonesia, the use of GNSS is mainly used to establish the control point network. The control point network is divided into 5 classes, namely Orde-0 to Orde 4. Orde-0 and Orde 1 are maintained by Badan Informasi Geospasial (BIG) while Orde-2 to Orde-4 are maintained by Badan Pertanahan Nasional (BPN). Those classes mainly divided by its baseline length. The baseline length for Orde-0, 1, 2, 3 and 4 are 200 to 1000 km, 100 to 200 km, 10 to 15 km, 1 to 2 km and up to 500 m respectively [8]. Those control point networks are represented by benchmark or monument which has coordinate as a reference point.

Control points network should be distributed evenly, however, in Indonesia, those control points network were not distribution evenly, especially for those outside the Java Island (figure 1). Therefore, the baseline length of reference point that used was so far away. Its time consuming when we use traverse method to established the control point, so that, GNSS method could overcome that problem.



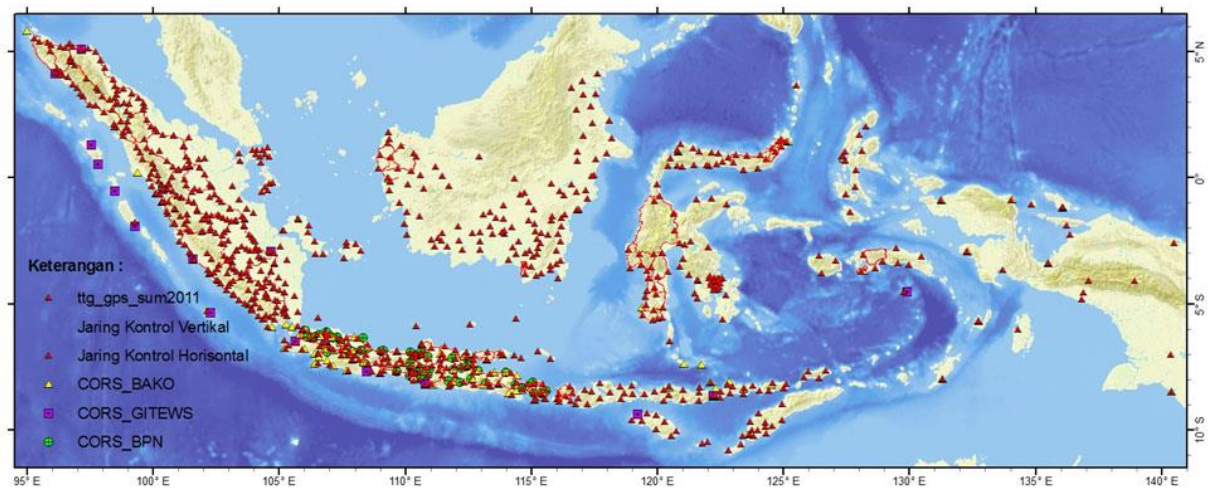


Figure 1. Distribution of horizontal control network of Indonesia [9]

GNSS data processing for longer baseline requires a specific processing strategy which can be done by using a scientific GNSS processing software. Orbital, ionosphere and troposphere error can be resolved by using scientific GNSS processing software, meanwhile, GNSS data processing for longer baseline by using commercial GNSS processing software should be done carefully.

On the long baseline GNSS data processing, the un-differenced biases in orbital, ionosphere and troposphere error are the main factors of poor position solution [10]. This research aims to investigate the contribution of BDS in GNSS long baseline data processing in Indonesia.

2. Data and Method

An experimental observation points was carried out in Bandung and Jakarta (figure 3) with baseline length up to 120 km. ITB1 which is located in Bandung was used as a reference point, while A001 which is located in Jakarta was used as a rover. Both of ITB1 and A001 were Continuous Operating Reference System (CORS) that can observed BDS data. ITB1 used ComNav M300 GNSS receiver while A001 used CHC N72 (figure 2).



Figure 2. ComNav M300 (left) and CHC N72 (right)

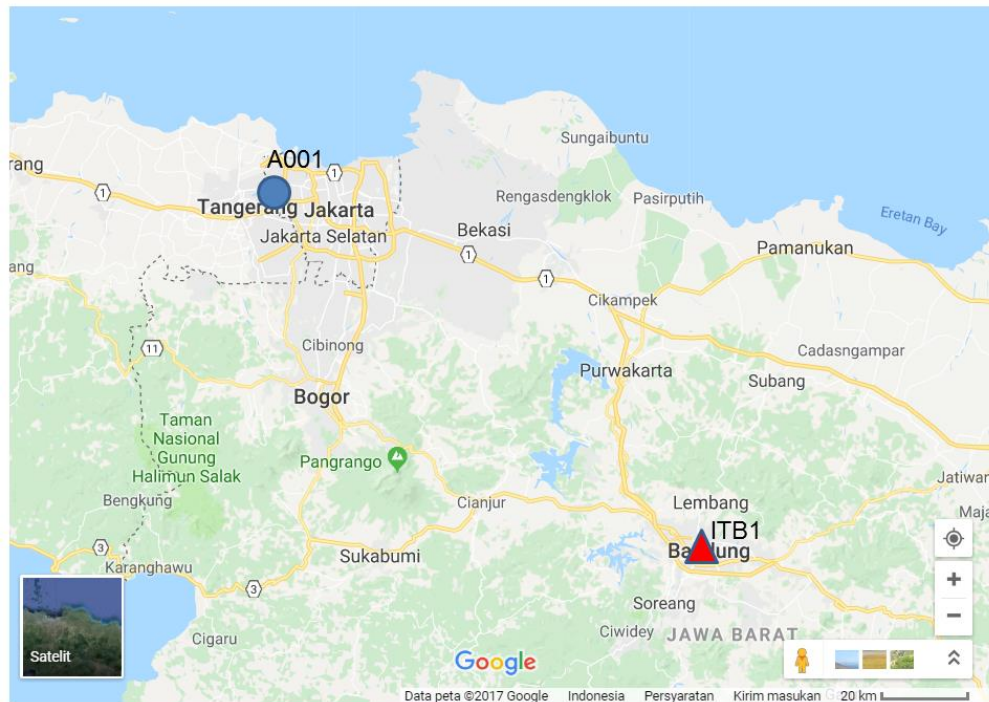


Figure 3. Experimental observation points

2.1. Geometry of the Satellites

Better satellite geometry leads a better position accuracy and precision. Satellite geometry is assessed by its satellite visibilities and the distribution of the satellites. The quality of the satellite geometry is quantified by the value of Dilution of Precision (DOP).

DOP is divided into several terms, namely vertical DOP (VDOP), horizontal DOP (HDOP), position DOP (PDOP) and time DOP (TDOP). These terms can be concluded by using geometric DOP (GDOP) term. In general, GDOP is defined based on the user-equivalent range error (UERE), which is the standard deviation of the satellite's pseudorange error at the determined position. DOP can be defined as follows [11]

$$GDOP = \frac{\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2 + \sigma_{ctb}^2}}{\sigma_{UERE}} \quad (1)$$

$$\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2} = PDOP \cdot \sigma_{UERE} \quad (2)$$

$$\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2} = HDOP \cdot \sigma_{UERE} \quad (3)$$

$$\sigma_{z_u} = VDOP \cdot \sigma_{UERE} \quad (4)$$

$$\sigma_{ctb} = TDOP \cdot \sigma_{UERE} \quad (5)$$

where σ_x , σ_y , σ_z is the standard deviation of the three-dimensional position and σ_{ctb} is the standard deviation of the clock timing defined in distance at the specified location (u). Better satellite geometry

is represented by low DOP value which lead to a better accuracy and precision. Better and poor satellites-receiver geometry is represented in figure 4.

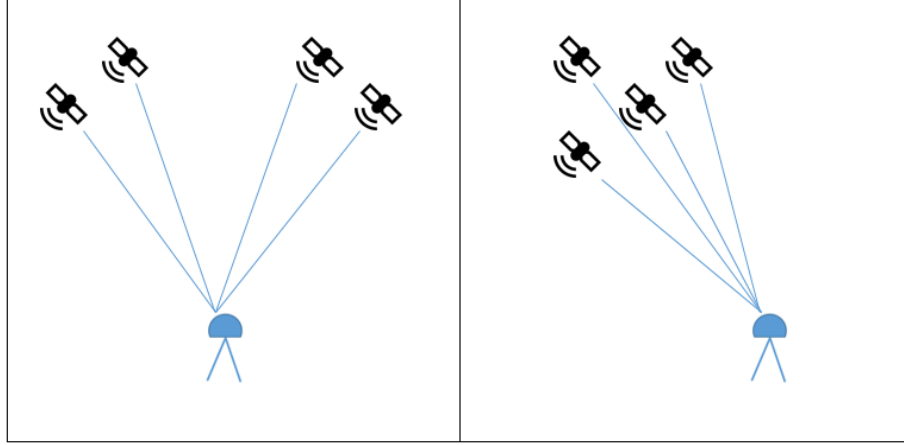


Figure 4. Illustration of better DOP (left) and poor DOP (right)

2.2. GNSS Positioning Algorithm

The GNSS positioning algorithm in relative positioning was used double difference (DD) positioning method. DD used carrier phase range that is constructed by differencing two single difference (SD) GNSS observation. Below is the brief equation for GNSS positioning algorithm [12]:

$$P_i = \rho + d\rho + d_{trop} + d_{ion} + c(dt - dT) + MP_i + \mathcal{P}P_i \quad (6)$$

$$L_i = \rho + d\rho + d_{trop} - d_{ion} + c(dt - dT) + ML_i + \lambda_i N_i + \mathcal{P}L_i \quad (7)$$

where P_i and L_i are pseudorange and carrier phase range on selected frequency ($i=1,2$), ρ is related to geometrical range from receiver to satellite, $d\rho$ is the orbital error, d_{trop} and d_{ion} are troposphere and ionosphere biases, c is the speed of light (299,729,458 m/s), dt and dT are time error of receiver and satellites, MP_i and ML_i are related to multipath error of pseudorange and carrier phase range, λ_i and N_i are related to wavelength and ambiguity number, while $\mathcal{P}P_i$ and $\mathcal{P}L_i$ are related to noise error. SD can be described as follows:

$$\Delta L_{A,B}^j = \Delta \rho_{A,B}^j + d_{trop,A,B}^j - d_{ion,A,B}^j + c(dt - dT)^j_{A,B} + ML_{A,B}^j + \lambda N_{A,B}^j + \mathcal{P}L_{A,B}^j \quad (8)$$

where Δ is the difference between receivers A and B. The superscript $-j$ is the observed satellite. The satellite clock error is eliminated by taking single difference between receivers that observed the same satellite, while the atmospheric biases like tropospheric and ionospheric may be eliminated depending to the length of the baseline. Multipath would be considered as a noise error that could not be eliminated.

The remaining receiver clock error is eliminated by subtracting two SD observation. Mathematically, a DD is defined as follows:

$$\nabla \Delta L_{A,B}^{jk} = \Delta \rho_{A,B}^{jk} + ML_{A,B}^{jk} + \lambda N_{A,B}^{jk} + \mathcal{P}L_{A,B}^{jk} \quad (9)$$

where the two satellites are denote as he superscript- j and k . The atmospheric biases are negligible in Equation 8, however, for a longer baseline the atmospheric biases should be carefully handle.

This research used RTKLib and Tersus Geomatic Office (TGO) to process the kinematic and static position respectively. RTKLib [13] is an open source program package to handle satellite based positioning. RTKLib consists of a portable program library which has support to handle GPS,

GLONASS, Galileo, QZSS, BDS and BDS with various positioning mode for both real-time and post processing. TGO is an integrated GNSS processing software to manage baseline processing and network adjustment.

The processing strategy was designed as follow:

- The data were processed with cutoff angle of 15° .
- The orbit used was broadcast ephemeris.
- The troposphere model is Saastomoinen
- The ionosphere model is from broadcast ephemeris

3. Result and Discussion

3.1. Geometry of the Satellite

Figure 5 shows the number of observed satellites along with DOP values for GPS, BDS and Combined GPS-BDS respectively. It can be found that at least 10 satellites of BDS can be observed for all observation, while at least 7 satellites of GPS can be observed. The number of BDS and GPS observed satellites is vary from 7 to 11 and 10 to 14 satellites respectively. Although BDS gave a better number of observed satellites than GPS, the DOP value for BDS was worse than GPS. The geometry of BDS satellites give smaller volume compared with the geometry of GPS satellites. This is due to the 5 geocentric satellites of BDS that makes the geometry of BDS satellites clustered into horizontal axis (figure 6). The combination of GPS-BDS can be significantly increased the number of observed satellites up to 25 satellites. This circumstances led to a better GDOP compared with GPS only observation, the GDOP improved from 1.694 to 1.195.

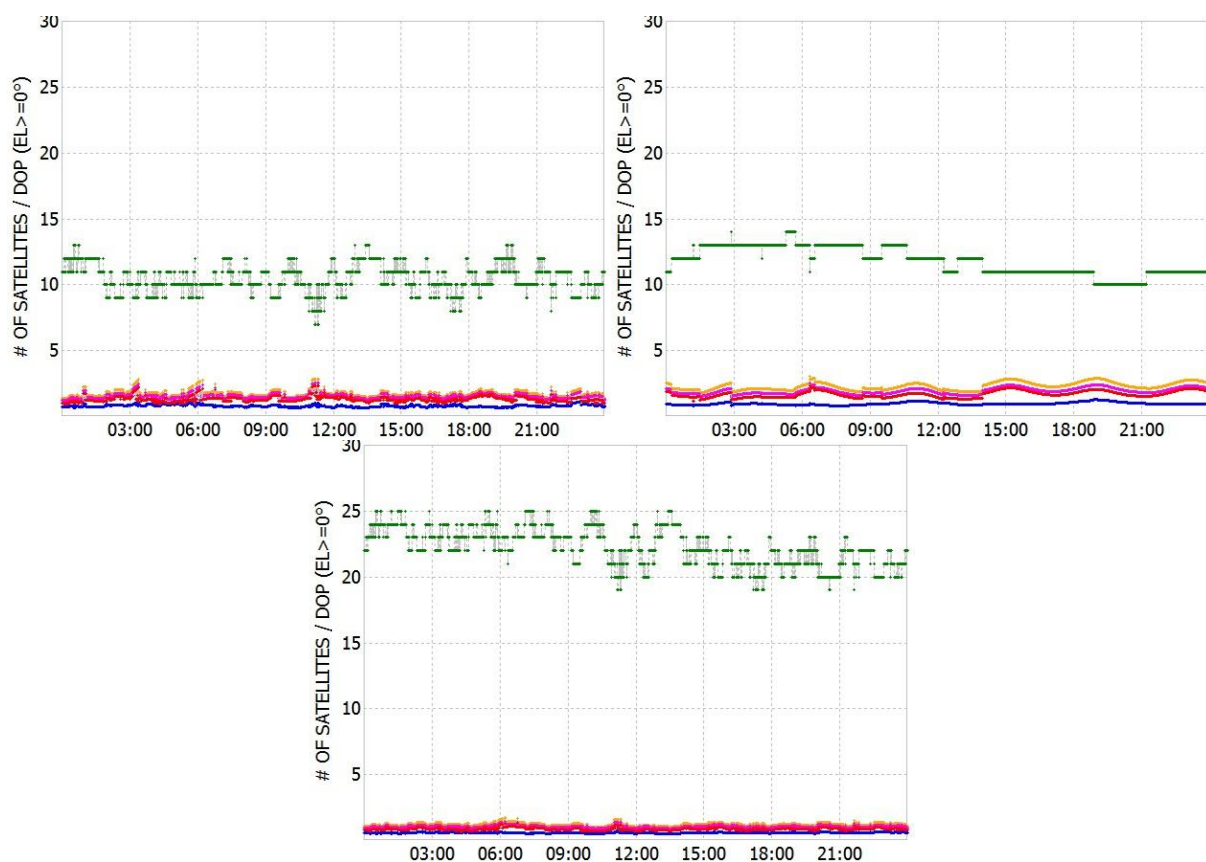


Figure 5. Number of observed satellites for GPS (upper left), BDS (upper right) and GPS-BDS (below)

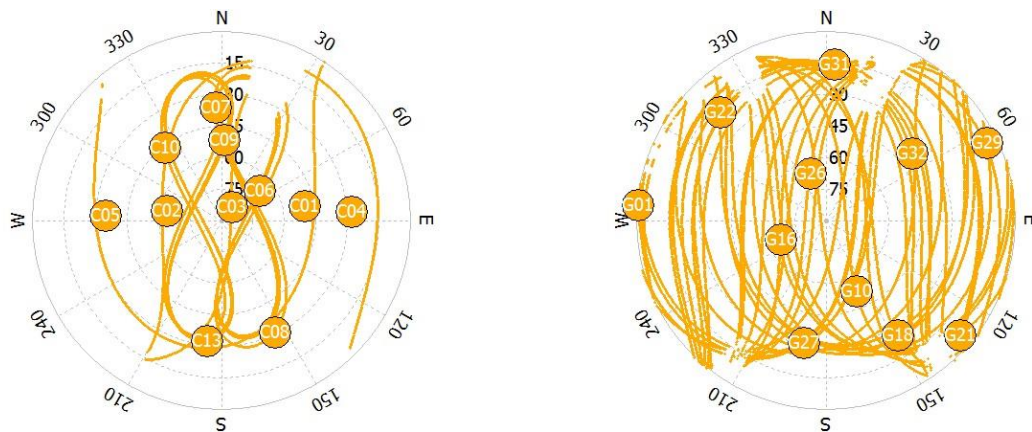


Figure 6. Satellite geometry of BDS (left) and GPS (right) at 2017-5-30 00:00:00 UTC

Table 1. Statistics of the number of satellite, GDOP, PDOP, HDOP and VDOP for each system

GPS					
Statistics	NSAT	GDOP	PDOP	HDOP	VDOP
Average	10.421	1.694	1.531	0.804	1.298
SD	1.039	0.239	0.202	0.099	0.204
Min	7	1.3	1.2	0.6	0.9
Max	13	2.9	2.5	1.1	2.3
BDS					
Statistics	NSAT	GDOP	PDOP	HDOP	VDOP
Average	11.805	2.303	1.94	0.967	1.68
SD	1.051	0.292	0.236	0.112	0.244
Min	10	1.6	1.4	0.8	1.2
Max	14	3	2.5	1.3	2.3
GPS-BDS					
Statistic	NSAT	GDOP	PDOP	HDOP	VDOP
Average	22.226	1.195	1.045	0.587	0.867
SD	1.408	0.119	0.097	0.042	0.096
Min	19	1	0.9	0.5	0.7
Max	25	1.7	1.4	0.7	1.3

3.2. Combined GPS and BDS Estimated Position

Figure 7 shows the daily solution of 5 days GNSS observations. The precision of daily solution is improved by using combined GPS-BDS observations. The precision of GPS-BDS observations is improved to cm level compared with GPS only observations. Kinematic solution were also analysed in this research, figure 8 shows the kinematic epoch-wise solution from each system. Unlike the daily solution, the combined solution gives poor result at around 2017-6-1 21:00 UTC. This is likely due to propagation error from GPS observation, hence, further investigation is required. In general, BDS only solution gives better precision compared with GPS only solution.

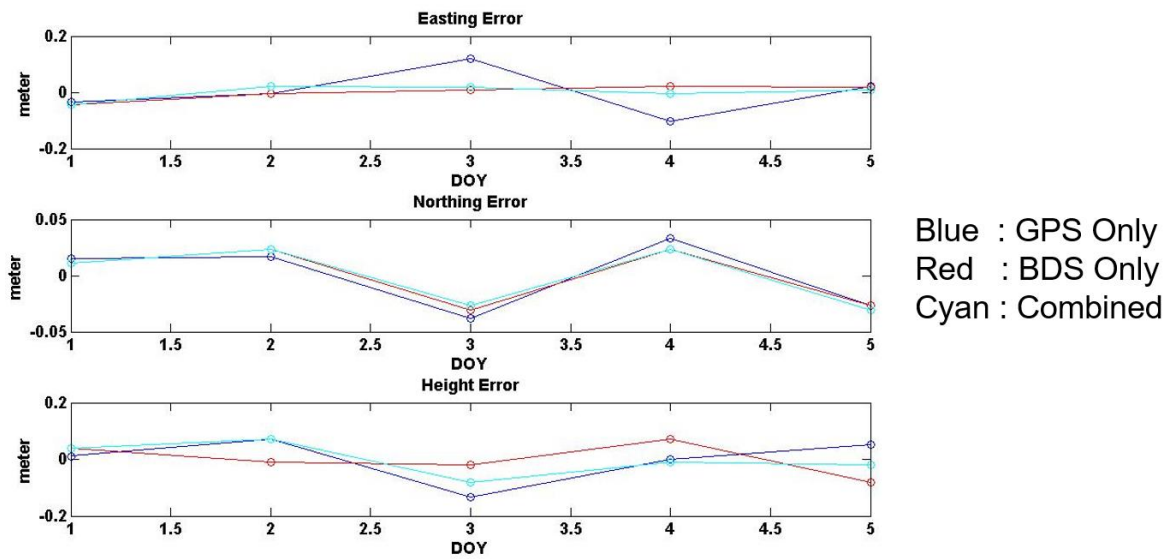


Figure 7. Daily position error solution for each constellation

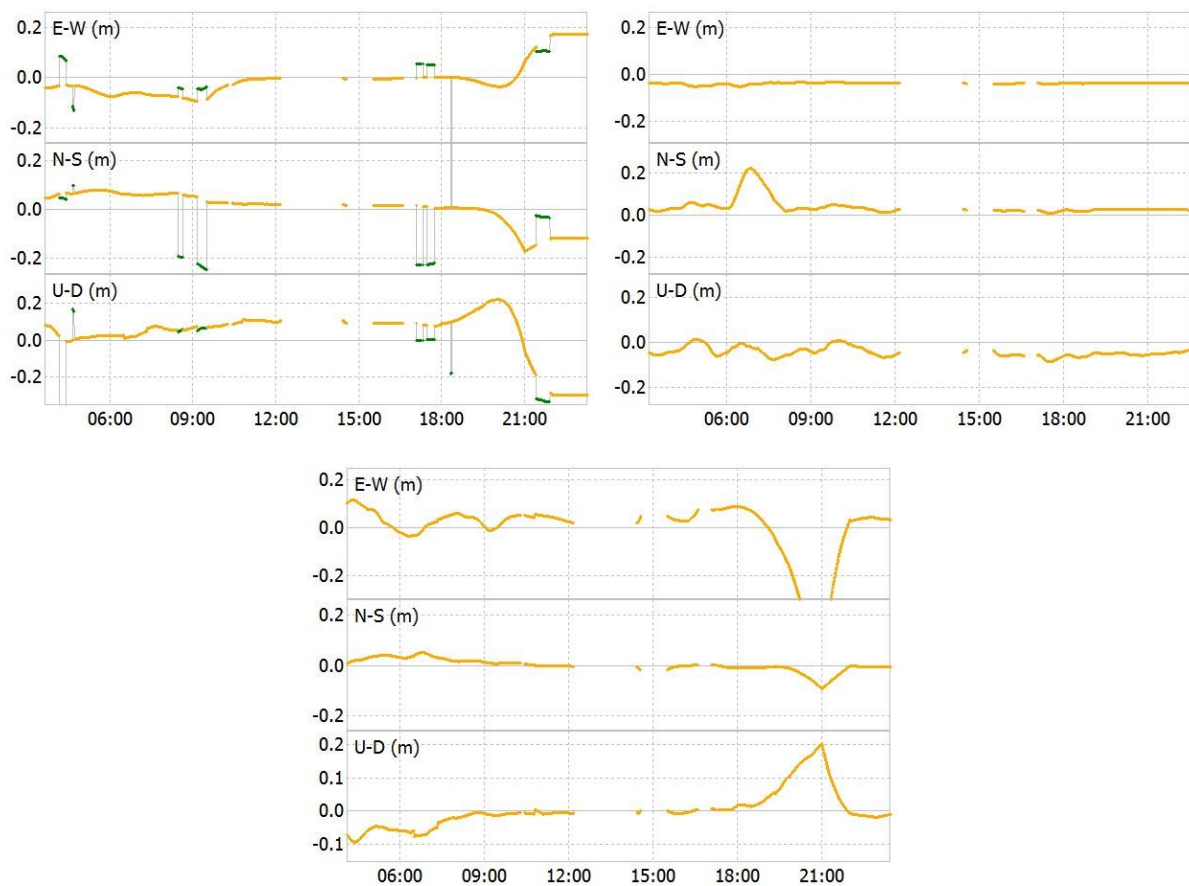


Figure 8. Kinematic epoch-wise point solution for GPS (upper left), BDS (upper right) and GPS-BDS (below)

4. Result and Discussion

The use of high point positioning accuracy and precision is not unneglectable in Indonesia. In accordance with the highly growth of positioning system, BDS will significantly help to achieve the high accuracy and precision positioning. The accuracy and precision for combined GPS-BDS daily solution is within 5 cm for horizontal position and 15 cm for vertical position, however, further researches to investigate the utilization of BDS in Indonesia is still needed.

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