Precise Positioning with the Modified Ambiguity Function Approach using BeiDou System and GPS observations

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Introduction

For many years, two Global Navigational Satellite Systems (GNSS): GPS and GLONASS were the only operating navigational systems. However, in recent years, two new satellite systems appeared. These systems are: the European Galileo and Chinese BeiDou System (BDS). The full operation of BeiDou System is foreseen for 2020. Currently, BDS is widely used in positioning. In this poster, a precise positioning using the Modified Ambiguity Function Approach (MAFA) is presented.

To combine GPS and BeiDou System satellites, there are two methods that can be used: the “loose” and “tight” combining methods. The “loose” combining method relies on a mathematical model, where a pivot satellite is required for each system. In this case, the pivot satellite has to be chosen separately for both GPS and BDS while creating Double Differences (DD). This approach can be easily used, for example, when two combined systems have different frequencies, as in the case of GPS L1 and BDS B1, as well as when both systems share the same frequencies, as in the case of GPS L1 and Galileo E1.

In the “tight” combining method, there is only one reference satellite chosen for all observations and the observational model assumes a single reference satellite for all the observations. Although this approach strengthens the adjustment model, “tight” combining also has disadvantages. While using this method, not only differences in coordinate and time systems but also the difference between the receiver hardware delays has to be taken taken into account. This factor affects the signals from different systems and is called an inter-system bias (ISB). ISB is caused by the correlation process within the GNSS receiver. ISB affects both carrier phase and code data. This issue has been the subject of many papers.

Test description

The experiment was held from June 9-11 2019 (DOY 160 - 162) on 12 km baseline. The baseline consists of two stations located on Philippines. For a short baseline, there is no need to take into account tropospheric and ionospheric refraction, which are mitigated while double differences are created, so there was no need to use any atmospheric corrections. The RINEX 3 files for both stations were obtained from IGS servers. For positioning purposes, the precise orbits and clocks were obtained from MGEX. For computing purposes, a self-made software created in MatLab, called “MAFA-GNSS”, was used. This software uses the MAFA method for the precise positioning. “MAFA-GNSS” software is still in development as well as the MAFA method. GPS L1 and L2 and BDS-2 B1 and B2 signals were used during the experiment along with loose combining.

The experiment was divided into two parts. For both parts, the data from three consecutive days were used The elevation mask was set on 10° in both cases. In the first part of the experiment, the “MAFA-GNSS” software was set in RTK mode. After every three epochs, the position was given separately for the GPS, BDS and GPS+BDS combination. The biases between received rover positions and station position were computed and transformed into local coordinate system, NEU, and presented in a further part of this poster. In the second part of the experiment, 6-hour static sessions were performed, for GPS, BDS and the GPS+BDS combination. For computation, the data from 00:00 UTC to 06:00 UTC for each day were used. After every epoch the observations from new epoch was added and then the results were computed, which allows to observe the increasing accuracy of positioning. For this part, the biases between received position and station coordinates were also computed and transformed into a local coordinate system. In test BDS-2 satellites were used.

About MAFA method

The Modified Ambiguity Function Approach (MAFA) is a method of GNSS carrier phase data processing.

In this method, the integer nature of the ambiguities is taken into account in the functional model of the adjustment.

General model

$$\boldsymbol{\phi}+\mathbf{v}=\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})+\mathbf{a}$$

where:

- $\boldsymbol{\phi}$ – vector of double differenced (DD) carrier phase observations
- $\mathbf{v}$ – residual vector $(n\times 1)$,
- λ – signal wavelength
- $\mathbf{x}$ – parameter vector (increments to *a priori* coordinates vector)
- $\boldsymbol{\rho}$ – DD geometric distance vector
- $\mathbf{a}$ – integer ambiguity vector

$$\boldsymbol{\phi}+\mathbf{v}-\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})=\mathbf{a}$$

because v << 0.5

$$\boldsymbol{\phi}+\mathbf{v}-\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})=int[\boldsymbol{\phi}-\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})]$$

$$\mathbf{v}=int[\boldsymbol{\phi}-\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})]-\left[\boldsymbol{\phi}-\tfrac{1}{\lambda}\boldsymbol{\rho}(\mathbf{x})\right]$$

Linearized model

$$\mathbf{v}=\tfrac{1}{\lambda}\mathbf{A}\mathbf{x}+\boldsymbol{\delta}$$

where

$$\boldsymbol{\delta}=int\left(\boldsymbol{\phi}-\tfrac{1}{\lambda}\boldsymbol{\rho}_0\right)-\left(\boldsymbol{\phi}-\tfrac{1}{\lambda}\boldsymbol{\rho}_0\right)$$ (misclosures vector)

$\mathbf{A}$ – design matrix $(n\times 3)$
$\boldsymbol{\rho}_0$ – DD geometric distance vector computed using *a priori* position

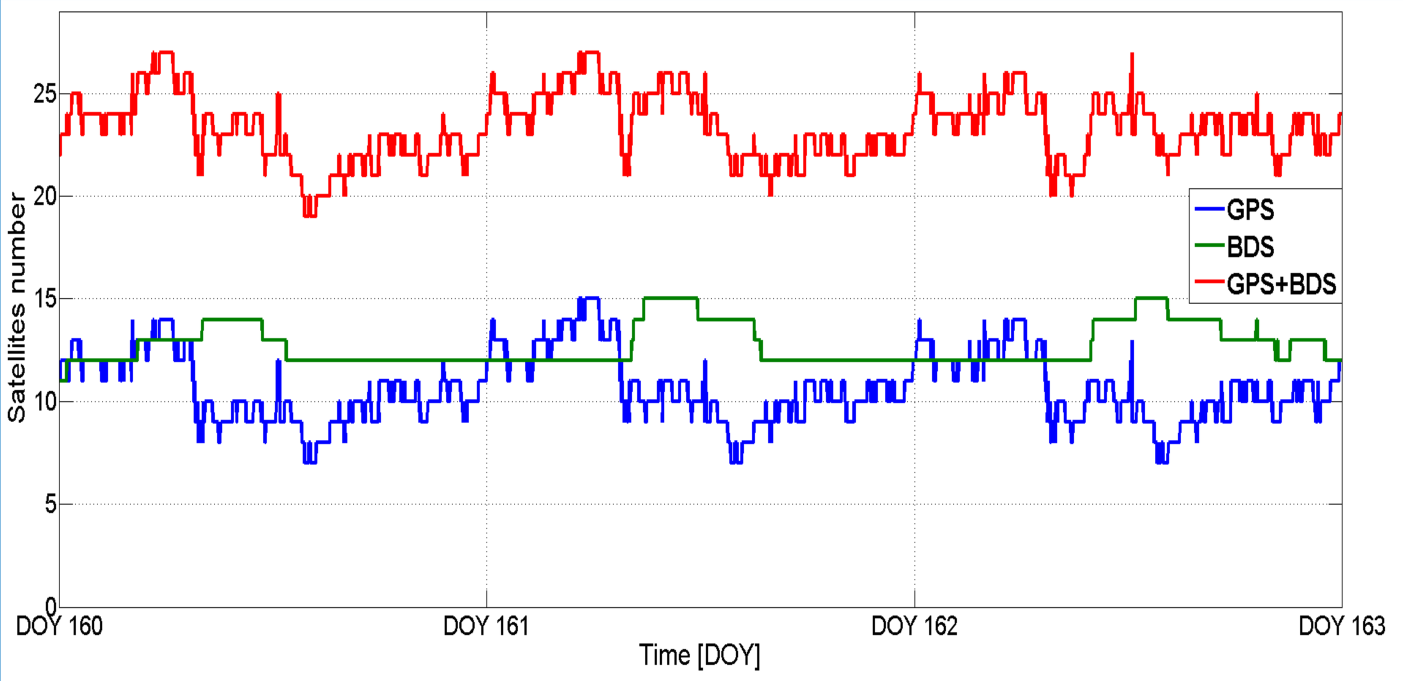
The Least Squares adjustment:

$$\mathbf{v}=\tfrac{1}{\lambda}\mathbf{A}\mathbf{x}+\boldsymbol{\delta}$$

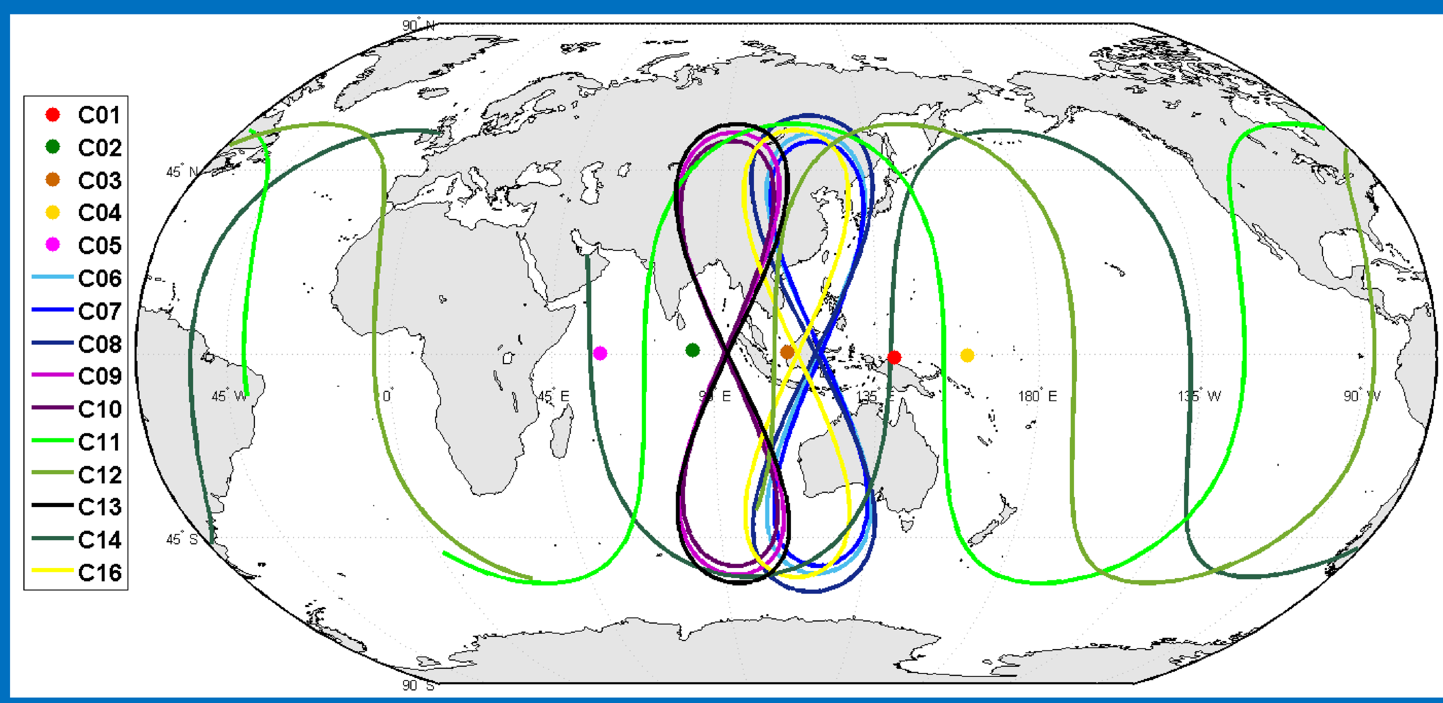
$$\mathbf{v}^T\mathbf{P}\mathbf{v}=min$$

$$\mathbf{x}=-\lambda(\mathbf{A}^T\mathbf{P}\mathbf{A})^{-1}\mathbf{A}^T\mathbf{P}\boldsymbol{\delta}$$

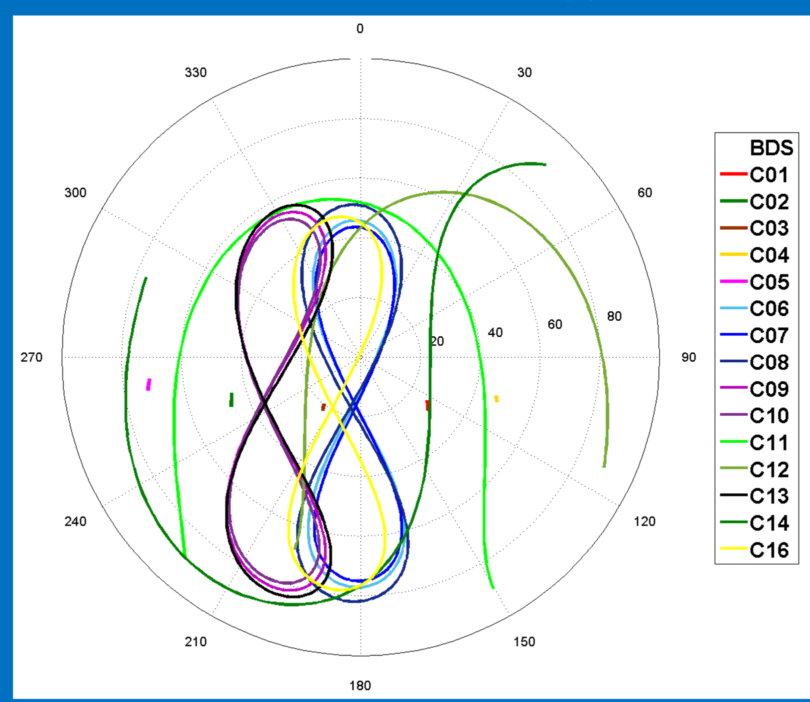
Satellites number



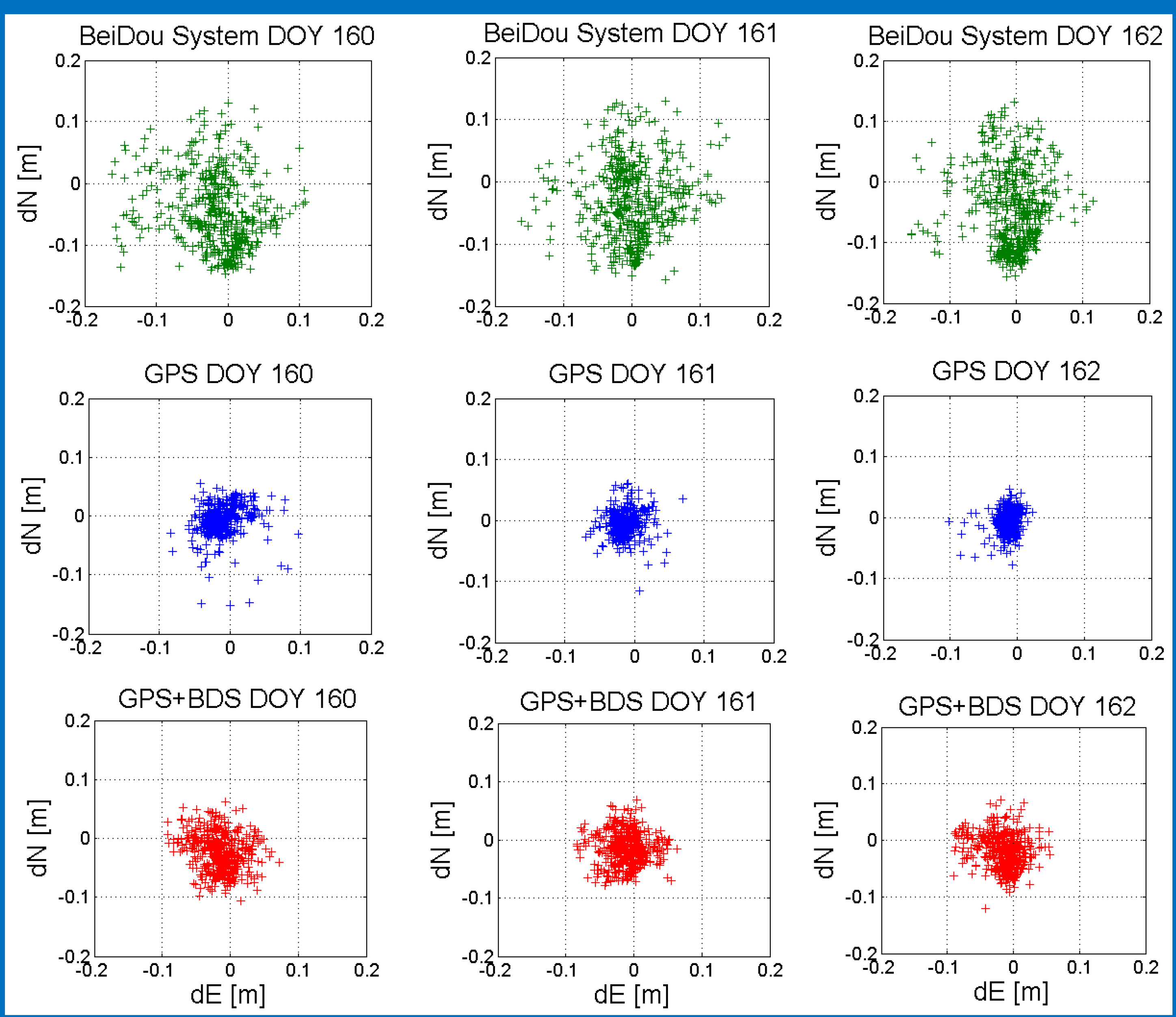
BDS Satellites



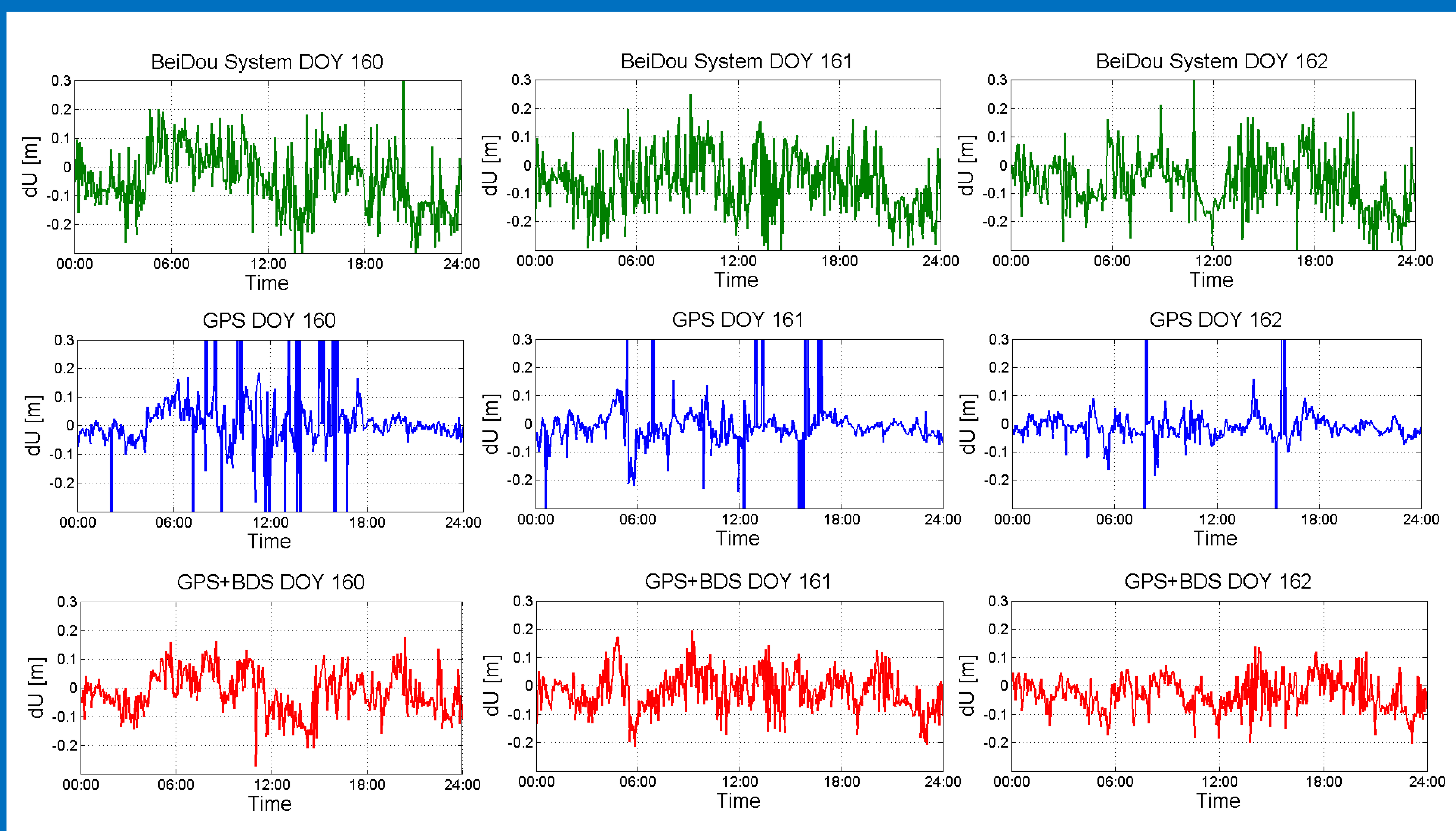
BDS Satellites Skyplot



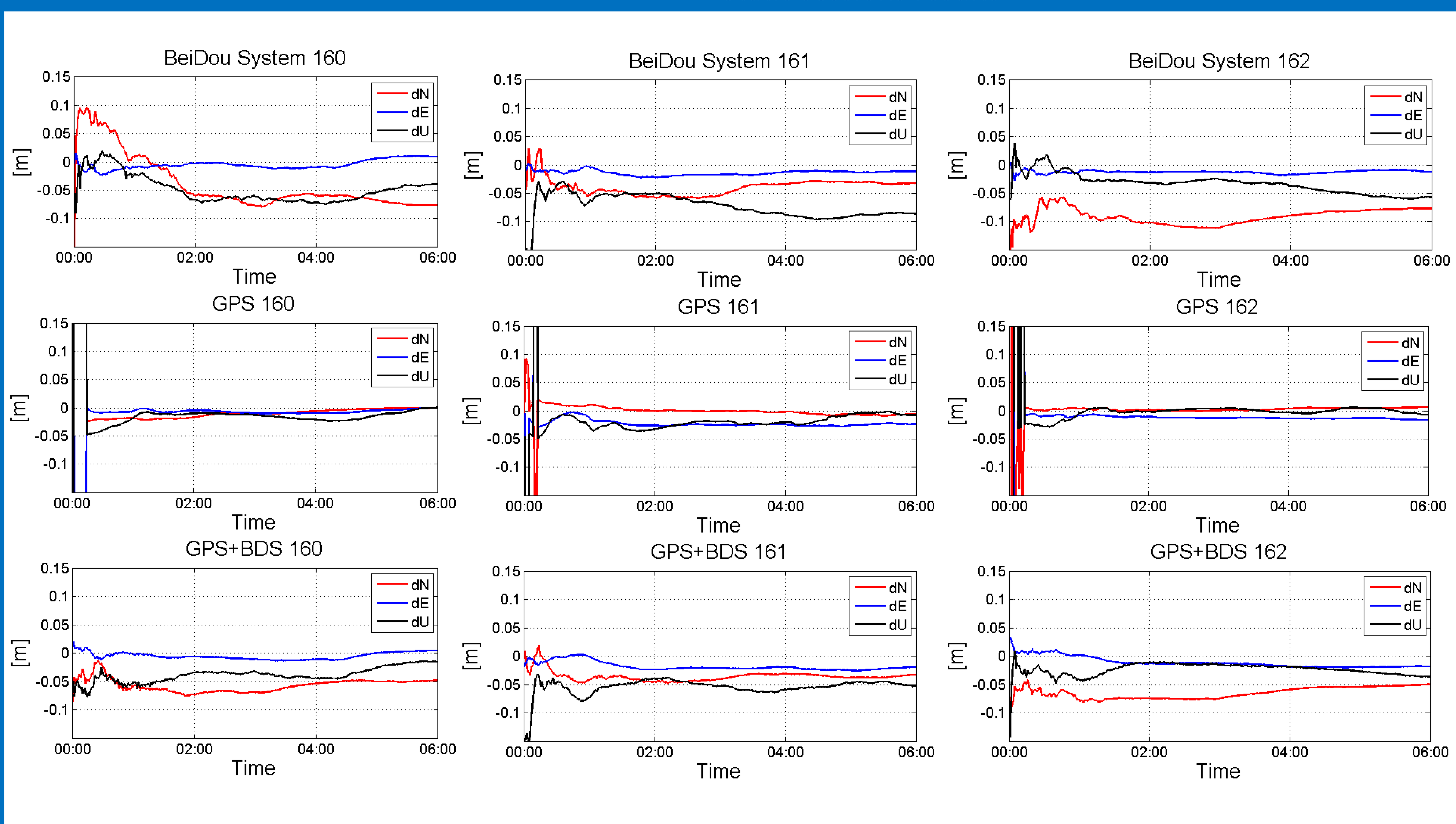
RTK NE results



RTK U results



Static sessions results



RTK NEU results

BDS			
	DOY 160	DOY 161	DOY 162
	RMS [m]	RMS [m]	RMS [m]
dN	0.074	0.069	0.076
dE	0.050	0.047	0.040
dU	0.117	0.124	0.118
Number of incorrect solutions			
	0/480	0/480	0/480
GPS			
	DOY 160	DOY 161	DOY 162
	RMS	RMS	RMS
dN	0.083	0.042	0.018
dE	0.067	0.100	0.019
dU	0.056	0.046	0.040
Number of incorrect solutions			
	29/480	20/480	7/480
GPS+BDS			
	DOY 160	DOY 161	DOY 162
	RMS	RMS	RMS
dN	0.039	0.031	0.037
dE	0.031	0.027	0.030
dU	0.074	0.072	0.066
Number of incorrect solutions			
	0/480	0/480	0/480

Summary and conclusions

The study shows the results from precise positioning using GPS, BDS and GPS+BDS positioning. Two experiments were conducted and the results from short (3-epoch) RTK positioning and 6 hours static positioning are presented. The results from both approaches were presented and compared. The MAFA method was used for positioning purposes.

It was demonstrated that combining GPS and BDS observations can improve an accuracy of positioning. Ina a case of GPS and BDS only solutions the obtained accuracy is similar, however GPS only solution provide more precise results. In BDS only solution there was no incorrect solutions. It was also shown that even in the development phase, the MAFA method is a very good positioning method that can easily be used for positioning, using not only GPS or BDS but also a combination of GPS and BDS. In conclusion, the results indicate that combined GPS and BeiDou System positioning has a clear advantage over single-system solutions and provides an accurate and reliable solution.

In Asia region BDS can be easily use for positioning purposes, providing accuracy and precision on very high level.

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