Chapter 26
Earth Rotation Parameters Determination Using BDS and GPS Data Based on MGEX Network

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Abstract Earth rotation parameters (ERPs) are necessary parameters to achieve mutual transformation of the celestial reference frame and earth-fix reference frame. They are very important for satellite precise orbit determination (POD), high-precision space navigation and positioning. In this paper, the determination of ERPs including polar motion (PM), polar motion rate (PMR) and length of day (LOD) are presented using BDS and GPS data of June 2013 from MEGX (Multi-GNSS Experiment) network based on least square (LS) estimation with constraint condition. BDS and GPS data of 16 stations from MGEX network are the first time used to estimate the ERPs. The results show that the RMSs of x and y component errors of PM and PM rate are about 0.92 mas, 1.0 mas, 0.20 mas/d and 0.32 mas/d respectively using BDS data. The RMS of LOD is about 0.028 ms/d using BDS data. The RMSs of x and y component errors of PM and PM rate are about 0.19 mas, 0.21 mas, 0.18 mas/d respectively using GPS data. The RMS of LOD is about 0.021 ms/d using BDS data. The optimal relative weight is between 1:2 and 1:3. The accuracy improvements of BDS is about 14 % in X component of PM, 8 % in Y component of PM, 21 % in X component of PM rate and 17 % in Y component of PM rate. There is no obvious improvement in LOD when BDS data is involved. System biases between BDS and GPS are resolved and they are different with different station and very stable day to day with about 20 cm accuracy.

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26.1 Introduction

Earth rotation parameters (ERPs) are necessary parameters to achieve mutual transformation of the celestial reference frame and earth-fix reference frame [1]. They include four time-varying rotational angels consisting of the polar motion coordinates (PMx, PMy), the universal time (UT1), together with the length of day (LOD, equivalent to the time rate of change of UT1). The PM is an important parameter to characterize the movement of Earth, which is used to describe the instantaneous movement of the earth's rotation axis in the body and the polar position on the earth surface is changing slowly [2]. EOP is the necessary parameters to achieve mutual conversion of the celestial reference frame and earth reference frame, and it is very important for high-precision space navigation and positioning. Modern measurement techniques such as VLBI, SLR, GPS and DORIS can provide people with high precision and high spatial and temporal resolution of Earth Orientation Parameters [3–9]. Nowadays, the International GPS Service (IGS) has been distributing, as part of its product combinations, three distinct ERP series: the IGS Utra-rapid series, the IGS Rapid series and the IGS Final series [10–13]. They are the combination of all IGS Analysis Centers (AC). In ERP determination, China drops behind to aboard such as America and Europe countries and is still under the way. The most fruit in this field is represented by ERP prediction with high accuracy [14–18]. With the development of BDS and open for public service, it is urgent and important task for us to study the ERP determination using BDS data. In this paper, we report on ERP determination using BDS and GPS data based on MGEX network in order to give some reference or advice on the ERP determination using BDS.

26.2 ERP Determination Using LS with Constraint Condition

For ERP determination using GNSS data, ionosphere free linear combination to eliminates the first order ionospheric path delay is usually used. For the code and carrier phase observations the ionosphere free combination can be expressed as

$$PC_i^j = \rho + c \cdot (dt_i - dT^j) + d_{i,trop}^j + \varepsilon_{PC} \tag{26.1}$$

$$LC_i^j = \rho + c \cdot (dt_i - dT^j) + d_{i,trop}^j + \lambda B_i^j + \varepsilon_{LC} \tag{26.2}$$

where PC_i^j and LC_i^j are ionosphere free combination of code and carrier phase respectively. ρ is the geometric distance from GPS satellite to GOCE satellite. c is the light speed; dt_i and dT^j are receiver clock offset and satellite clock offset respectively. $d_{i,trop}^j$ is the tropospheric refraction; λB^j is the ambiguity parameter of ionosphere free combination. ε_{PC} and ε_{LC} are code and carrier phase noise respectively. After linearization from Eqs. (26.2) and (26.3), the error equations can be expressed asEquation ID="Equ3"> V_{pc} = PC_{i}^{\,j} - \phi_{m} = AX + c \cdot dt_{i} - c \cdot dT^{\,j} + d_{i,trop}^{\,j} + \phi_{nm} + \varepsilon_{pc} \eqno\rm(26.2)

$$V_{lc} = LC_i^j - \phi_m = AX + c \cdot dt_i - c \cdot dT^j + d_{i,trop}^j + \lambda B_i^j + \phi_{nm} + \varepsilon_{lc} \tag{26.4}$$

where ϕ_m is the error corrections which can be calculated by models such as solid Earth tide, ocean tide and antenna phase centre corrections. X *is* the position correction vector expressed as (dx, dy, dz); A *is* the design matrix for position parameters expressed as $\left(\frac{x_i - x^j}{\rho}, \frac{y_i - y^j}{\rho}, \frac{y_i - y^j}{\rho}\right)$; ϕ_{nm} includes other non-modelling corrections such as multipath error, GPS orbit errors and atmospheric errors. ε_{pc} and ε_{lc} are the residual vector of ionosphere free combination.

In order to compute the difference vector between the observing station and GPS satellite, both positions must be given in the same reference frame. Therefore, we need to know Earth orientation parameter between the two frames when analyzing GPS data. The transformation between the celestial and the Earth-fixed coordinate system may be performed by means of equation

$$\vec{r}_{CIS} = P^T(t)R_1(\Delta\varepsilon)R_2(-\Delta\phi\sin\varepsilon_0)R_3(-\Theta_{GM})R_1(y_p)R_2(x_p)\vec{r}_{CTS} \tag{26.5}$$

where $P(t)$ is the rotation matrix referring to precession and $R_i(\alpha)$characterizes a rotation around axis i, about angle α. $\vec{r}_{CIS}$ and $\vec{r}_{CTS}$ are the position vectors of a station in the terrestrial and inertial systems, respectively. $\Delta\varepsilon$ and $\Delta\phi$ denote the nutation in longitude and obliquity, ε_0 denotes the mean obliquity of the ecliptic, and Θ_{GM} stands for the Greenwich mean sidereal time.

Unfortunately, due to correlations with the orbital elements, a subset of the Earth orientation parameter is not directly accessible to the GPS such as UT1-UTC and the nutation parameters. Therefore the possible solved parameters by GPS data are PM, and LOD, which is called ERPs without UT1-UTC in this paper.

Based on the error Eqs. (26.4) and (26.5) and the dynamic Eq. (26.1), orbit determination can be performed using least square batch strategy. When a prior or constraint condition are known, it is better for us to solve the observation equation by least square with constraint condition, which can be expressed as:

$$\begin{cases} V = AX - L & P \\ V_x = X - X_0 & P_{X_0} \end{cases} \tag{26.6}$$

where P and P_{X_0} are weight matrices of observation and constraint condition. The estimator of least square with constraint condition can be written as:

$$\begin{aligned} X &= X_0 + \delta X \\ \delta X &= (A^T PA + P_{X_0})^{-1} A^T P \delta L \\ \delta L &= L - AX_0 \end{aligned} \quad (26.7)$$

It is very flexible to set up the solved parameter in GNSS data processing according to our need or concern. For example, if we want to do POD, we can added a strong constraint on the station coordinate. For ERP determination, we can use the predicted ERPs as X_0 and added a loose constraint condition to get the solution of ERPs.

26.3 ERP Determination Using BDS and GPS Data

The functional model and stochastic model should be adjusted when combing the BDS and GPS data for ERP determination based on the above error equations. The adjusted error equations can be written as:

$$V_{BDS} = A_{BDS} X_{COM} + B_{BDS} X_{BDS} + X_{ISB} - L_{BDS} \quad (26.8)$$

$$V_{GPS} = A_{GPS} X_{COM} + B_{GPS} X_{GPS} - L_{GPS} \quad (26.9)$$

where the formula (26.8) and (26.9) are the error equation of BDS and GPS. The difference lies in the parameter estimation of system biases between BDS and GPS for the determination ERP combining BDS and GPS data. The parameters are set to constant in the same station and same observation session and solved with other unknown parameters.

In the aspect of stochastic model, the relative weight should be considered between BDS and GPS data since they are different in the quality and accuracy. The commonly used methods for relative weight determination follow in two types: experiential method and variance component estimation. The former is simple and easy but no strict background adjustment. The latter is strict and perfect but very complex and need to iteration with huge computation. In this paper, an approach combing experiential method and numerical testing method are presented for determining the relative weight reasonably.

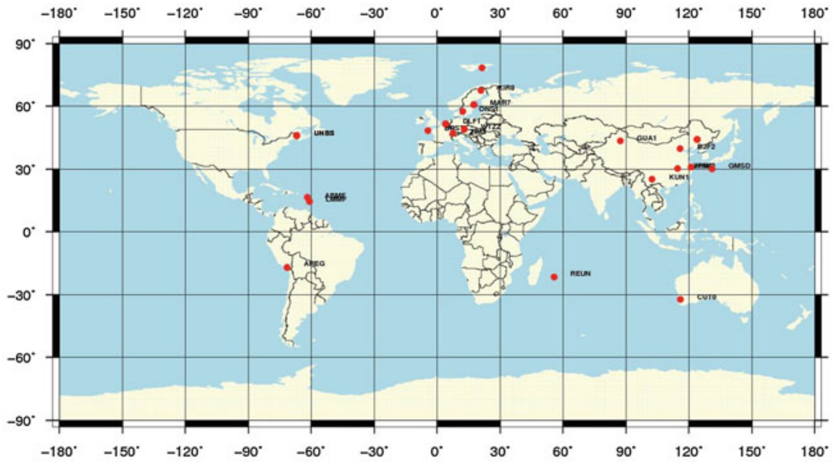


Fig. 26.1 The station distribution with BDS and GPS receiver of MEGX network

26.4 Computations and Comparisons

The BDS and GPS data of 15 IGS stations belong to MGEX network span from 1/6/2013 to 30/6/2013 are used for the test ERPs determination. The selected stations including areg, brst, brux, cut0, dlf1, gmsd, jfng, kir8, mar7, ons1, reun, unb3, unbs, wtzz, zim3 and their distribution are shown in Fig. 26.1. The zero-difference code and carrier phase observations are used. It should be pointed out that the UT1 cannot be determined only by GPS data since GPS provides distance observation. According to this reason, a strong constraint of 0.1 ms on UT1 are added and loose constraint of 300 mas, 300 mas, 30 mas/d, 30 mas/d, 20 ms/d on PM, PMR and LOD are added respectively in LS estimation. The estimated parameters include the initial orbit vector per day, five parameters of solar radiation pressure per day, satellite and receiver clock offset per epoch, ambiguity and ZTD per hour per station, ERPs per day. The following three schemes are performed.

Scheme 1: ERP determination using GPS data
Scheme 2: ERP determination using BDS data
Scheme 3: ERP determination using BDS and GPS data.

The time series EOP 08C04 file provided by the IERS is used as reference for evaluation the accuracy of ERP determination. The absolute value of x and y component of PM errors per day are shown in Figs. 26.2 and 26.3 respectively. The absolute value of x and y component of PM rate errors per day are shown in Figs. 26.4 and 26.5 respectively. The absolute value of LOD errors per day are given in Fig. 26.6. The RMSs of ERP are shown in Fig. 26.7. The RMSs of ERP with different relative weight between BDS and GPS are listed in Table 26.1. All the

Fig. 26.2 The absolute value of x-component error of pole motion

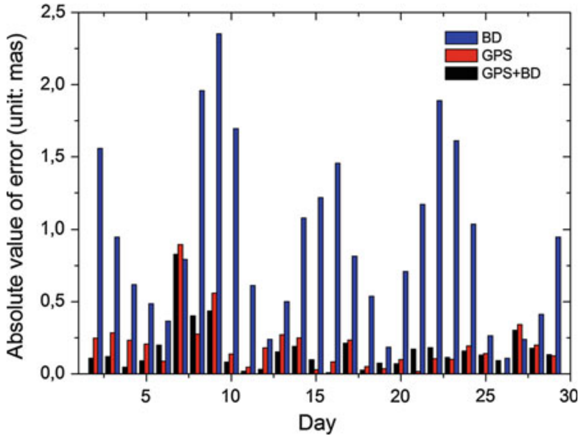


Fig. 26.3 The absolute value of y-component error of pole motion

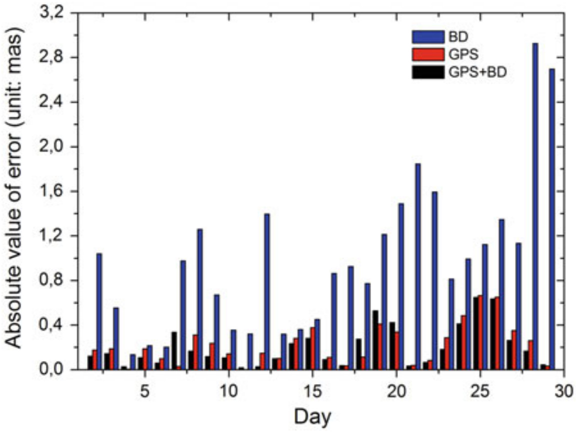
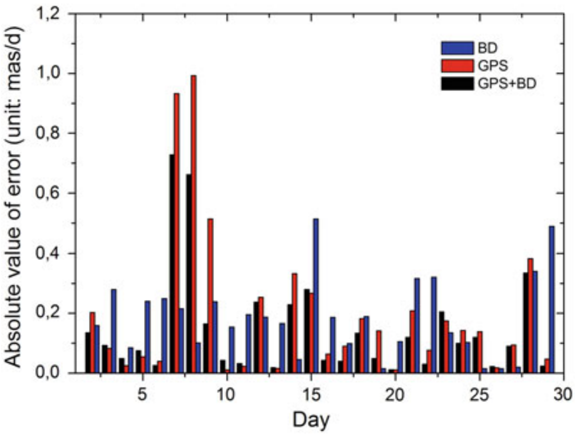


Fig. 26.4 The absolute value of x-component error of pole motion rate



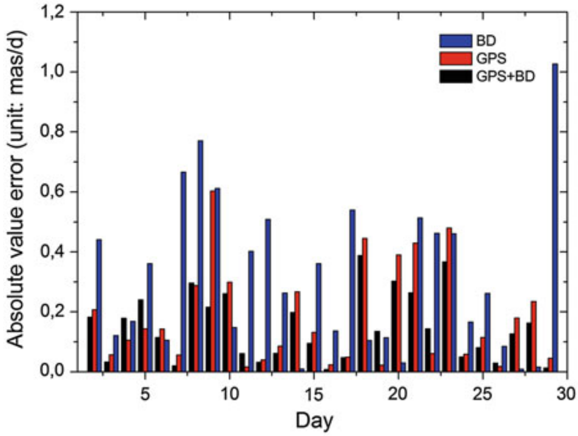


Fig. 26.5 The absolute value of y-component error of pole motion rate

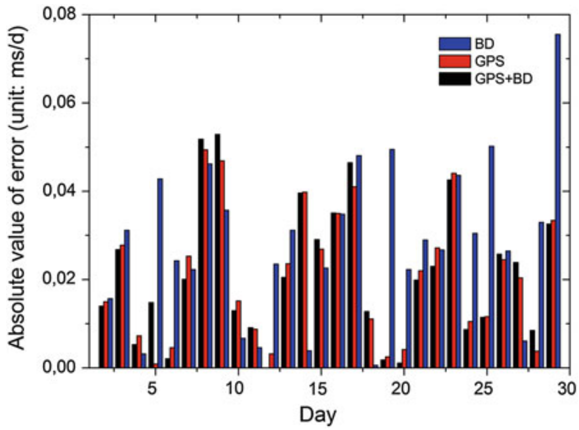


Fig. 26.6 The absolute value of LOD error

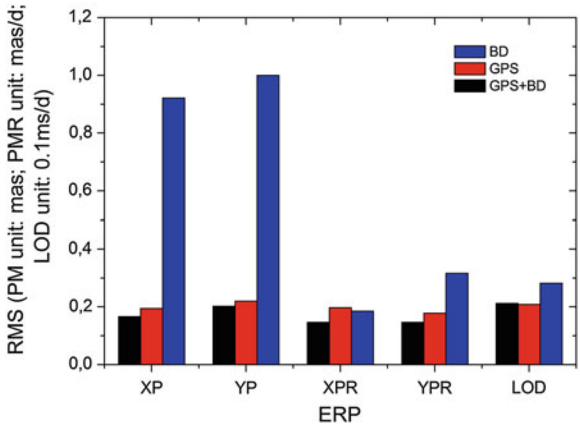


Fig. 26.7 The RMS of ERP errors

Table 26.1 The RMS of ERP errors using BDS and GPS with different relative weight (PM unit: mas, PM rate unit: mas/d; LOD unit: ms/d)

ERP	1:1	2:1	3:1	4:1	5:1
XP	0.1560	0.1624	0.1664	0.1733	0.1753
YP	0.2463	0.2246	0.2023	0.2143	0.2175
XPR	0.1416	0.1442	0.1464	0.1510	0.1528
YPR	0.1480	0.1431	0.1469	0.1509	0.1525
LOD	0.0213	0.0212	0.0212	0.0212	0.0212

Table 26.2 The RMS of ERP using BDS, GPS and GPS+BD (relative weight is 1:3) (PM unit: mas, PM rate unit: mas/d; LOD unit: ms/d)

ERP	GPS	BD	GPS+BD	BD contribution (%)
XP	0.1944	0.9217	0.1664	14.4
YP	0.2197	1.0001	0.2023	8.1
XPR	0.1854	0.1973	0.1464	21.0
YPR	0.1785	0.3167	0.1469	17.7
LOD	0.0209	0.0282	0.0212	−1.4

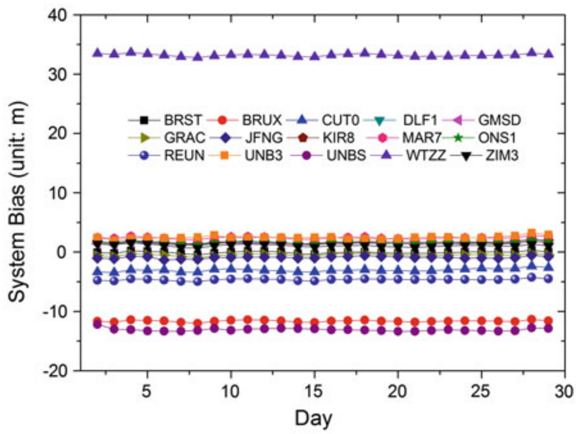


Fig. 26.8 System bias between BDS and GPS of stations

RMSs of ERP errors are listed in Table 26.2. The system biases between BDS and GPS are shown in Fig. 26.8 and Table 26.3.

From the above results, the following conclusions can be drawn.

1. The relative weight between BDS and GPS is better to chose as one to two or one to three for the determination of ERP when combing them. In this case, the accuracy of ERP can be improved to some extent.
2. The RMSs of x and y component error of PM is about 0.19 mas and 0.21 mas by using GPS data. The RMS of x and y component error of PM is about 0.92

Table 26.3 The statistical results of system bias between BDS and GPS of stations (unit: m)

Station	Mean	STD
BRST	−0.062	0.177
BRUX	−11.637	0.152
CUT0	−3.048	0.258
DLF1	1.471	0.172
GMSD	1.395	0.165
GRAC	−0.485	0.178
JFNG	−0.914	0.174
KIR8	1.701	0.165
MAR7	2.394	0.172
ONS1	1.607	0.167
REUN	−4.646	0.157
UNB3	2.480	0.238
UNBS	−13.073	0.246
WTZZ	33.205	0.210
ZIM3	1.087	0.224

mas and 1.0 mas by using BDS data, which are obviously larger than those by GPS data.

3. The RMSs of x and y component error of PM is about 0.15 mas by combining BDS and GPS data. The accuracy of ERP determination is improved to some extent, and the improvements of x and y component of PM are about 14 and 8 % respectively.
4. The RMSs of x and y component error of PM rate is about 0.18 mas/d by using GPS data of MEGX network. The RMSs of x and y component error of PM rate is about 0.20 mas/d and 0.32 mas/d by using BDS data of MEGX network, which are the same accuracy level to those by GPS data.
5. The RMSs of x and y component error of PM is about 0.16 mas/d and 0.2 mas/d by combining BDS and GPS data. The accuracy of ERP determination is improved to some extent, and the improvements of x and y component of PM rate are about 21 % and 17 % respectively.
6. The RMS of LOD errors is about 0.021 ms/d determined from GPS data and about 0.028 ms/d from BDS data. The RMS of LOD errors is about 0.021 ms/d by combining BDS and GPS data, which is equivalent to those by using just GPS data.
7. The system biases between BDS and GPS when combing them to determine the EPRs. They are different in different stations. The maximum of the them can reach several tens of meters which needs to be estimated in ERP determination. The estimated system biases are very stable and their accuracy is about 20 cm.

26.5 Conclusion

GNSS technique is one of the important approach to determine the ERPs of pole motion, pole motion rate and length of day. However, the whole Earth orientation parameters cannot be obtained just by GNSS, and need other space techniques such as VLBI, SLR and DORIS et al. The computational results in this paper show that the ERPs can be independently obtained by BDS data, although the accuracy of pole motion is obvious lower than those of GPS. The difference must be shortened when the global BDS will be established. The accuracies of pole motion rate and length of day is almost on the same level between GPS and BDS using MEGX network. The ERP accuracy can be further improved to some extent when the BDS data is combined in GPS data.

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