

B2bLIB User Manual

B2bLIB: an open-source PPP-B2b embeddable RTKLIB
decoding package

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GNSS+ under
Complex Conditions

**Research group of GNSS+ under
Complex Conditions (GCC)**

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1 Introduction

With the completion of the BeiDou-3 Satellite Navigation System (BDS-3), China has been providing global services, including navigation, positioning, international search and rescue, and short message communication (Yang et al. 2019). In addition, BDS-3 supports featured services including satellite-based precise point positioning service via B2b signal (PPP-B2b), the BDS satellite-based augmented service, radio determination satellite service, regional and global short message communication service, and satellite-based search and rescue service (Yang 2021). The BDS-3 designed constellation comprises 30 satellites, including 24 medium earth orbit satellites (MEO), 3 geostationary orbit (GEO) satellites, and 3 inclined geosynchronous orbit satellites (IGSO). BDS-3 mainly transmits 6 signals including B1I, B3I, B1C, B2a, B2a+b and B2b. Broadcast via GEO satellites, the B2b signal delivers augmentation data, enabling real-time precise clock offset corrections and orbit error corrections without a network connection (CSNO 2020). This technology provides centimeter-level accuracy for static applications and decimeter-level accuracy for dynamic applications, enabling wide-area real-time high-precision positioning (Zhang and Wang 2025).

Since its launch, related studies have been conducted on the product accuracy and service performance of PPP-B2b. Results show that its augmentation messages exhibit smaller satellite-specific clock biases than GPS and achieve radial orbit errors of 0.056 m (BDS-3 MEO), 0.069 m (GPS), and 0.172 m (BDS-3 IGSO) relative to GFZ final products. (Tao et al. 2021; Lan et al. 2022; Zhang et al. 2022; Sun et al. 2023; Ouyang et al. 2023). For positioning performance, static BDS-3/GPS dual-system PPP attains $\text{RMS} < 1 \text{ cm}$ (E/N) and $\sim 3 \text{ cm}$ (U), and simulated kinematic PPP reaches $< 2.5 \text{ cm}$, 3.5 cm , and 8.5 cm (N/E/U) after convergence (Tang et al. 2022). In real applications, static solutions achieve mean east, north, and up errors of 2.4 cm, 1.6 cm, and 2.3 cm, while kinematic PPP converges to 8.1 cm, 3.6 cm, and 8.0 cm RMS (Nie et al. 2021).

However, open-source software supporting B2b messages decoding remains scarce. Additionally, most open-source global navigation satellite system (GNSS) software is based on C/C++. To support user applications, a C/C++ PPP-B2b decoding package called B2bLIB has been developed. The B2bLIB decoding package seamlessly integrates with RTKLIB and is expected to promote research and application of the PPP-B2b and even other satellite-based augmentation systems.

2 Methodology of PPP-B2b

The mathematical model of PPP-B2b is given firstly, where the corrections are discussed comprehensively.

2.1 Mathematical Model of PPP-B2b

In the PPP-B2b service, the raw observation equations of dual-frequency (DF) observations can be written as (Li et al. 2019; Nie et al. 2019; Zang et al. 2019)

$$P_{r,\text{IF}}^S = \rho_r^S + dt_r - dt^S + \xi_{r,\text{IF}} - \xi_{\text{IF}}^S + T_r^S + \varepsilon_{r,\text{IF}}^S \quad (1)$$

$$\phi_{r,IF}^s = \rho_r^s + dt_r - dt^s + \zeta_{r,IF} - \zeta_{IF}^s + T_r^z + N_{r,IF}^s + \epsilon_{r,IF}^s \quad (2)$$

where $P_{r,IF}^s$ and $\phi_{r,IF}^s$ denote the dual-frequency ionospheric-free (IF) code measurement and IF phase measurement, respectively; ρ_r^s denote the geometric distance from the satellite to receiver; dt_r and dt^s are the receiver and satellite clock offsets, respectively; $\xi_{r,IF}$ and $\zeta_{r,IF}$ are the code and phase hardware delays in the receiver-end, respectively; ξ_{IF}^s and ζ_{IF}^s are the code and phase hardware delays in the satellite-end, respectively; T_r^z denote the tropospheric delay; $N_{r,IF}^s$ denote the ambiguity parameter; ϵ_r^s and ϵ_r^s are the code and phase measurement noise, respectively.

The other systematic errors are assumed to be corrected in advance, including phase center offset (PCO) and phase center variation (PCV), phase windup, relativistic effect, solid earth tide, ocean tide loading, pole tide, and earth rotation, etc. Also, the timing group delay (TGD) in BDS, TGD and inter-signal correction (ISC) in GPS are also considered and corrected. The corrections are provided in PPP-B2b service via B2b signal, including precise satellite orbits error correction, clock offset correction, and difference code bias (DCB) correction. These parameters are updated at 48 s, 6 s, and 48 s intervals, respectively. The valid time of satellite orbit error correction is 96 s, while that of satellite clock offset correction is 12 s. Due to the stability of satellite DCB, the valid time of DCB provided by PPP-B2b is 86,400 s

2.2 Orbit Error Correction

In the PPP-B2b service, satellite position corrections are applied by adjusting the broadcast ephemeris position using an orbit error correction vector. If the Issue of Data of Navigation (IODN) associated with the orbit error correction matches the Issue of Data of the Clock (IODC) from the broadcast ephemeris, the corrected satellite position \mathbf{X}_{orbit} is given by (CSNO 2020):

$$\mathbf{X}_{orbit} = \mathbf{X}_{broadcast} - \delta\mathbf{X} \quad (3)$$

where \mathbf{X}_{orbit} is the corrected satellite orbit; $\mathbf{X}_{broadcast}$ is the satellite position derived from the broadcast ephemeris; $\delta\mathbf{X}$ is the satellite position correction vector. The correction vector $\delta\mathbf{X}$ is computed as:

$$\delta\mathbf{X} = [\mathbf{e}_r \quad \mathbf{e}_a \quad \mathbf{e}_c] \cdot \delta\mathbf{O} \quad (4)$$

where \mathbf{e}_r , \mathbf{e}_a and \mathbf{e}_c are the unit vectors along the radial, tangential, and normal directions, respectively. $\delta\mathbf{O}$ is the orbit error correction parameters provided in the augmentation message. This formulation enables an accurate adjustment of the satellite position.

2.3 Clock Offset Correction

The satellite clock offset correction in PPP-B2b adjusts the clock offset obtained from the broadcast ephemeris using correction parameters from augmentation messages. The corrected satellite clock offset is computed as follows (CSNO 2020):

$$t_{satellite} = t_{broadcast} - \frac{c_0}{c} \quad (5)$$

where $t_{\text{satellite}}$ is the precisely corrected clock offset; $t_{\text{broadcast}}$ is the satellite clock offset derived from the broadcast ephemeris; C_0 is the clock offset correction parameter which is provided in the augmentation message; c is the velocity of light.

2.4 Differential Code Bias Correction

In the PPP-B2b service, due to variations in satellite tracking modes, each observation contains a deviation associated with the signal tracking method. To achieve synchronous processing of multiple signals at different frequencies, it is necessary to first eliminate this deviation. The corrected observation is computed as follows (CSNO 2020):

$$\tilde{l}_{\text{sig}} = l_{\text{sig}} - \text{DCB}_{\text{sig}} \quad (6)$$

where \tilde{l}_{sig} is the observation after correction of the sig signal; l_{sig} is the observation directly captured by the sig signal receiver; DCB_{sig} is the DCB corresponding to the signal.

Taking the BeiDou Navigation Satellite System as an example, if the user employs dual-frequency ranging signals B1Cp and B2ap, the DCB for the B1Cp signal, as provided in the PPP-B2b message, is denoted as DCB_{B1Cp} , while that for the B2ap signal is DCB_{B2ap} . The corresponding inter-code bias correction is then given by the following formula (CSNO 2020):

$$\tilde{l}_{\text{B1Cp}} = l_{\text{B1Cp}} - \text{DCB}_{\text{B1Cp}} \quad (7)$$

$$\tilde{l}_{\text{B2ap}} = l_{\text{B2ap}} - \text{DCB}_{\text{B2ap}} \quad (8)$$

For dual-frequency users, the ionosphere-free combination observation is computed as follows:

$$\tilde{l}_{\text{IF}} = \frac{\gamma \tilde{l}_{\text{B1Cp}} - \tilde{l}_{\text{B2ap}}}{\gamma - 1} = \frac{\gamma l_{\text{B1Cp}} - l_{\text{B2ap}}}{\gamma - 1} - \frac{\gamma \text{DCB}_{\text{B1Cp}} - \text{DCB}_{\text{B2ap}}}{\gamma - 1} \quad (9)$$

with $\gamma = \frac{f_{\text{B1Cp}}^2}{f_{\text{B2ap}}^2}$, where f_{B1Cp} is the B1Cp carrier center frequency; f_{B2ap} is the B2ap carrier center frequency. This formulation ensures that dual-frequency users can accurately correct for differential code biases when applying the PPP-B2b service.

3 Architecture of the B2bLIB

The detailed introduction to the structure of the B2b messages is given firstly. This is followed by a description of the architecture of the B2bLIB program.

3.1 Introduction to B2b Messages

The B2b messages used in this package are pre-decoded text files, categorized into four separate files based on message type. The format of Message Type 1 is as follows:

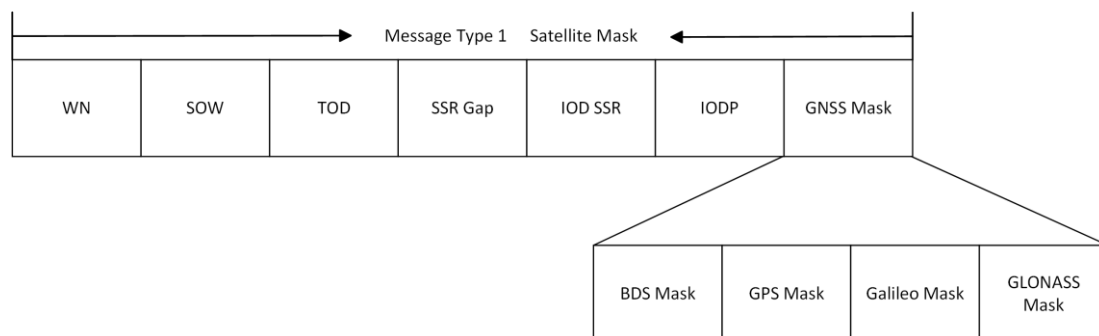


Fig. 1 Format of Message Type 1

This message includes satellite mask information. WN, SOW, and TOD denote the BeiDou week number, seconds of the week, and seconds of the day, respectively. SSR Gap denotes the SSR update interval, with no reserved mask. IOD SSR denotes a change in the data generation configuration. To ensure proper matching, all data types must share the same IOD SSR value before use. Message Type 4 also contains an IODP field. When this field matches the IODP value in Message Type 1, the two messages are considered part of the same data group. The GNSS Mask includes the BDS Mask, GPS Mask, Galileo Mask, and GLONASS Mask, which correspond to the satellite mask information for BDS, GPS, Galileo, and GLONASS, respectively. A bit value of 1 denotes that differential corrections for the corresponding satellite are broadcast, while a bit value of 0 denotes that no correction is transmitted. For detailed information, please refer to Appendix A.

The format of Message Type 2 is as follows:

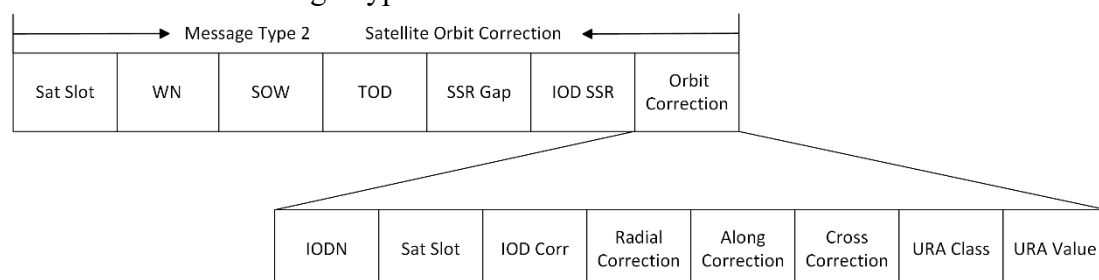


Fig. 2 Format of Message Type 2

This message includes satellite orbit error correction parameters. Sat Slot denotes the position of the satellite in the mask. IODN denotes the data version number of the satellite clock and ephemeris broadcast by the GNSS downlink signal. It corresponds to the IODC field in the BDS CNAV1 and GPS LNAV messages. IODN is used to determine whether the ephemeris and clock parameters in the basic navigation message match the orbit corrections provided in Message Type 2. IOD Corr denotes the version number of the orbit and clock correction parameters. It is included in both Message Type 2 and Message Type 4. For a given satellite, if the IOD Corr values of the orbit and clock corrections are identical, the two can be used together. Satellite orbit error correction parameters include the Radial Correction, Along Correction, and Cross Correction, which correspond to the corrections in the radial, along, and cross directions of the satellite orbit, respectively. URA Class and URA Value denote the parameters used to calculate the User Range Accuracy index. For detailed information, please refer to Appendix B. The remaining parameters are identical to those in Message Type 1 and

will not be described here or in the following sections.

The format of Message Type 3 is as follows:

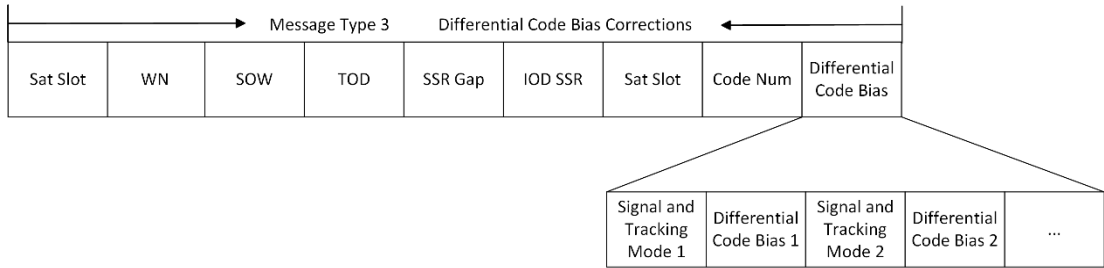


Fig. 3 Format of Message Type 3

This message includes differential code bias correction parameters. Signal and Tracking Mode denote the signal component corresponding to the Differential Code Bias and the signal-receiving mode of that component. Code Num denotes the number of differential code bias included for each satellite. For detailed information, please refer to Appendix C.

The format of Message Type 4 is as follows:

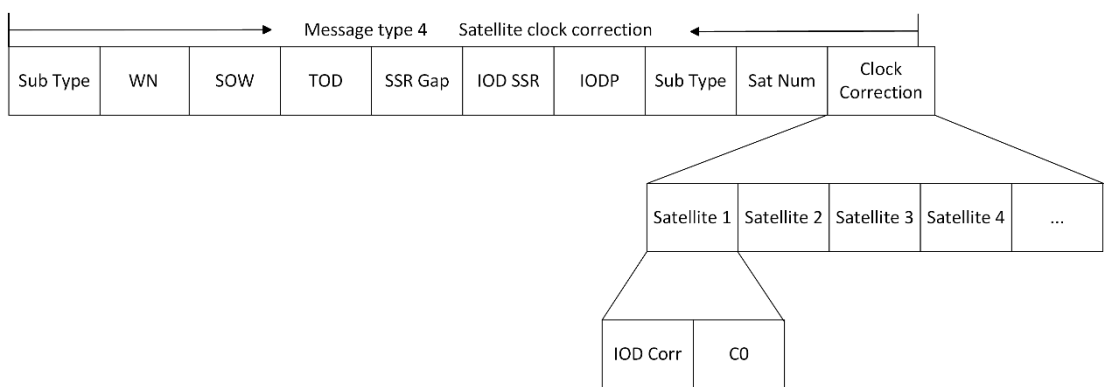


Fig. 4 Format of Message Type 4

This message includes satellite clock offset correction parameters. Sub Type denotes the corresponding relationship between the satellite and the mask. Message type, mask, and Sub Type collectively determine the satellites corresponding to the clock offset corrections: all satellites whose masks are set to 1 are compressed in order of their slot locations in the mask. Sat Num denotes the number of satellites for which clock offset corrections are provided. C0 denotes the clock offset correction value. For detailed information, please refer to Appendix D.

3.2 Introduction to the B2bLIB Program

The B2bLIB program employs B2b messages for PPP in accordance with ICD specifications. The program is primarily divided into two components: message reading and message processing. Message processing is further divided into two components: one uses MT2 and MT4 for satellite position calculation, and the other uses MT3 for DCB correction. The process flowchart is as follows:

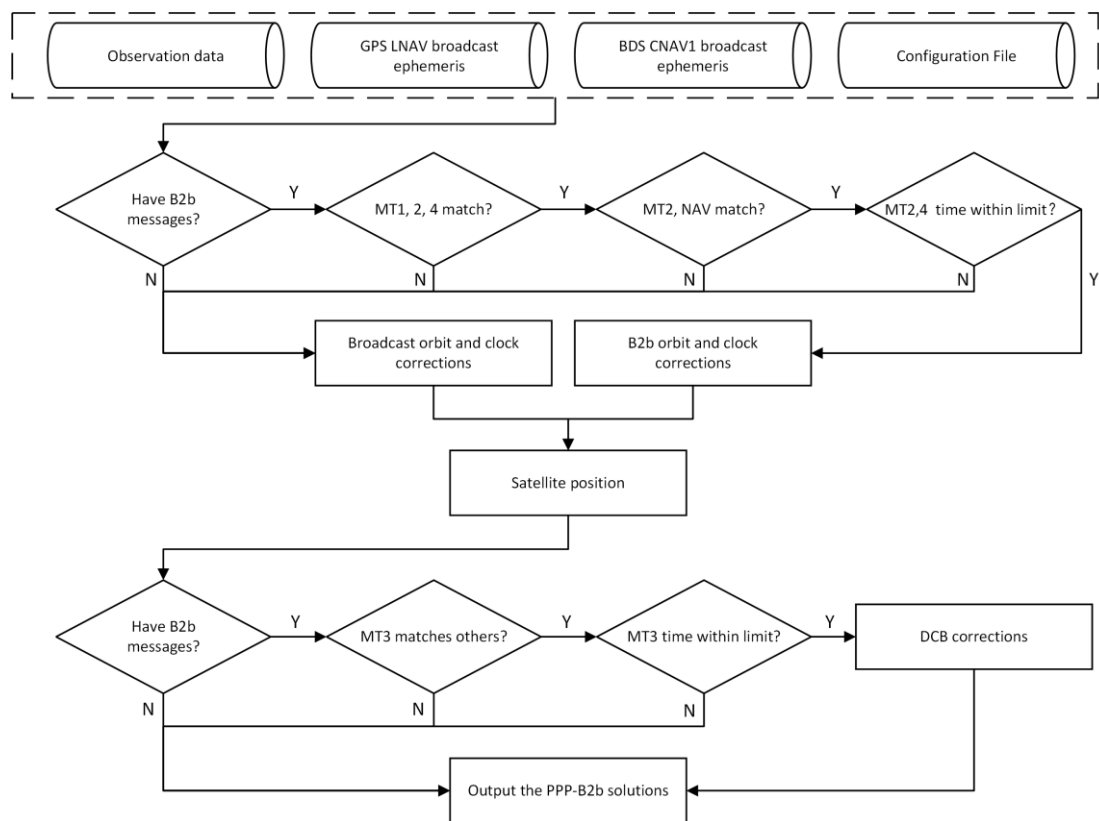


Fig. 5 Flowchart of the B2bLIB

The essential input files for the B2bLIB program include the observation file, configuration file, GPS LNAV broadcast ephemeris, and BDS CNAV1 broadcast ephemeris. These ephemerides can be extracted from Rinex 4.0 files. If B2b message data is available, it corrects orbit errors and clock offsets. If a satellite does not match a B2b message, the program reverts to broadcast ephemeris for orbit error corrections and clock offset corrections. For DCB corrections, if a satellite matches a B2b message, the program applies DCB correction; otherwise, it outputs the positioning result directly.

4 Download

No additional libraries need to be downloaded. The B2bLIB executable file and its dependencies are all included within the " Program " folder. The contents are as follows:

新加卷 (D:) > Program				
名称	修改日期	类型	大小	
src	2025/5/7 20:55	文件夹		
testdata	2025/5/7 9:02	文件夹		

B2b messages are relatively difficult to obtain; therefore, we provide several B2b messages for reference. Additionally, we provide a complete learning project for

reading and using B2b messages, which helps users quickly familiarize themselves with the software. The B2bLIB is a specialized software package designed for receiving and processing B2b messages. The source code for processing B2b messages with the B2bLIB is stored in the " Program/Src" folder. The contents of this folder are as follows:

新加卷 (D:) > Program > src

名称	修改日期	类型	大小
B2bLIB.c	2025/5/5 14:42	C Source File	51 KB
B2bLIB.h	2025/5/7 20:56	C Header File	2 KB
B2bMSG.h	2025/5/7 20:32	C Header File	5 KB
binex.c	2025/5/5 14:42	C Source File	44 KB
convgpx.c	2025/5/5 14:42	C Source File	7 KB
convkml.c	2025/5/5 14:42	C Source File	9 KB
convrnx.c	2025/5/5 14:42	C Source File	49 KB
crescent.c	2025/5/5 14:42	C Source File	23 KB
datum.c	2025/5/5 14:42	C Source File	5 KB
download.c	2025/5/5 14:42	C Source File	30 KB
ephemeris.c	2025/5/5 14:42	C Source File	37 KB
geoid.c	2025/5/5 14:42	C Source File	592 KB
gis.c	2025/5/5 14:42	C Source File	11 KB
ionex.c	2025/5/5 14:42	C Source File	17 KB

5 How to Run the B2bLIB

5.1 Compile

Step 1: Prepare the Source Code.

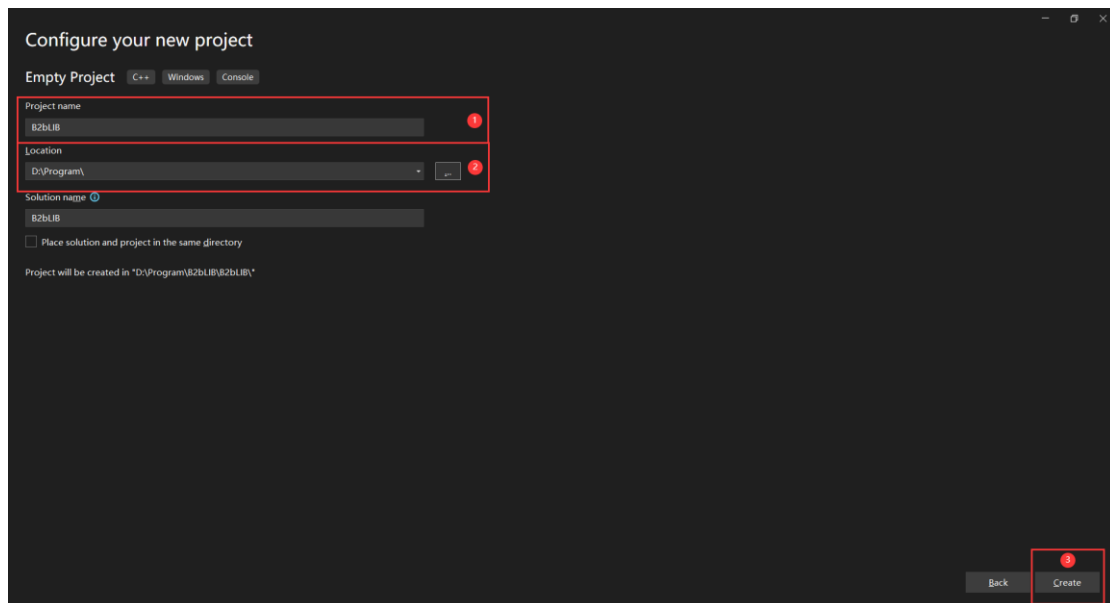
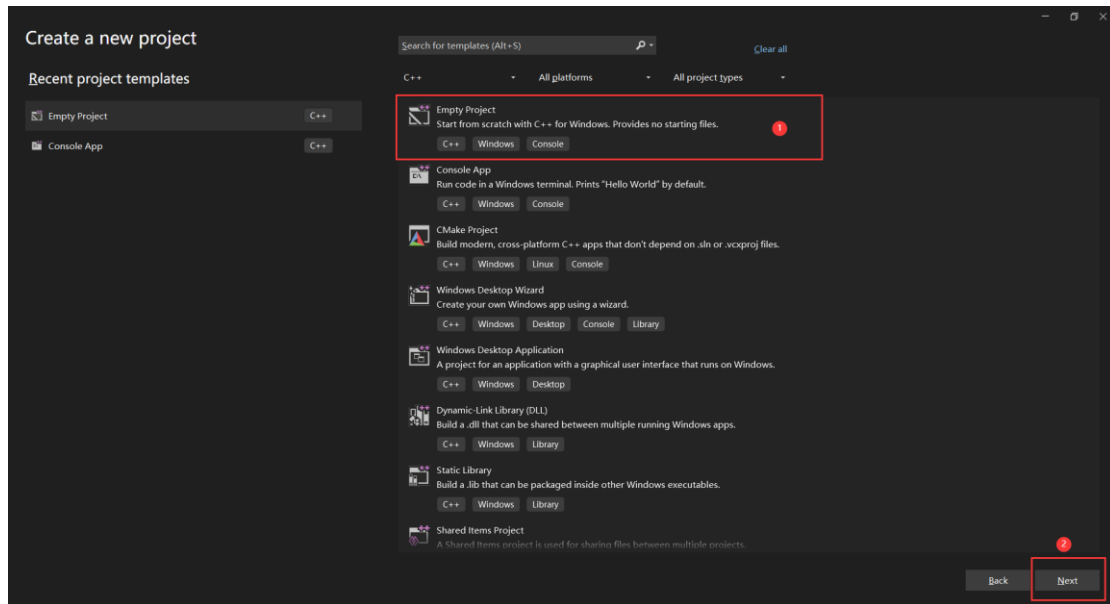
The source code for the B2bLIB is located in the "src" folder, as shown below:

新加卷 (D:) > Program

名称	修改日期	类型	大小
src	2025/5/7 20:55	文件夹	
testdata	2025/5/7 9:02	文件夹	

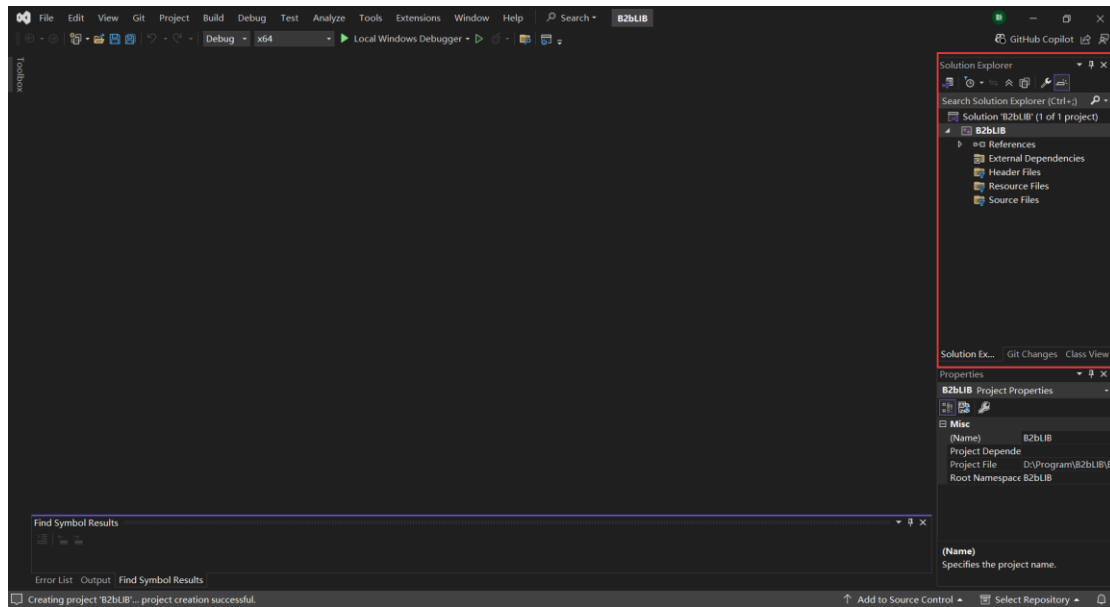
Step 2: Create a New Project.

Visual Studio 2022 software is required for this process. Create a new project named " B2bLIB," as shown below:



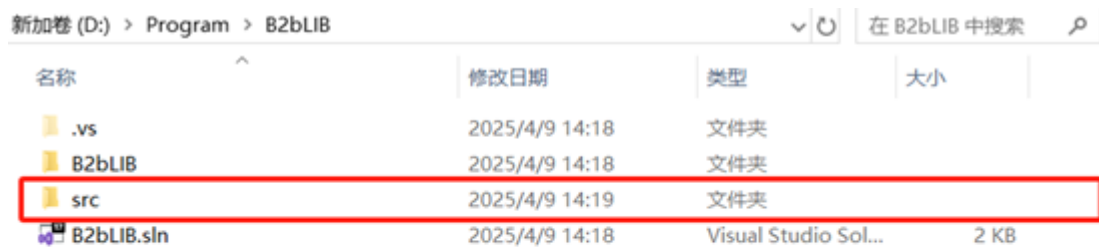
Note: The project should be created in the same folder as the test data; otherwise, the input file paths must be manually modified

Upon completion, the result will appear as shown below:

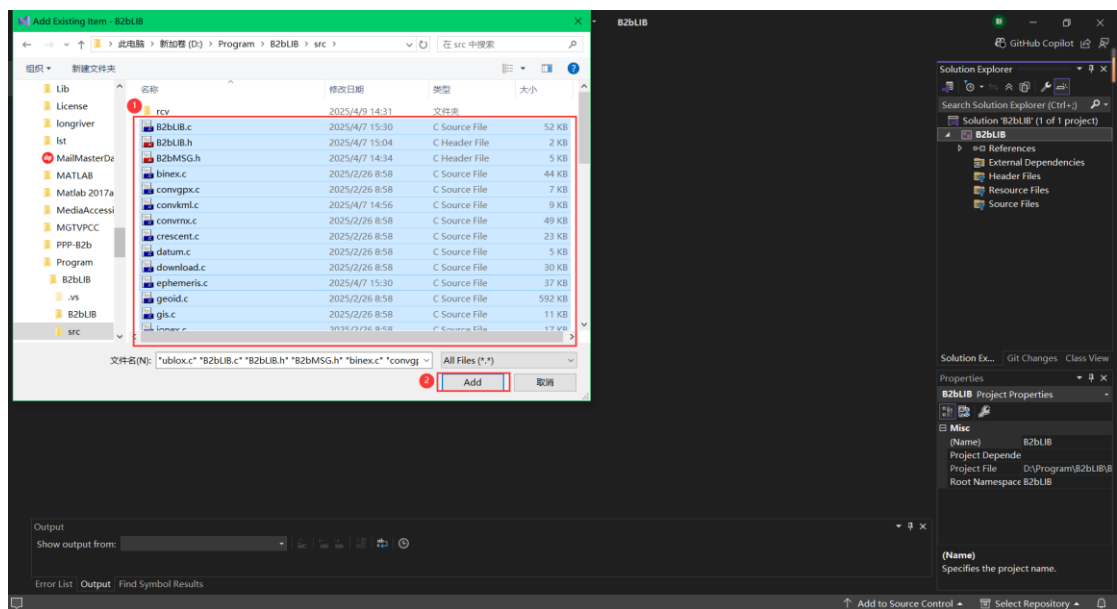
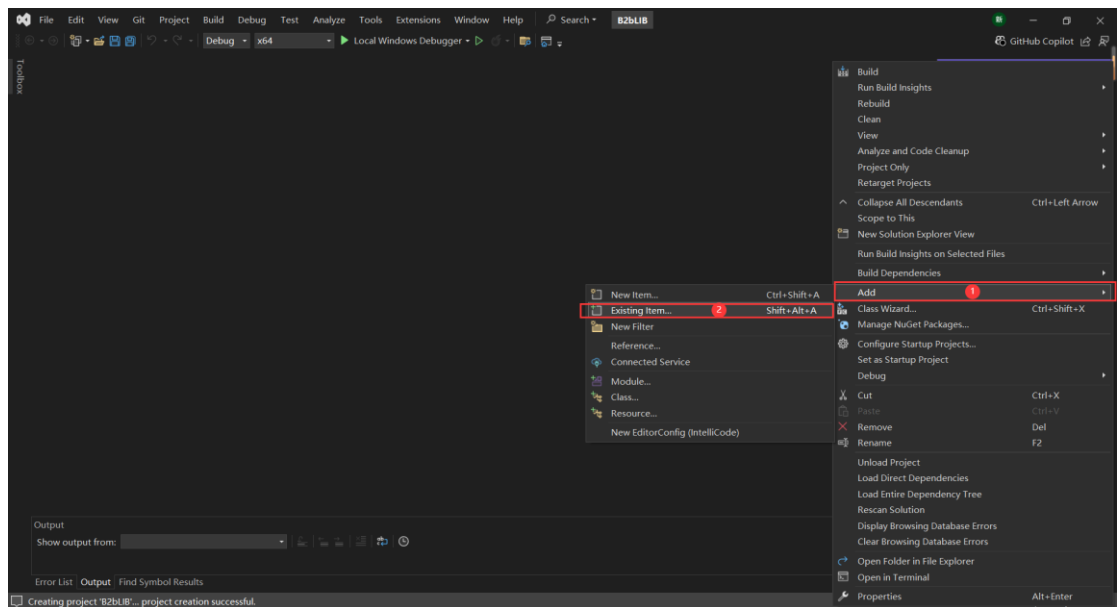


Step 3: Import the Source Files.

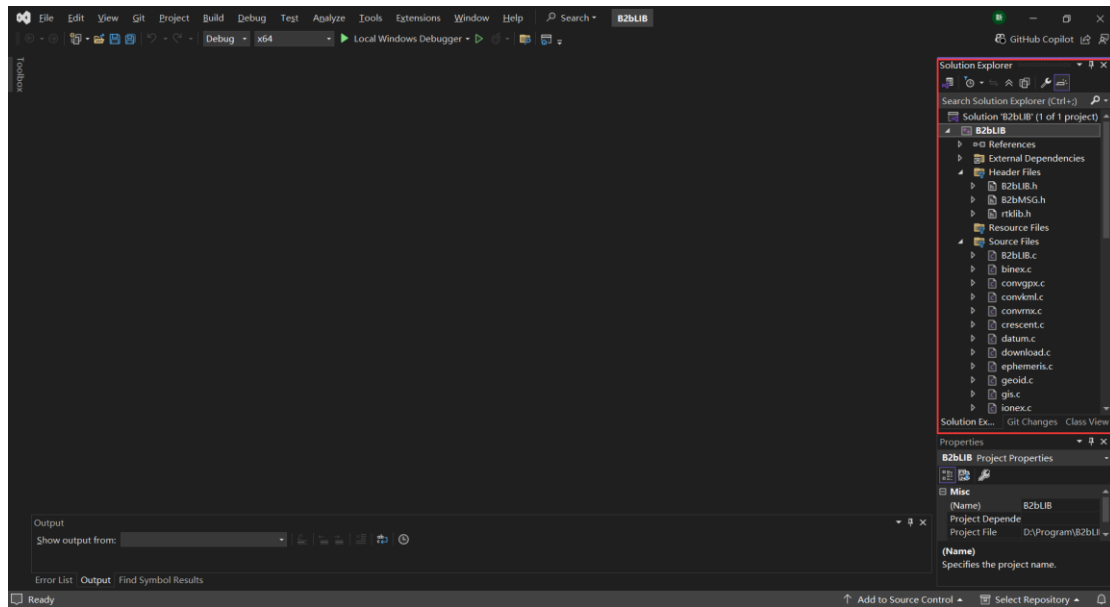
Copy the contents of the "src" folder into the project directory for " B2bLIB."



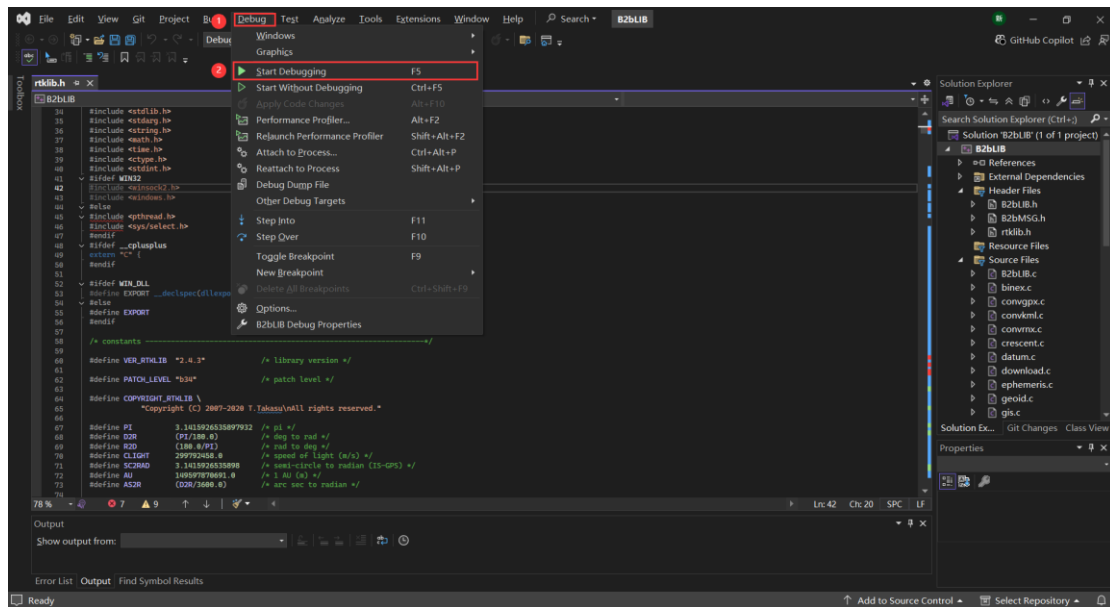
Add all the files from the "src" folder to the project:



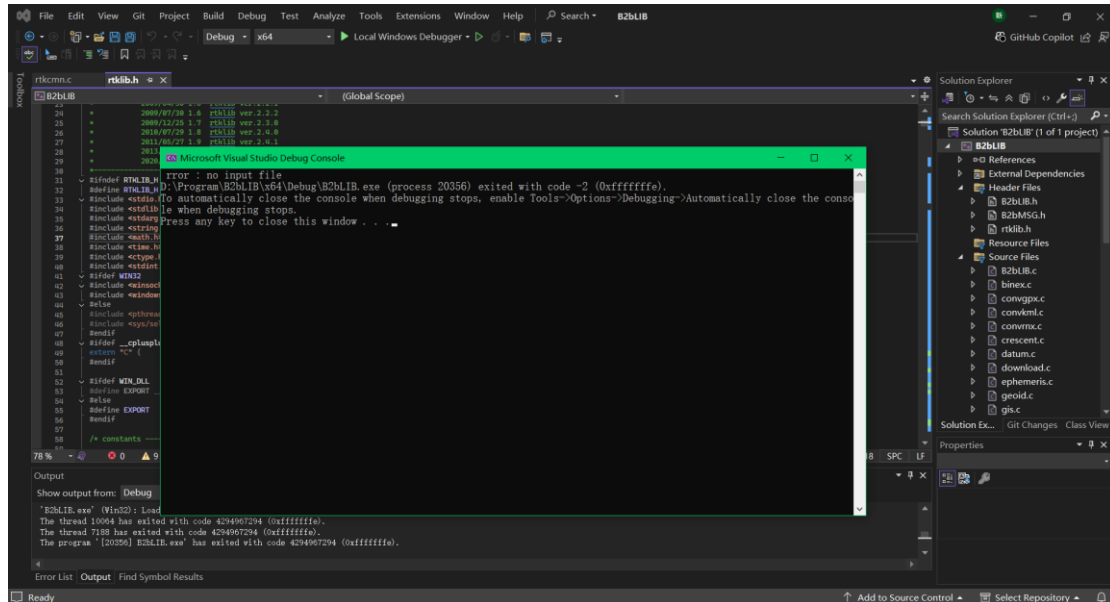
The result will appear as shown below:



Step 4: Debug.



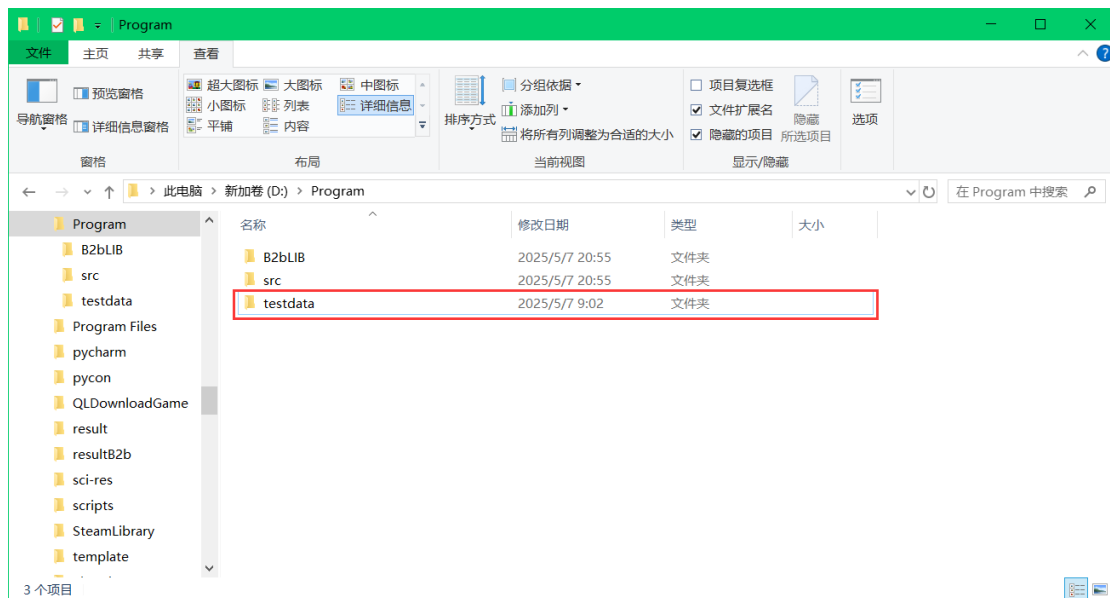
If the debugging is successful, the result will appear as shown below:



5.2 Run

Step 1: Prepare Files.

The test data is located in the "testdata" folder:

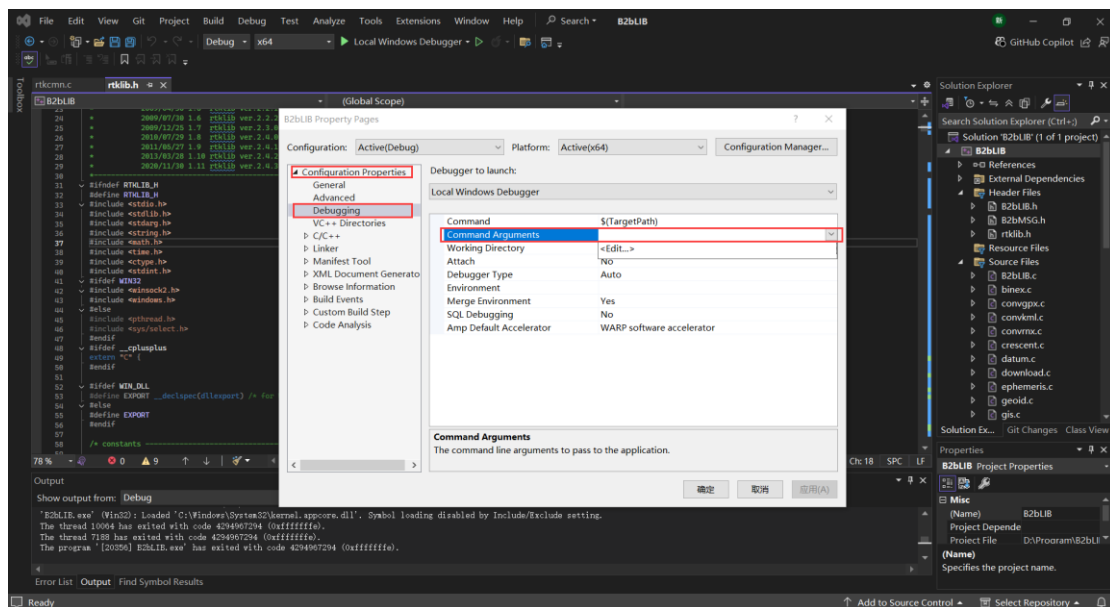


The specific contents are as follows:

名称	修改日期	类型	大小	
WUH22370.24o	2024/12/5 9:50	24O 文件	65,762 KB	Observation file
brd42370.24p	2025/3/26 9:18	24P 文件	21,954 KB	Broadcast ephemeris
PPPB2b.conf	2025/4/27 21:19	CONF 文件	5 KB	Configuration
ClkCorr20240824.dat	2024/11/22 17:02	DAT 文件	23,287 KB	B2b message
DcbCorr20240824.dat	2025/2/21 9:18	DAT 文件	3,865 KB	
OrbCorr20240824.dat	2024/11/22 16:59	DAT 文件	4,101 KB	
PrnMask20240824.dat	2024/11/22 17:00	DAT 文件	391 KB	

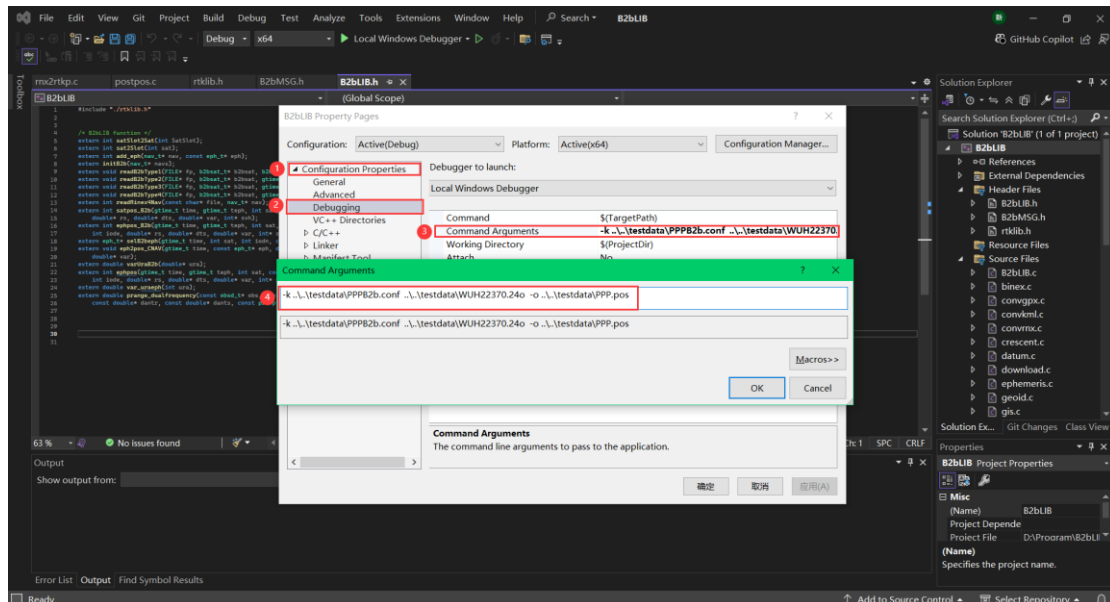
Step 2: Set Configuration File, Observation File and Output File Paths.

Enter the following properties interface:



Input:

-k ..\..\testdata\PPPB2b.conf ..\..\testdata\WUH22370.24o -o ..\..\testdata\PPP.pos

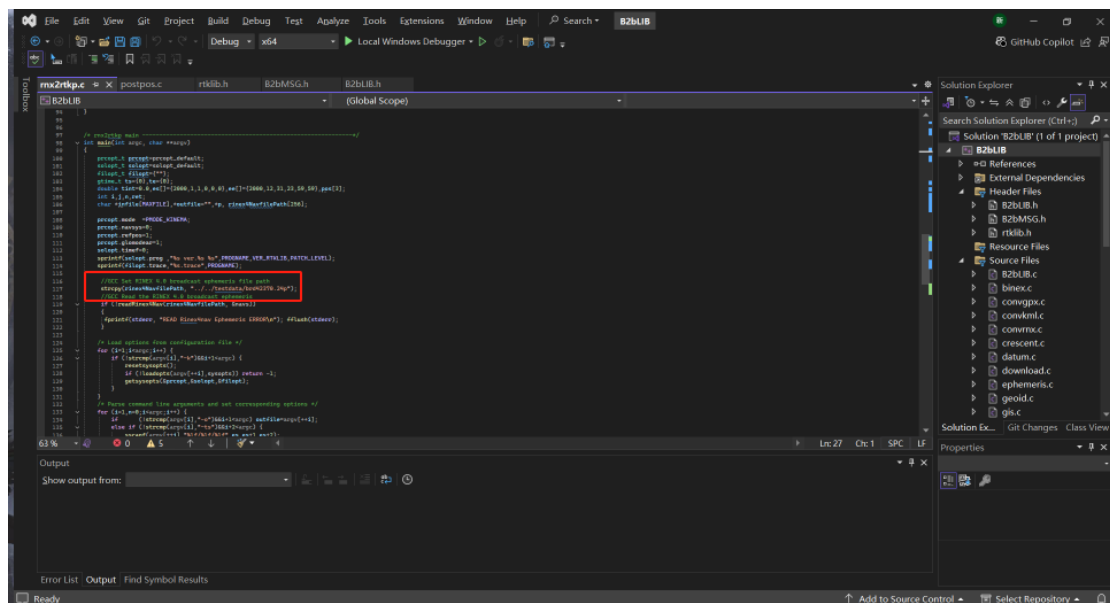


Note: When the project is created in the same directory as the test data, the path can be used as is.

Step 3: Set Broadcast Ephemeris and B2b Message Paths.

If the project is created in the same folder as the test data, this step can be skipped.

Set the broadcast ephemeris path under the main function:



Set the B2b message path under the inputobs function:

新加卷 (D:) > B2bLIB > testdata

在 testdata 中搜索

名称	修改日期	类型	大小
WUHZ2370.24o	2024/12/5 9:50	24O 文件	65,762 KB
brd42370.24p	2025/3/26 9:18	24P 文件	21,954 KB
PPPB2b.conf	2025/4/2 15:17	CONF 文件	5 KB
CDCorr20240824.dat	2025/2/21 9:18	DAT 文件	3,865 KB
ClkCorr20240824.dat	2024/11/22 17:02	DAT 文件	23,287 KB
OrbCorr20240824.dat	2024/11/22 16:59	DAT 文件	4,101 KB
PrnMask20240824.dat	2024/11/22 17:00	DAT 文件	391 KB
PPP.pos	2025/4/9 15:15	POS 文件	408 KB

6 Results and Verification

Previous chapters stated that the final result generates a PPP.pos file. This file contains the observation epoch (GPST), PPP coordinates, PPP status (Q), number of valid satellites (ns), and PPP coordinate variance, as shown in. Fig. 6-11 show the number of satellites, PDOP values, and positioning errors for BDS-only, GPS-only, and BDS/GPS, respectively.

```

$ program : RTRLIB ver.2.4.3
$ inp file : D:\test-res\kaiyuan\PPP-B2b\testdata\WUHZ2370.24o
$ obs start : 2024/08/24 23:58:42.0 UTC (week3228 518400.0s)
$ obs end : 2024/08/24 23:59:12.0 UTC (week3228 604770.0s)
$ pos mode : PPP Static
$ solution : Forward
$ elev mask : 10.0 deg
$ dynamics : off
$ tidecorr : off
$ tropo opt : Estimate STD
$ ephemeris :
$ nav sys : GPS BDS
$ antenna :
( 0.0000 0.0000 0.0000)

$ (x/y/z-ecf-WGS84, q1:fix,2:float,3:abas,4:dpps,5:single,6:ppp,ns# of satellites)
$ UTC x-ecf(m) y-ecf(m) z-ecf(m) Q ns sdx(m) sdy(m) sdz(m) sdx(m) sdy(m) sdz(m) sdx(m) sdy(m) age(s) ratio
2024/08/24 00:00:12.000 -2267750.3011 5009156.7073 3221296.0724 6 9 1.8731 3.4575 2.1078 -2.2877 2.2293 -1.5546 0.00 0.0
2024/08/24 00:01:12.000 -2267751.3110 5009155.2401 3221295.9894 6 15 0.9303 1.5509 0.9460 -0.9455 0.9168 -0.4684 0.00 0.0
2024/08/24 00:01:42.000 -2267751.4345 5009154.6648 3221295.1401 6 15 0.6985 1.1651 0.7252 -0.7272 0.6739 -0.4889 0.00 0.0
2024/08/24 00:02:12.000 -2267751.7102 5009154.5999 3221295.6121 6 15 0.5686 0.9503 0.5726 -0.5795 0.5405 -0.3874 0.00 0.0
2024/08/24 00:02:42.000 -2267751.6294 5009154.5550 3221295.4181 6 14 0.4816 0.8123 0.4499 -0.4836 0.4559 -0.3208 0.00 0.0
2024/08/24 00:03:12.000 -2267751.6490 5009154.5221 3221294.9987 6 14 0.4165 0.7072 0.3967 -0.4115 0.3957 -0.2733 0.00 0.0
2024/08/24 00:03:42.000 -2267751.5064 5009154.4692 3221295.1394 6 14 0.3701 0.6265 0.3434 -0.3402 0.3513 -0.2384 0.00 0.0
2024/08/24 00:04:12.000 -2267751.3787 5009154.4895 3221294.9663 6 14 0.3325 0.5633 0.3036 -0.3205 0.3189 -0.2129 0.00 0.0
2024/08/24 00:04:42.000 -2267751.4281 5009154.6234 3221294.9598 6 14 0.2965 0.5094 0.2732 -0.2828 0.2846 -0.1939 0.00 0.0
2024/08/24 00:05:12.000 -2267751.4422 5009154.7233 3221294.8447 6 13 0.2726 0.4694 0.2497 -0.2596 0.2753 -0.1791 0.00 0.0
2024/08/24 00:05:42.000 -2267751.3993 5009154.6754 3221294.9497 6 14 0.2473 0.4330 0.2310 -0.2355 0.2598 -0.1675 0.00 0.0
2024/08/24 00:06:12.000 -2267751.2620 5009154.6320 3221294.8935 6 13 0.2307 0.4053 0.2158 -0.2209 0.2469 -0.1580 0.00 0.0
2024/08/24 00:06:42.000 -2267751.2420 5009154.7121 3221294.8127 6 15 0.2121 0.3790 0.2030 -0.2045 0.2357 -0.1459 0.00 0.0
2024/08/24 00:07:12.000 -2267751.1533 5009154.6758 3221294.7538 6 14 0.1969 0.3548 0.1921 -0.1915 0.2257 -0.1428 0.00 0.0
2024/08/24 00:07:42.000 -2267751.0845 5009154.5681 3221294.7041 6 14 0.1839 0.3374 0.1826 -0.1807 0.2165 -0.1365 0.00 0.0
2024/08/24 00:08:12.000 -2267751.0277 5009154.5781 3221294.6567 6 13 0.1745 0.3211 0.1740 -0.1733 0.2081 -0.1310 0.00 0.0
2024/08/24 00:08:42.000 -2267751.0124 5009154.6370 3221294.6886 6 13 0.1659 0.3061 0.1662 -0.1663 0.2002 -0.1259 0.00 0.0
2024/08/24 00:09:12.000 -2267750.9787 5009154.6490 3221294.6969 6 14 0.1579 0.2921 0.1590 -0.1596 0.1926 -0.1211 0.00 0.0
2024/08/24 00:09:42.000 -2267750.9223 5009154.5810 3221294.6667 6 14 0.1504 0.2790 0.1522 -0.1533 0.1854 -0.1165 0.00 0.0
2024/08/24 00:10:12.000 -2267750.8401 5009154.5237 3221294.6297 6 15 0.1412 0.2657 0.1458 -0.1452 0.1781 -0.1117 0.00 0.0
2024/08/24 00:10:42.000 -2267750.7761 5009154.4586 3221294.5683 6 14 0.1349 0.2542 0.1398 -0.1395 0.1713 -0.1074 0.00 0.0
2024/08/24 00:11:12.000 -2267750.6775 5009154.4641 3221294.5070 6 14 0.1275 0.2429 0.1339 -0.1330 0.1646 -0.1030 0.00 0.0
2024/08/24 00:11:42.000 -2267750.6463 5009154.4680 3221294.5200 6 15 0.1207 0.2319 0.1284 -0.1265 0.1580 -0.0987 0.00 0.0
2024/08/24 00:12:12.000 -2267750.6524 5009154.4328 3221294.4960 6 14 0.1156 0.2221 0.1230 -0.1215 0.1517 -0.0947 0.00 0.0

```

Fig. 6 Example of final file

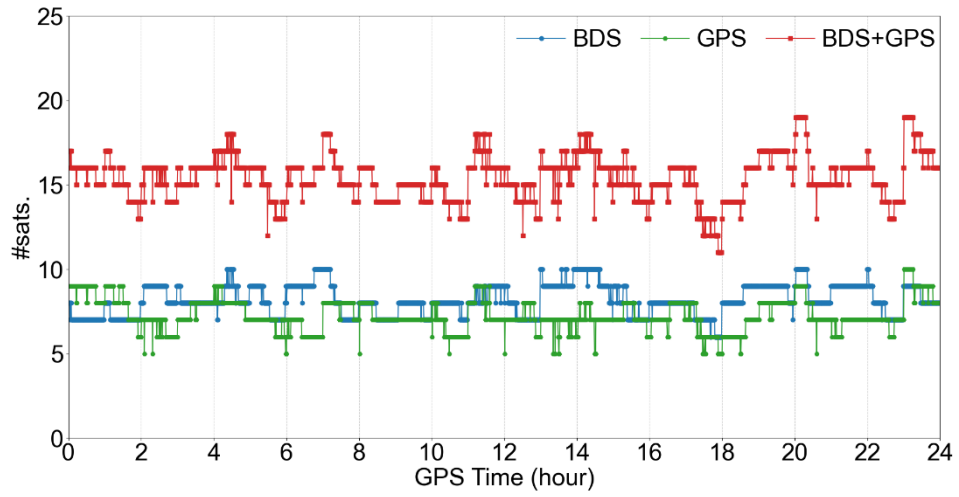


Fig. 7 Numbers of BDS (blue), GPS (green), and BDS+GPS (red) satellites

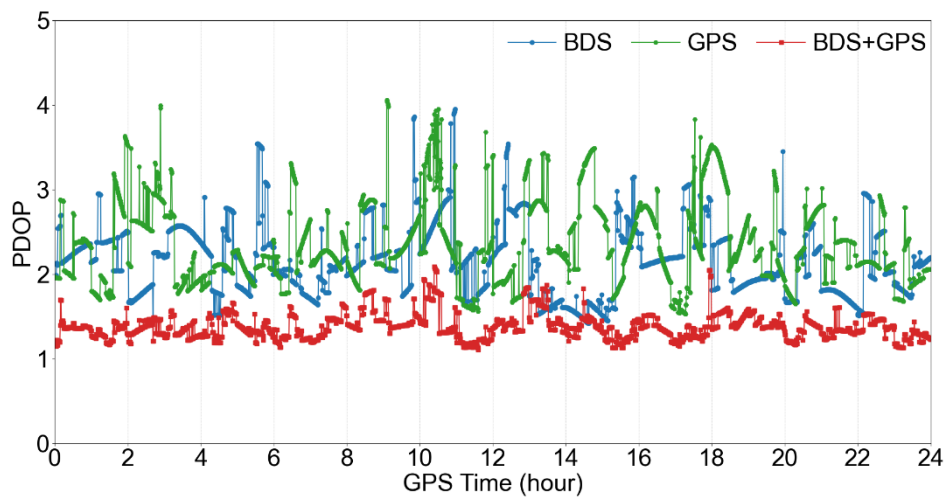


Fig. 8 PDOP values of BDS (blue), GPS (green), and BDS+GPS (red)

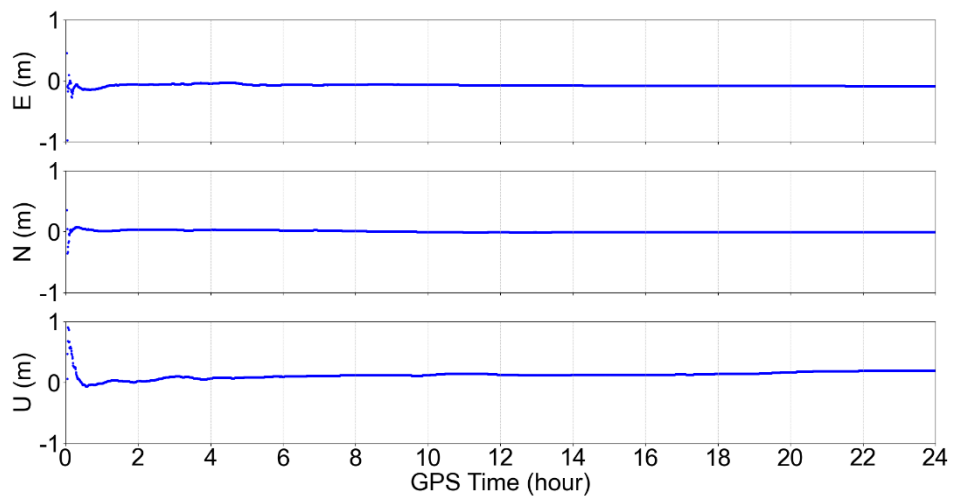


Fig. 9 BDS positioning errors in E, N, and U directions

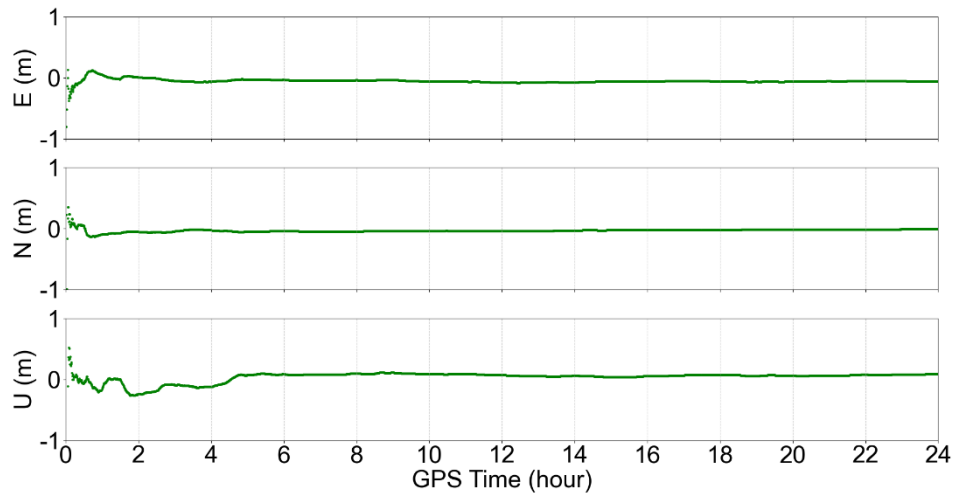


Fig. 10 GPS positioning errors in E, N, and U directions

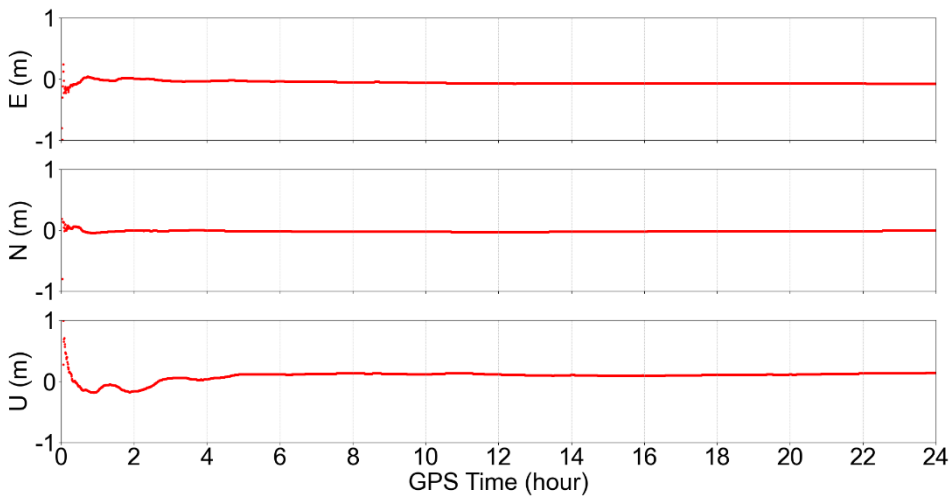


Fig. 11 BDS+GPS positioning errors in E, N, and U directions

7 Appendix

In this appendix, supplementary information is given for the four types of B2b messages, respectively.

7.1 Message Type 1

The satellite mask assignment of the message type 1 is described in Table 1.

Table 1 Satellite mask assignment of the message type 1

Mask	Name	Scale factor	Range	Basic description
BDS mask	Satellite slot 1	1	0~1	Broadcasting ID of the first satellite of BDS
	to slot 63	1	0~1	Broadcasting ID of the 63 rd satellite of BDS
GPS mask	Satellite slot 64	1	0~1	Broadcasting ID of the first satellite of GPS
	to slot 100	1	0~1	Broadcasting ID of the 37 th satellite of GPS
Galileo mask	Satellite slot 101	1	0~1	Broadcasting ID of the first satellite of Galileo
	to slot137	1	0~1	Broadcasting ID of the 37 th satellite of Galileo
GLONASS mask	Satellite slot 138	1	0~1	Broadcasting ID of the first satellite of GLONASS
	to slot 174	1	0~1	Broadcasting ID of the 37 th satellite of GLONASS

7.2 Message Type 2

The formula for calculating URA is:

$$\text{URA}[\text{mm}] \leq 3^{\text{UR}_{\text{CLASS}}} (1 + 0.25 \times \text{UR}_{\text{VALUE}}) - 1 \quad (8)$$

where URA is the user range accuracy in mm.

When URAI = 000000 (binary), it means that URA is undefined or unknown, and the corresponding satellite correction is not reliable.

When URAI = 111111 (binary), it means that $\text{URA} > 5466.5$ mm.

7.3 Message Type 3

The "signal and tracking mode" indicates the signal component corresponding to the differential code bias and the signal-receiving mode of that component. See Table 2 for specific definitions.

Table 2 Definitions of signal and tracking modes

ID of signal and tracking mode	BDS	GPS	GLONASS	Galileo
0	B1I	L1 C/A	G1 C/A	Reserved
1	B1C(D)	L1 P	G1 P	E1 B
2	B1C(P)	Reserved	G2 C/A	E1 C
3	Reserved	Reserved	Reserved	Reserved
4	B2a(D)	L1C(P)	Reserved	E5a Q
5	B2a(P)	L1C(D+P)	Reserved	E5a I
6	Reserved	Reserved	Reserved	Reserved
7	B2b-I	L2C(L)	Reserved	E5b I
8	B2b-Q	L2C(M+L)	Reserved	E5b Q
9	Reserved	Reserved	Reserved	Reserved
10	Reserved	Reserved	Reserved	Reserved
11	Reserved	L5 1	Reserved	E6 C
12	B3 I	L5 Q	Reserved	Reserved
13	Reserved	L5 I+Q	Reserved	Reserved
14	Reserved	Reserved	Reserved	Reserved
15	Reserved	Reserved	Reserved	Reserved

7.4 Message Type 4

Message type, mask, and Sub Type collectively determine the satellites corresponding to the clock offset corrections: all satellites whose masks are set to 1 are compressed in order of their slot locations in the mask. See Table 3 for the correspondence of SubType1 and satellites.

Table 3 Correspondence of subtype1 and satellites in message type 4

Subtype ID	Corresponding satellites
0	The 1 st ~ 23 rd of the satellites whose masks are set to "1".
1	The 24 th ~ 46 th of the satellites whose masks are set to "1".
2	The 47 th ~ 69 th of the satellites whose masks are set to "1".
3	The 70 th ~ 92 th of the satellites whose masks are set to "1".
4	The 93 th ~ 115 th of the satellites whose masks are set to "1".
5	The 116 th ~ 138 th of the satellites whose masks are set to "1".
6	The 139 th ~ 161 th of the satellites whose masks are set to "1".
7	The 162 th ~ 184 th of the satellites whose masks are set to "1".
8	The 185 th ~ 207 th of the satellites whose masks are set to "1".
9	The 208 th ~ 230 th of the satellites whose masks are set to "1".
10	The 231 th ~ 253 th of the satellites whose masks are set to "1".
11	The 254 th ~ 255 th of the satellites whose masks are set to "1".
Other values	Reserved

8 Acknowledgement

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9 Disclaimer

The experiment is carried out in Visual Studio 2022 environment. With the update of the software, proper modifications of the code may be needed. Some bugs may still exist in the B2bLIB, comments and suggestions are welcome to send to the authors.

10 Contact us

GCC research group of dedicated developers earnestly seeks your valuable insights and suggestions to improve the B2bLIB. We welcome all users to share and exchange technical details, as well as provide improvement suggestions. Here are our contact details:

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References

- CSNO (2020) BeiDou navigation satellite system signal in space interface control document precise point positioning service signal PPP-B2b. <http://www.beidou.gov.cn/xt/gfxz/202008/P020230516574071340728.pdf>
- Lan R, Yang C, Zheng Y, Xu Q, Lv J, Gao Z (2022) Evaluation of BDS-3 B1C/B2b Single/Dual-Frequency PPP Using PPP-B2b and RTS SSR Products in Both Static and Dynamic Applications. *Remote Sens* 14(22):5835. <https://doi.org/10.3390/rs14225835>
- Li X, Li X, Liu G, Feng G, Yuan Y, Zhang K, Ren X (2019) Triple-frequency PPP ambiguity resolution with multi-constellation GNSS: BDS and Galileo. *J Geod* 93(8):1105–1122. <https://doi.org/10.1007/s00190-019-01229-x>
- Nie Z, Liu F, Gao Y (2019) Real-time precise point positioning with a low-cost dual-frequency GNSS device. *GPS Solut* 24(1):9. <https://doi.org/10.1007/s10291-019-0922-3>
- Nie Z, Xu X, Wang Z, Du J (2021) Initial Assessment of BDS PPP-B2b Service: Precision of Orbit and Clock Corrections, and PPP Performance. *Remote Sens* 13(11):2050. <https://doi.org/10.3390/rs13112050>
- Ouyang C, Shi J, Peng W, Dong X, Guo J, Yao Y (2023a) Exploring characteristics of BDS-3 PPP-B2b augmentation messages by a three-step analysis procedure. *GPS Solut* 27(3):119. <https://doi.org/10.1007/s10291-023-01457-x>
- Sun S, Wang M, Liu C, Meng X, Ji R (2023) Long-term performance analysis of BDS-3 precise point positioning (PPP-B2b) service. *GPS Solut* 27(2):69. <https://doi.org/10.1007/s10291-023-01409-5>
- Tang C, Hu X, Chen J, Liu L, Zhou S, Guo R, Li X, He F, Liu J, Yang J (2022) Orbit determination, clock estimation and performance evaluation of BDS-3 PPP-B2b service. *J Geod* 96(9):60. <https://doi.org/10.1007/s00190-022-01642-9>
- Tao J, Liu J, Hu Z, Zhao Q, Chen G, Ju B (2021) Initial Assessment of the BDS-3 PPP-B2b RTS compared with the CNES RTS. *GPS Solut* 25(4):131. <https://doi.org/10.1007/s10291-021-01168-1>
- Yang Y, Gao W, Guo S, Mao Y, Yang Y (2019) Introduction to BeiDou-3 navigation satellite system. *NAVIGATION* 66(1):7–18. <https://doi.org/10.1002/navi.291>
- Yang Y, Liu L, Li J, Yang Y, Zhang T, Mao Y, Sun B, Ren X (2021) Featured services and performance of BDS-3. *Sci Bull* 66(20):2135–2143. <https://doi.org/10.1016/j.scib.2021.06.013>
- Zang N, Li B, Nie L, Shen Y (2019) Inter-system and inter-frequency code biases: simultaneous estimation, daily stability and applications in multi-GNSS single-frequency precise point positioning. *GPS Solut* 24(1):18. <https://doi.org/10.1007/s10291-019-0926-z>
- Zhang W, Lou Y, Song W, Sun W, Zou X, Gong X (2022) Initial assessment of BDS-3 precise point positioning service on GEO B2b signal. *Adv Space Res* 69(1):690–700. <https://doi.org/10.1016/j.asr.2021.09.006>
- Zhang Z, Wang H (2025) Integrated BeiDou satellite-based augmentation system framework combining B2a and B1C services. *GPS Solut* 29(2):74.

<https://doi.org/10.1007/s10291-025-01834-8>