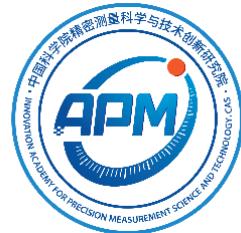




MRCB User Manual



**MRCB: An Open-Source Multi-system time-varying
Receiver Code Bias Analysis Software**

**Innovation Academy for Precision Measurement Science and Technology,
Chinese Academy of Sciences[©]**

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1 Overview

Multi-system and Multi-frequency Receiver Code Bias Analysis Software (MRCB) is an open-source GNSS data processing package specifically designed for extracting time-varying receiver code biases (RCBs). MRCB is developed in C/C++, which can be easily ported to different operating systems, such as Windows and Linux. It is a post-processing software, which can process multi-frequency data from GPS, Galileo, BDS, GLONASS, and QZSS. Using a least-squares filter (LSF) based on undifferenced and uncombined observations to estimate time-varying RCBs. Furthermore, it requires observation files and broadcast ephemeris, offering a simple operation process. Processing strategies for different data can be configured in the formatted configuration file. The main features of MRCB are as follows:

- Undifferenced and uncombined observations
- Support for both CDMA and FDMA
- Extract time-varying RCBs
- Multi-frequency (dual-frequency and above) data processing
- Least square filter

2 MRCB software

2.1 Structure of MRCB

Generally, the processing can be summarized into three parts.

- (1) Data preparation is the first step. In this step, we just need observation file, broadcast ephemeris file. Then, set the parameters in the configuration file.
- (2) Data processing is the second step. In this step, MRCB first calculates the satellite

information. Cycle slip detection is then performed using the geometry-free combination and the Melbourne-Wübbena combination. After finishing cycle slip detection, the LSF is employed to estimate unknown parameters. Finally, quality control is performed using the DIA method.

(3) Information output is the third step. In this step, the processing information and estimated parameters such as satellite clock offsets, elevation and azimuth, post-fit code and carrier phase residuals, the SPP positioning results, time-varying RCBs are all output to formatted files. The log file mainly contains the record of satellite eliminations.

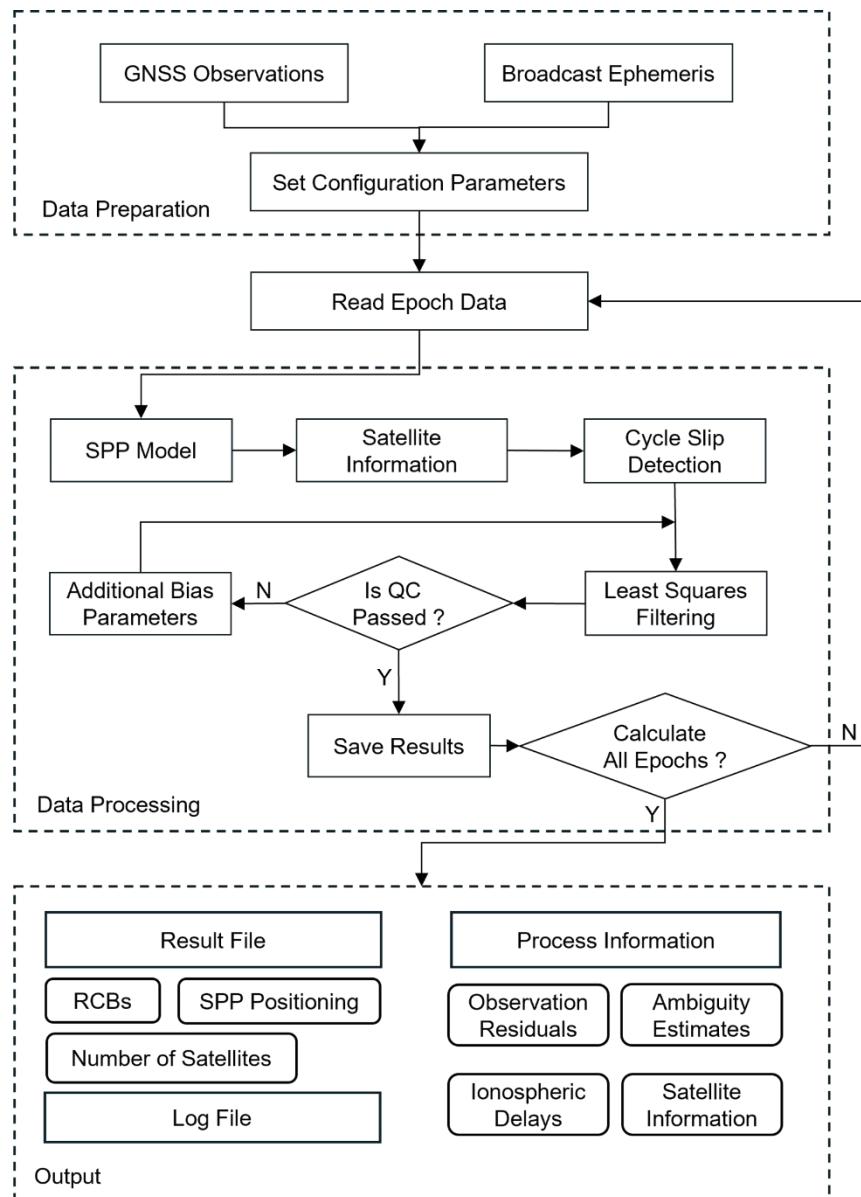


Fig. 1 The processing framework of MRCB software

2.2 Processing strategies

For the processing strategies. The frequency-independent parameters in this study, including the range, receiver clock offsets, satellite clock offsets, and tropospheric delays, were combined into a single parameter, which was estimated as white noise. The ionospheric delays, ambiguity, and time-varying RCBs were also estimated. Detailed information is summarized in Table 1.

Complete mathematical derivations are provided in the Appendix for reference.

Table 1 Processing strategies of MRCB

Item	Processing strategies
Satellite constellation	GPS/GLONASS/BDS/Galileo/QZSS
Frequency number	Dual-frequency and above (up to 5 frequencies)
Functional mode	Uncombined model
Sampling rate	30s
Cut-off mask angle	10°
Observation weight	$P = \sin^2(E) / \sigma^2$ (σ^2 indicates variance of code or carrier phase) A priori precision of 0.003 and 0.3 m for raw phase and code
Filtering method	Least square filter
Frequency-independent parameters	Estimated as white noise
Ionospheric delays	Estimated as white noise
Phase ambiguities	Estimated as float constants for each satellite and frequency
SCB	Estimated as day constants for each satellite on the third or higher frequency band
RCB	Estimated as white noise
IFB	GLONASS, Estimated as white noise

Note: Ensure at least 3 satellites are available for each processed GNSS system. Because mixed-frequency processing is not yet supported, the selected frequencies must be present in

the observations.

Table 2 Frequency priorities for each system

GNSS	1	2	3	4	5
GPS	P1	P2	P5	\	\
GLONASS	R1	R2	\	\	\
Galileo	E1	E5a	E5b	E6	E5
QZSS	P1	P2	P5	\	\
BDS-2	B1I	B3I	B2I	\	\
BDS-3	B1I	B3I	B2b	B1C	B2a

3 Requirements

3.1 Supported platforms

MRCB software was developed in the C/C++ language using the cross-platform CMAKE build system. It can be compiled and executed on both Windows and Linux operating systems. It is recommended to compile and debug MRCB under Visual Studio 2022 in Windows or using GCC/Clang in Linux. Computer configuration requirements are as follows:

Operating system: Linux or Windows

System type: 32 or 64 bit

Memory: at least 512MB

Hard disk space: at least 500MB

CMAKE Version: CMAKE version higher than 3.10

Visual Studio Version: at least version 2022

The software has been tested under Windows 10 and Ubuntu 16.04 or higher, with all tests passed.

3.2 License

Copyright (C) 2025 by APM, CAS, All rights reserved.

This program is an open-source software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation.

4 File structure

The project directory structure is as follows.

```
└── conf
    └── conf
        └── config.dat      # Process configuration file
    └── include
        └── *.h            # Your .h header files
    └── result
        └── # Output result
    └── script
        └── RCB_day_by_day.m   # Visualizes RCBs for a single day
        └── RCB_Continues.m    # Visualizes RCBs for continues day
    └── src
        └── *.cpp          # Your .cpp source files
    └── Testdata
        └── day-by-day processing/ # Daily processing test data/
            └── XXX.o
            └── XXX.n
        └── continuous processing/ # Continuous processing test data/
            └── obs/ # Continuous days observation data from same station
            └── nav/ # Continuous days broadcast ephemeris from same station
    └── User Manual      # User manual documentation
```

Fig. 2 File list

```
└── Your Project Root Directory/
    ├── conf/
    │   └── config.dat      # Process configuration file
    ├── include/
    │   └── *.h            # Your .h header files
    ├── result/
    │   └── # Output result
    ├── script/
    │   └── RCB_day_by_day.m   # Visualizes RCBs for a single day
    │   └── RCB_Continues.m    # Visualizes RCBs for continues day
    ├── src/
    │   └── *.cpp          # Your .cpp source files
    └── Testdata/
        └── day-by-day processing/ # Daily processing test data/
            └── XXX.o
            └── XXX.n
        └── continuous processing/ # Continuous processing test data/
            └── obs/ # Continuous days observation data from same station
            └── nav/ # Continuous days broadcast ephemeris from same station
    └── User Manual      # User manual documentation
```

Fig. 3 The structure of File

5 Configuration File (config.dat)

The configuration file mainly contains four parts:

- a) Input file configuration
- b) Output file configuration
- c) Processing strategies configuration
- d) Station names

It is noted that '#' represents the function of annotation in the configuration file. Users can choose different process options according their realistic needs. Users configure the input and output paths according to their specific requirements.

5.1 Input file configuration

Users need to set an absolute path.

- OBS_PATH: single station observation file path
- NAV_PATH: broadcast ephemeris file path

```
# MRCB_Version 1.0 Configuration File  
#=====  
# Input File Path  
  
OBS_PATH      =F:\MRCB\Testdata\day-by-day processing\MRO100AUS_R_20242980000_01D_30S_MO.24o    # obs file path  
NAV_PATH      =F:\MRCB\Testdata\day-by-day processing\BRDC00IGS_R_20242980000_01D_MN.24n    # nav file path (broadcast ephemeris)
```

Fig. 4 Input file configuration

5.2 Output file configuration

Users need to set an absolute path.

- OUT_PRO: Dir for process information file; file name is auto-generated.
- OUT_PATH: Dir for result file; file name is auto-generated.
- OUT_LOG: Dir for sat log file; file name is auto-generated. record the satellite elimination records

```

10 #=====
11 # Output File Path
12
13 OUT_PRO    =E:\open_source\result\  

14 OUT_PATH   =E:\open_source\result\  

15 OUT_LOG    =E:\open_source\result\  

16
17 #=====

```

Fig. 5 Output file configuration

Note: The slash direction varies by operating system

- **Windows:** Use backslashes (\). Example: C:\Users\username\input\data.obs
- **Linux:** Use forward slashes (/). Example: C:/Users/username/input/data.obs

5.3 Processing strategies configuration

- UseBDS2: Distinguishes between BDS-2 and BDS-3 satellites due to differing RCB variations trends. 0→Uses only BDS-3 satellite data 1→Uses only BDS-2 satellite data
- Frequency: Number of frequency bands to process
- Exclsats: Satellites to be manually excluded
- System: GNSS systems to be processed

```

17 #=====
18 # Process Option1
19 Ephopt      =0          # Satellite Ephemeris :0->broadcast
20 FiltMode    =0          # Filting Mode       :0->Forward Mode
21 UseBDS2    =0          # Is Use BDS2        :0->use bds3 , 1->use bds2
22 Frequency  =2          # Frequency number
23 Elmask     =10         # Satellite elevation mask
24 Exclsats   =C01 C02 C03 C04 C05 # prn ...
25 System     =41         # 1:gps+4:glo+8:gal+16:qzs+32:comp

```

Fig. 6 Processing options 1 configuration

- **Continue:** day-by-day means processes data one day at a time, used to analyze RCB variations within a single day; continuous processing means processes multiple consecutive days together, used to analyze RCB variations across several days.
- OBS_DIR: Observation data folder for multiple consecutive days
- NAV_DIR: Broadcast ephemeris folder for multiple consecutive days

```

27 # Process Option2
28 Continue      =0
29 OBS_DIR       =E:\open_source\Testdata\continuous processing\obs\
30 NAV_DIR       =E:\open_source\Testdata\continuous processing\nav\
31
32 =====

```

Fig. 7 Processing options 2 configuration

5.4 Station Information

```

=====
# Station information
StaName      =MRO1          # Station Name
DOY         =2024298        # DOY

```

Fig. 8 Station information configuration

6 Compile and Run

6.1 Compile

6.1.1 Windows

Ensure that the complete compilation tool and CMAKE (version 3.10 or higher) is installed.

- Extract the files downloaded from GitHub

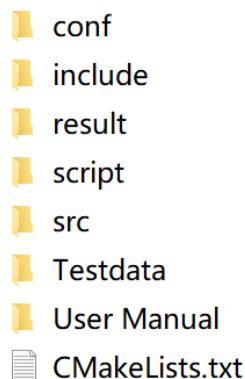


Fig. 9 The extracted files

- Search "x64 Native Tools Command Prompt for VS 2022"

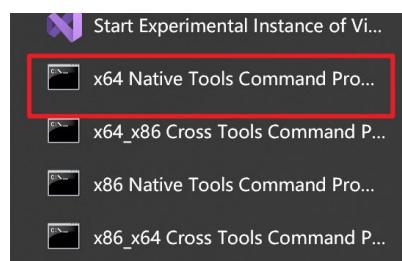


Fig. 10 Open Command Prompt

- Navigate to Project Directory and Compile. Execute these commands in sequence

① cd your_project_path ②mkdir build ③cmake -B build ④cmake --build build

```
D:\VS2022\VS2022>F:
F:>cd F:\MRCB (1)
F:\MRCB>mkdir build (2)
F:\MRCB>cmake -B build (3)
Building for: Visual Studio 17 2022
-- Selecting Windows SDK version 10.0.26100.0 to target Windows 10.0.19045.
-- The CXX compiler identification is MSVC 19.41.34123.0
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Check for working CXX compiler: D:/VS2022/VS2022/VC/Tools/MSVC/14.41.34120/bin/xHostx64/x64/cl.exe - skipped
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Configuring done (3.2s)
-- Generating done (0.0s)
-- Build files have been written to: F:/MRCB/build

F:\MRCB>cmake --build build (4)
适用于 .NET Framework MSBuild 版本 17.11.9+a69bbfa#5

1>Checking Build System
Building Custom Rule F:/MRCB/CMakeLists.txt
MRCB_ComFun.cpp
MRCB_DataPre.cpp
MRCB_DataProcess.cpp
MRCB_Ephemeris.cpp
MRCB_Inpfile.cpp
MRCB_Options.cpp
MRCB_Pntpos.cpp
MRCB_RcbProcess.cpp
MRCB_ReadRinex.cpp
MRCB_SolBody.cpp
MRCB_SolHead.cpp
main.cpp
正在生成代码...
MRCB.vcxproj -> F:/MRCB/build\Debug\MRCB.exe
'pwsch.exe' 不是内部或外部命令，也不是可运行的程序
或批处理文件。
Building Custom Rule F:/MRCB/CMakeLists.txt

F:\MRCB>
```

Fig. 11 Finish compile under Windows

6.1.2 Linux

Ensure that the complete compilation tool and CMAKE (version 3.10 or higher) is installed.

Execute these commands in sequence: ① cd your_project_path ② mkdir build ③ cd build

④ cmake .. ⑤ make

```
dd@dd-virtual-machine:~/Documents/MRCB/build
dd@dd-virtual-machine:~$ cd /home/dd/Documents/MRCB (1)
dd@dd-virtual-machine:~/Documents/MRCB$ mkdir build(2)
dd@dd-virtual-machine:~/Documents/MRCB$ cd build(3)
dd@dd-virtual-machine:~/Documents/MRCB/build$ cmake .. (4)
-- The CXX compiler identification is GNU 5.4.0
-- Check for working CXX compiler: /usr/bin/c++
-- Check for working CXX compiler: /usr/bin/c++ -- works
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Configuring done
-- Generating done
-- Build files have been written to: /home/dd/Documents/MRCB/build
dd@dd-virtual-machine:~/Documents/MRCB/build$ make (5)
Scanning dependencies of target MRCB
[ 7%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_ComFun.cpp.o
[ 15%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_DataPre.cpp.o
[ 23%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_DataProcess.cpp.o
[ 30%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_Ephemeris.cpp.o
[ 38%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_Inpfile.cpp.o
[ 46%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_Options.cpp.o
[ 53%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_Pntpos.cpp.o
[ 61%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_RcbProcess.cpp.o
[ 69%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_ReadRinex.cpp.o
[ 76%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_SolBody.cpp.o
[ 84%] Building CXX object CMakeFiles/MRCB.dir/src/MRCB_SolHead.cpp.o
[ 92%] Building CXX object CMakeFiles/MRCB.dir/src/main.cpp.o
[100%] Linking CXX executable MRCB
[100%] Built target MRCB
dd@dd-virtual-machine:~/Documents/MRCB/build$
```

Fig. 12 Finish compile under Linux

6.2 Run

Using Windows as an example, we will introduce the operational process with two examples:

the day-by-day process and continuous processing

6.2.1 day-by-day process

(1) Compile code

Reference the **section 6.1**.

(2) Data Preparation

In the **config.dat** file, configure the parameters by setting the input and output paths according

to your specific needs and file locations.

```
1 # MRCB_Version 1.0 Configuration File
2
3 # Input File Path
4
5 OBS_PATH      =F:\MRCB\testdata\day-by-day processing\MRO100AUS_R_20242980000_01D_30S.MO.24o      # obs file path
6 NAV_PATH      =F:\MRCB\testdata\day-by-day processing\BRDC00IGS_R_20242980000_01D_MN.24n      # nav file path (broadcast ephemeris)
7
8 # Output File Path
9
10 OUT_PRO       =F:\MRCB\result\                                         #processing information file
11 OUT_PATH      =F:\MRCB\result\                                         #result file
12 OUT_LOG       =F:\MRCB\result\                                         #sat Log
13
14 =====
15 # Process Option1
16 Ephopt        =0          # Satellite Ephemeris :0->broadcast
17 FiltMode      =0          # Filtting Mode           :0->Forward Mode
18 UseBDS2       =0          # Is Use BDS2            :0->use bds3 , 1->use bds2
19 Frequency     =5          # Frequency number
20 Elmask        =10         # Satellite elevation mask
21 Exclsats     =C01 C02 C03 C04 C05 # prn ...
22 System        =33         # 1:gps+4:glo+8:gal+16:qzs+32:comp
23
24 # Process Option2
25 Continue      =0          # 0->day-by-day  1->continuous processing
26 OBS_DIR       =F:\MRCB\testdata\continuous processing\obs\ # obs dir
27 NAV_DIR       =F:\MRCB\testdata\continuous processing\nav\ # nav dir
28
29 =====
30 # Station information
31 StaName       =MRO1      # Station Name
32 DOY           =2024298    # DOY
33
34
```

Fig. 13 Paths Requiring Configuration

(3) Run code

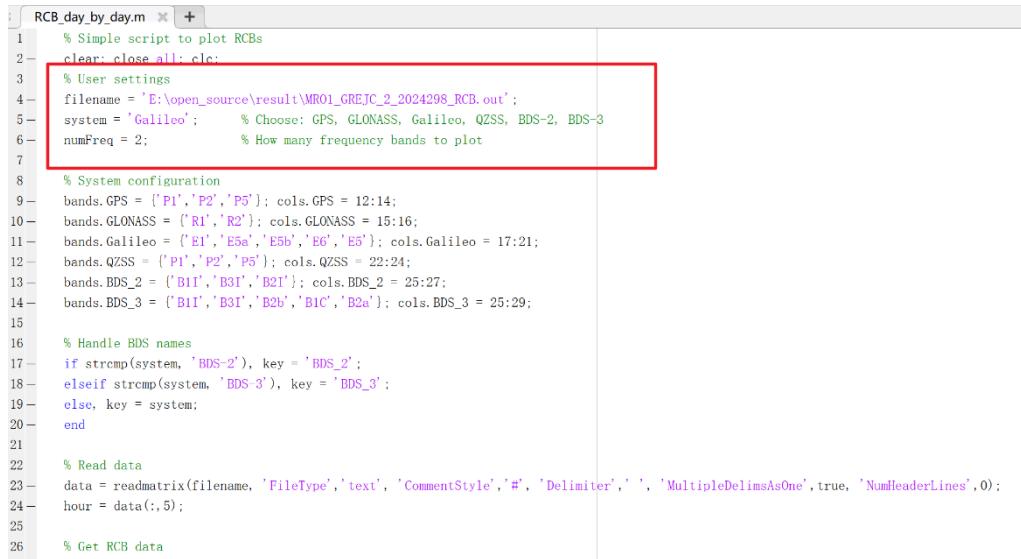
Recommend running in the command line: ① cd ./build/Debug ② MRCB.exe

Fig. 14 Runtime Display

(4) Visualization

Two simple visualization scripts are located in the `\script` directory and require MATLAB (version R2020b or higher) to run.

- `RCB_day_by_day.m`: Visualizes RCBs for a single day. Simply configure the file paths and specify the frequencies and systems to visualize.



```

1 % Simple script to plot RCBs
2 clear; close all; clc;
3 % User settings
4 filename = 'E:\open_source\result\MRO1_GREIC_2_2024298_RCB.out';
5 system = 'Galileo'; % Choose: GPS, GLONASS, Galileo, QZSS, BDS-2, BDS-3
6 numFreq = 2; % How many frequency bands to plot
7
8 % System configuration
9 bands.GPS = {'P1','P2','P5'}; cols.GPS = 12:14;
10 bands.GLONASS = {'R1','R2'}; cols.GLONASS = 15:16;
11 bands.Galileo = {'E1','E5a','E5b','E6','E5'}; cols.Galileo = 17:21;
12 bands.QZSS = {'P1','P2','P5'}; cols.QZSS = 22:24;
13 bands.BDS_2 = {'B1I','B3I','B2I'}; cols.BDS_2 = 25:27;
14 bands.BDS_3 = {'B1I','B3I','B2U','B1C','B2a'}; cols.BDS_3 = 25:29;
15
16 % Handle BDS names
17 if strcmp(system, 'BDS-2'), key = 'BDS_2';
18 elseif strcmp(system, 'BDS-3'), key = 'BDS_3';
19 else, key = system;
20 end
21
22 % Read data
23 data = readmatrix(filename, 'FileType', 'text', 'CommentStyle', '#', 'Delimiter', ' ', 'MultipleDelimsAsOne', true, 'NumHeaderLines', 0);
24 hour = data(:,5);
25
26 % Get RCB data

```

Fig. 15 Visualizes RCBs for a single day

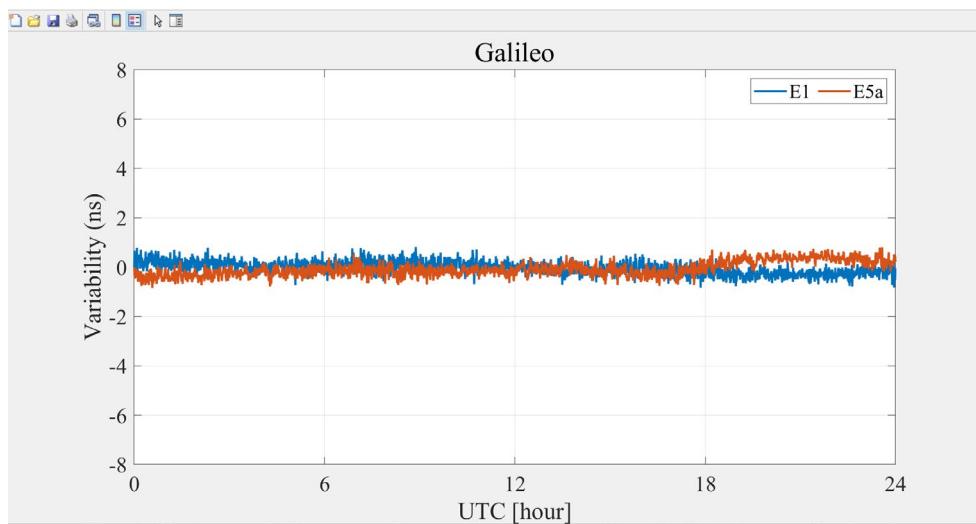


Fig. 16 Visualization Results

6.2.2 continuous processing

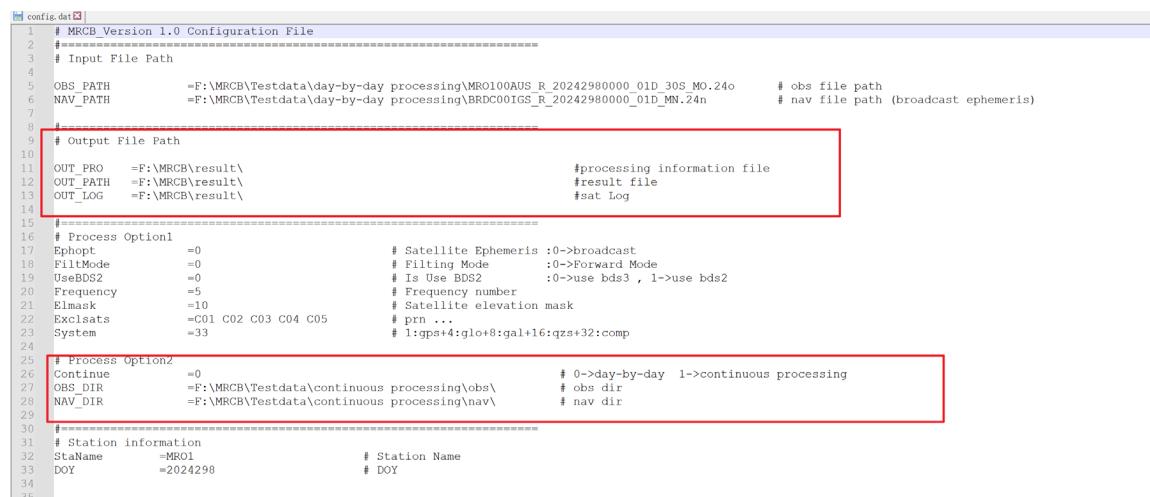
(1) Compile code

Reference the **section 6.1.**

(2) Data Preparation

In the **config.dat** file, configure the parameters by setting the input and output paths according to your specific needs and file locations. When use **continuous processing**, the following parameters do not need to be set and can be left as default: OBS_PATH, NAV_PATH, DOY.

Configure the following input and output parameters:



```
1 # MRCB_Version 1.0 Configuration File
2 #
3 # Input File Path
4
5 OBS_PATH      =F:\MRCB\Testdata\day-by-day processing\MRO100AUS_R_20242980000_01D_30S_MO_24o      # obs file path
6 NAV_PATH      =F:\MRCB\Testdata\day-by-day processing\BRDC00IGS_R_20242980000_01D_MN_24n      # nav file path (broadcast ephemeris)
7
8
9 # Output File Path
10 OUT_PRO       =F:\MRCB\result\                                         #processing information file
11 OUT_PATH      =F:\MRCB\result\                                         #result file
12 OUT_LOG       =F:\MRCB\result\                                         #sat Log
13
14
15 # Process Option1
16 Ephopt        =0          # Satellite Ephemeris :0->broadcast
17 FiltrMode     =0          # Filtering Mode :0->Forward Mode
18 UseBDS2       =0          # Is Use BDS2 :0->use bds3 , 1->use bds2
19 Frequency     =5          # Frequency number
20 Elmask         =10         # Satellite elevation mask
21 Exclsats      =C01 C02 C03 C04 C05      # prn ...
22 System         =33         # 1:gps+4:glo+8:gal+16:qzs+32:comp
23
24
25 # Process Option2
26 Continue      =0          # 0->day-by-day 1->continuous processing
27 OBS_DIR       =F:\MRCB\Testdata\continuous processing\obs\      # obs dir
28 NAV_DIR       =F:\MRCB\Testdata\continuous processing\nav\      # nav dir
29
30
31 # Station information
32 StaName       =MRO1      # Station Name
33 DOY           =2024298      # DOY
34
35
```

Fig. 17 Paths Requiring Configuration

Note: When using the Continuous processing mode, ensure the observation files in the OBS_DIR directory and navigation files in the NAV_DIR directory follow consistent naming and maintain strict day-to-day correspondence. This ensures the continuous processor can correctly associate observation and navigation data across multiple consecutive days.

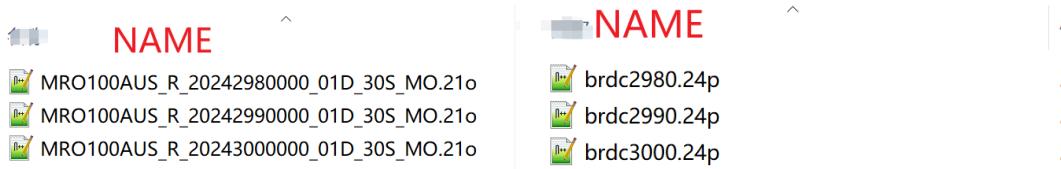


Fig. 18 Example of Correct File Organization

(3) Run code

Recommend running in the command line.

(4) Visualization

- RCB_Continues.m: Visualizes RCBs for continues day. Simply configure the file paths and specify the frequencies and systems to visualize.

```
RBC_Continues.m
1 % Simple script to plot RCBs
2 clear; close all; clc;
3 % User settings
4 filename = 'E:\open_source\result\MRO1_GREJC_2_Continues_RCB.out';
5 system = 'Galileo'; % Choose: GPS, GLONASS, Galileo, QZSS, BDS-2, BDS-3
6 numFreq = 2; % How many frequency bands to plot
7
8 % System configuration
9 bands.GPS = {'P1','P2','P5'}; cols.GPS = 12:14;
10 bands.GLONASS = {'R1','R2'}; cols.GLONASS = 15:16;
11 bands.Galileo = {'E1','E5a','E5b','E6','E5'}; cols.Galileo = 17:21;
12 bands.QZSS = {'P1','P2','P5'}; cols.QZSS = 22:24;
13 bands.BDS_2 = {'B1I','B3I','B2I'}; cols.BDS_2 = 25:27;
14 bands.BDS_3 = {'B1I','B3I','B2b','B1C','B2a'}; cols.BDS_3 = 25:29;
15
16 % Handle BDS names
17 if strcmp(system, 'BDS-2'), key = 'BDS_2';
18 elseif strcmp(system, 'BDS-3'), key = 'BDS_3';
19 else, key = system;
20 end
21
22 % Read data
23 data = readmatrix(filename, 'FileType', 'text', 'CommentStyle', '#', 'Delimiter', ' ', 'MultipleDelimsAsOne', true, 'NumHeaderLines', 0);
24 hour = data(:,4);
25
```

Fig. 19 Visualizes RCBs for continues day

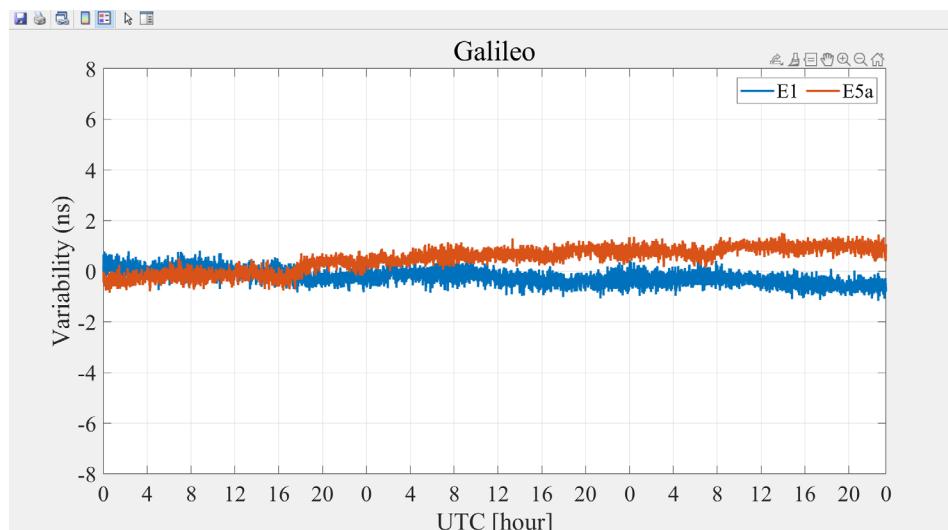


Fig. 20 Visualization Results

6.2.3 Linux Run

If you want run on the Linux system.

Execute these commands in sequence: ./MRCB

Fig. 21 Run on Linux

7 Output file format description

7.1 Result File

Name: XXXX_GEC_2_YYYYDOY_RCB.out

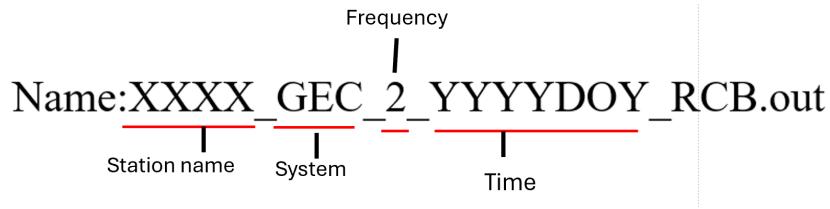


Fig. 22 Structure of output file name

Table 3 Result output file format description

Items		Value Type	Range
Epoch Time (GPST)	Year	char	1-4
	Month	char	6-7
	Day	char	9-10
	Hour	char	12-13
	Minute	char	15-16
	Second	char	18-22
Receiver Position (SPP)	X (m)	double	25-37
	Y (m)	double	41-52
	Z (m)	double	55-67
Number of valid satellites		int	71-72
GDOP		double	76-81

	P1	double	86-91
GPS Time-varying RCB	P2	double	95-100
	P5	double	104-109
GLONASS Time-varying RCB	R1	double	115-120
	R2	double	124-130
	E1	double	136-141
	E5a	double	146-151
Galileo Time-varying RCB	E5b	double	157-162
	E6	double	167-172
	E5	double	177-182
	P1	double	190-195
QZSS Time-varying RCB	P2	double	199-204
	P5	double	208-213
	B1I	double	218-223
	B3I	double	230-235
BDS-3 Time-varying RCB	B2b	double	242-248
	B1C	double	255-260
	B2a	double	266-271
	B1I	double	218-223
BDS-2 Time-varying RCB	B3I	double	230-235
	B2I	double	242-248

Fig. 23 Screenshot of RCBs result file

7.2 Process Information File

Name: XXXX GEC 2 YYYYDOY Inf.pro

Table 4 Process information file description

Items	Value Type	Range
Satellite Sys. & PRN	int	1-4
Satellite Positions	X (m)	double
		6-13

Y (m)	double	23-35	
Z (m)	double	38-51	
Satellite Clock Offset	(m)	double	56-67
Ion Delays	(m)	double	75-83
F1 (cycle)	double	91-99	
F2 (cycle)	double	107-115	
Ambiguity	F3 (cycle)	double	124-131
	F4 (cycle)	double	140-147
	F5 (cycle)	double	156-163
Satellite Elevation and Azimuth	Elevation (°)	double	173-179
	Azimuth (°)	double	188-195
post-fit carrier phase residuals	F1 (m)	double	199-211
	F2 (m)	double	215-227
	F3 (m)	double	231-243
	F4 (m)	double	247-259
	F5 (m)	double	263-275
post-fit code residuals	F1 (m)	double	280-292
	F2 (m)	double	296-308
	F3 (m)	double	312-324
	F4 (m)	double	328-340
	F5 (m)	double	344-356
SCB	F3 (m)	double	365-372
	F4 (m)	double	381-388
	F5 (m)	double	397-404

sat	sat-X(n)	sat-Y(n)	sat-Z(n)	sat-clock(n)	lon(n)	anl-f1 (cycle)	anl-f2 (cycle)	anl-f3 (cycle)	anl-f4 (cycle)	anl-f5 (cycle)	elevation	azimuth	resL-f1 (n)	resL-f2 (n)	
2	2024	10372671.4743	60.634.40	-19291894.6334	192933.8358	-18236664.8246	-18914.9992	28.3550	248.0933	270.2344	0.0000	0.0000	24.6474	125.7362	
3	G11	-22952520.2599	11569492.0525	-6725103.1392	-223739.1483	20.2393	141.5703	242.2969	0.0000	0.0000	43.9578	78.0539	2195722.5074	21957291.6442	
4	G12	-6688145.2220	24035423.1139	-164120.3803	-164120.3803	17.7666	345.4469	236.9691	0.0000	0.0000	53.4226	180.9323	-5112.0531	-5112.0531	
5	G13	-5379459.8550	20364484.7342	15814893.0376	-6586.3804	27.1984	204.4047	161.7893	0.0000	0.0000	11.4148	349.7059	24136462.3674	24136444.9456	
6	G15	-2765059.4550	18037009.7136	-2375059.4550	-2375059.4550	27.7334	21.5747	245.3434	0.0000	0.0000	82.7463	22.1760	20404231.2746	20404242.4755	
7	G24	-1267009.7136	21736955.4361	-3342758.8376	-144955.5362	21.5796	214.1562	245.3434	0.0000	0.0000	87.2763	204.4231	213.1970	213.1970	
8	G26	-1267009.7136	21736955.4361	-18037009.7136	-18037009.7136	24.7746	437.0000	299.5234	0.0000	0.0000	32.2430	231.8700	22980729.9861	22980729.9861	
9	G29	-3479498.1558	26298935.1989	-1312281.4374	-170549.2907	21.8082	287.4669	273.2422	0.0000	0.0000	34.2481	306.4660	22980729.9861	22980729.9861	
10	G32	14781303.3804	13505941.2603	-17337163.4338	-174691.2590	25.5527	139.0559	257.5234	0.0000	0.0000	15.0980	235.8700	24326832.7720	24326852.6445	
11	R01	10372671.4743	60.634.40	-19291894.6334	-192933.8358	-18236664.8246	-18914.9992	28.3550	248.0933	270.2344	0.0000	0.0000	235.8700	24326832.7720	24326852.6445
12	R09	761129.5764	11293525.0138	-22838571.0329	-22838571.0329	14.2422	241.6641	241.6641	0.0000	0.0000	36.4535	199.7548	2117363.2559	2117363.2559	
13	R16	-18028549.5984	7995960.8187	-16189412.4553	9657.3613	15.0161	290.0000	175.7033	0.0000	0.0000	44.6668	121.3662	20668356.4337	20668334.8397	
14	R17	-18028549.5984	7995960.8187	-16189412.4553	9657.3613	15.0161	290.0000	175.7033	0.0000	0.0000	52.9357	121.3662	20668356.4337	20668334.8397	
15	R19	-16055591.8405	17521010.2822	-87862.0992	-87862.0992	12.7183	150.1602	204.7070	0.0000	0.0000	69.7340	73.5158	19554867.8384	19554877.6936	
16	R20	-7296924.5395	21403399.1813	13849152.0755	-36243.4042	22.6333	298.1197	295.5234	0.0000	0.0000	351.5274	253.8007	217.7118	22530008.4392	
17	R21	-21550511.7116	18120553.2444	-18037009.7136	-18037009.7136	21.5796	13.4517	101.2138	0.0000	0.0000	36.9125	123.2594	213.1970	213.1970	
18	E06	-9256001.5733	22053111.2204	16362247.0304	-11557.5756	18.0391	113.2243	137.0039	0.0000	0.0000	17.7499	355.6030	27059252.5710	27059224.3262	
19	E09	-3357348.6744	27847450.1874	9137679.8151	-191349.7637	18.8364	71.2305	90.4922	0.0000	0.0000	334.5769	24047812.9295	26047811.5095	26047811.5095	
20	E10	-3357348.6744	27847450.1874	9137679.8151	-191349.7637	18.8364	125.2712	125.2712	0.0000	0.0000	45.2310	25.1930	256.0000	256.0000	
21	E11	-12130965.7624	21627047.9435	16024860.8196	313089.4463	12.2979	147.2773	182.6836	0.0000	0.0000	18.6987	2.9330	26430793.4203	26430803.6946	
22	E12	-24765813.9513	16026238.0008	-2294343.8362	-379533.3396	8.1533	104.2773	81.1250	0.0000	0.0000	44.5486	57.9731	25195956.1232	25195984.3029	
23	E13	-21550511.7116	18120553.2444	-18037009.7136	-18037009.7136	21.5796	104.2944	120.3200	0.0000	0.0000	39.3984	123.2594	213.1970	213.1970	
24	E25	17520549.4177	18914595.1643	-14541123.1729	31.8912	13.4517	75.7344	101.2138	0.0000	0.0000	17.7597	245.6762	27072280.7272	27072281.4823	
25	E26	-21550511.7116	18120553.2444	-18037009.7136	-18037009.7136	21.5796	121.2717	121.2717	0.0000	0.0000	36.9125	123.2594	213.1970	213.1970	
26	E33	-21550511.7116	18120553.2444	-18037009.7136	-18037009.7136	21.5796	104.2944	120.3200	0.0000	0.0000	25.1200	123.2594	213.1970	213.1970	
27	J02	-41436777.7657	18120553.2444	-24805442.1107	-414.5282	20.4521	197.7344	263.8906	0.0000	0.0000	59.8460	126.6744	33489071.7620	33489095.3491	
28	J03	-28319898.0000	18120553.2444	-18037009.7136	-18037009.7136	21.5796	24.0500	26.9798	0.0000	0.0000	50.8460	123.2594	213.1970	213.1970	
29	J04	-19547836.1458	14024815.4479	26301441.5707	6365.5120	-24.1194	216.2933	216.7500	0.0000	0.0000	17.4973	15.7338	4295232.4217	4295232.4217	
30	J07	-23726711.4743	33667242.8607	-3176.6121	-10.7448	19.1758	233.2951	278.4844	0.0000	0.0000	56.7694	22.1741	36713930.1181	36713930.1181	
31	C20	-17443745.6463	780843.6293	-25456214.2119	-101053.8960	-12.6021	144.3906	144.3906	0.0000	0.0000	42.4950	133.8964	23138607.5958	23138644.3268	
32	C29	-17443745.6463	780843.6293	-25456214.2119	-101053.8960	-15.6025	-121.3438	-146.3906	0.0000	0.0000	42.4950	133.8964	23138607.5958	23138644.3268	
33	C35	-11610486.5328	24035423.1139	-5309832.4755	67884.0718	-14.5752	-125.7189	-159.6016	0.0000	0.0000	69.6810	354.2779	21830176.8118	21830170.8316	
34	C36	-22460059.5288	18120553.2444	-18037009.7136	-18037009.7136	21.5796	104.2944	120.3200	0.0000	0.0000	15.1793	123.2594	213.1970	213.1970	
35	C39	-22460059.5288	34098733.0349	-16372311.0172	-30439.3143	-15.2664	117.9062	87.8906	0.0000	0.0000	69.6480	21.4794	34297526.5258	36297625.2371	
36	C40	-22460059.5288	34098733.0349	-16372311.0172	-30439.3143	-17.2705	62.1094	81.5626	0.0000	0.0000	72.4322	227.0986	35797441.2635	35797447.4896	
37	C41	-19547836.1458	14024815.4479	18037009.7136	-18037009.7136	-24.1194	24.0500	26.9798	0.0000	0.0000	23.2520	123.2594	213.1970	213.1970	
38	C45	-19547836.1458	14024815.4479	18037009.7136	-18037009.7136	-26.8846	-188.6641	-261.8793	0.0000	0.0000	58.6013	105.3907	23349674.8281	23349674.8281	
39	G01	10.25 20.90	1457939.1667	-10239407.4557	-11557.2534	28.1134	244.0069	266.3035	0.0000	0.0000	24.5478	125.9470	4507.1707	4507.1707	
41	G11	-22976557.0100	13797136.5603	-2196771.4553	-164120.3780	17.7666	345.4469	236.9691	0.0000	0.0000	53.4226	180.9323	-5112.0531	-5112.0531	
42	G12	-6688145.2220	18120553.2444	-18037009.7136	-18037009.7136	21.5796	231.0000	231.0000	0.0000	0.0000	12.1740	123.2594	213.1970	213.1970	
43	G13	-22976557.0100	13797136.5603	-2196771.4553	-164120.3780	20.4521	231.0000	231.0000	0.0000	0.0000	12.1740	123.2594	213.1970	213.1970	
44	G24	-12665891.0181	2751070.9523	-2845890.5288	-144955.5308	21.5747	214.0064	245.1582	0.0000	0.0000	78.0175	21.9579	-1621.4198	-1621.4198	
45	G25	8109019.1340	17152446.2536	-18037009.7136	-18037009.7136	24.5609	436.4221	200.7493	0.0000	0.0000	33.5623	231.7659	-13256.6666	-13256.6659	
46	G29	3474294.0200	26234031.5429	1216397.1543	-170549.2742	21.2748	266.3360	266.3360	0.0000	0.0000	34.4392	304.2630	-18443.9897	-18443.9897	

Fig. 24 Screenshot of Process Information file

7.3 Log file

Name: XXXX_GEC_2_YYYYDOY_Sat.log

The log file mainly contains the record of satellite eliminations.

```
2024/10/25 00:00:00.00
 2 Deleter Sat for lack observations, need freq 3:G12(Frq:2)
 3 Deleter Sat for lack observations, need freq 3:G15(Frq:2)
 4 Deleter Sat for lower 10.0 degree:G19(Ele:8.6)
 5 Deleter Sat for lower 10.0 degree:G20(Ele:2.8)
 6 Deleter Sat for lack observations, need freq 3:G29(Frq:2)
 7 Deleter Sat for lower 10.0 degree:E03(Ele:8.8)
 8 Deleter Sat for lower 10.0 degree:C21(Ele:6.6)
 9 Deleter Sat for lower 10.0 degree:C42(Ele:5.1)
10 Deleter Sat for lower 10.0 degree:C50(Ele:7.4)
11 2024/10/25 00:00:30.00
12 Deleter Sat for lack observations, need freq 3:G12(Frq:2)
13 Deleter Sat for lack observations, need freq 3:G15(Frq:2)
14 Deleter Sat for lower 10.0 degree:G19(Ele:8.5)
15 Deleter Sat for lower 10.0 degree:G20(Ele:2.9)
16 Deleter Sat for lack observations, need freq 3:G29(Frq:2)
17 Deleter Sat for lower 10.0 degree:E03(Ele:8.9)
18 Deleter Sat for lower 10.0 degree:C21(Ele:6.5)
19 Deleter Sat for lower 10.0 degree:C42(Ele:5.1)
20 Deleter Sat for lower 10.0 degree:C50(Ele:7.3)
21 2024/10/25 00:01:00.00
22 Deleter Sat for lack observations, need freq 3:G12(Frq:2)
23 Deleter Sat for lack observations, need freq 3:G15(Frq:2)
24 Deleter Sat for lower 10.0 degree:G19(Ele:8.3)
25 Deleter Sat for lack observations, need freq 3:G29(Frq:2)
26 Deleter Sat for lower 10.0 degree:E03(Ele:9.0)
27 Deleter Sat for lower 10.0 degree:C21(Ele:6.4)
28 Deleter Sat for lower 10.0 degree:C42(Ele:5.0)
29 Deleter Sat for lower 10.0 degree:C50(Ele:7.2)
30 2024/10/25 00:01:30.00
31 Deleter Sat for lack observations, need freq 3:G12(Frq:2)
32 Deleter Sat for lack observations, need freq 3:G15(Frq:2)
33 Deleter Sat for lower 10.0 degree:G19(Ele:8.1)
34 Deleter Sat for lack observations, need freq 3:G29(Frq:2)
35 Deleter Sat for lower 10.0 degree:E03(Ele:9.0)
36 Deleter Sat for lower 10.0 degree:C21(Ele:6.3)
37 Deleter Sat for lower 10.0 degree:C42(Ele:4.9)
38 Deleter Sat for lower 10.0 degree:C50(Ele:7.1)
```

Fig. 25 Screenshot of Log file

When use Continues processing, the file name become:

XXXX_GEC_2_Continues_RCB.out

XXXX_GEC_2_Continues_Inf.pro

XXXX_GEC_2_Continues_Sat.log

7.4 Execution Interface

Finish read raw file:	E:\open source\Tesi\data\day-by-day processing\BRDCDOUGS R 20242908000 OID MN_21n	read obs file header:E:\open source\Tesi\data\day-by-day processing\WR010AU.S_R 20242908000 OID MO_21o	QZSS	BDS-3/BDS-2	num of sat
2024 10 24 00 00 00 FLOT	0.000 0.000 0.000 0.000 0.000 0.000	0.000 0.000 0.000 0.000 0.000 0.000	-0.000 0.000 0.000 0.000 0.000 0.000	0.000 0.000 0.000 0.000 0.000 0.000	35 999999.990
2024 10 24 00 30 FLOT	-0.234 0.082 0.000 -0.002 -0.117 0.018	-0.003 0.000 0.000 0.000 0.000 0.000	-0.247 0.014 0.000 0.000 0.000 0.000	0.126 -0.009 0.000 0.000 0.000 0.000	34 0.123
2024 10 24 00 01 FLOT	0.255 0.056 0.000 0.158 -0.178 0.198	-0.102 0.000 0.000 0.000 0.000 0.000	-0.001 -0.020 0.000 0.000 0.000 0.000	0.067 0.014 0.000 0.000 0.000 0.000	34 0.101
2024 10 24 00 01 30 FLOT	-0.227 0.146 0.000 -0.128 -0.054 0.057	-0.131 0.000 0.000 0.000 0.000 0.000	-0.041 0.074 0.000 0.000 0.000 0.000	-0.019 -0.033 0.000 0.000 0.000 0.000	34 0.157
2024 10 24 00 02 FLOT	-0.058 0.070 0.000 -0.373 -0.030 0.023	-0.138 0.000 0.000 0.000 0.000 0.000	0.150 0.056 0.000 0.000 0.000 0.000	0.043 -0.026 0.000 0.000 0.000 0.000	34 0.197
2024 10 24 00 02 30 FLOT	0.050 0.043 0.000 -0.128 -0.006 0.091	-0.118 0.000 0.000 0.000 0.000 0.000	-0.138 -0.026 0.000 0.000 0.000 0.000	-0.016 -0.005 0.000 0.000 0.000 0.000	34 0.224
2024 10 24 00 03 FLOT	-0.024 0.076 0.000 -0.030 -0.030 0.030	-0.127 0.000 0.000 0.000 0.000 0.000	-0.078 0.012 0.000 0.000 0.000 0.000	-0.153 -0.016 0.000 0.000 0.000 0.000	34 0.139
2024 10 24 00 03 30 FLOT	0.027 0.023 0.000 0.081 -0.003 0.022	-0.083 0.000 0.000 0.000 0.000 0.000	-0.003 0.061 0.000 0.000 0.000 0.000	-0.087 -0.028 0.000 0.000 0.000 0.000	34 0.183
2024 10 24 00 04 FLOT	-0.217 0.070 0.000 -0.073 -0.093 0.025	-0.021 0.000 0.000 0.000 0.000 0.000	0.064 0.043 0.000 0.000 0.000 0.000	0.081 -0.032 0.000 0.000 0.000 0.000	34 0.111
2024 10 24 00 04 30 FLOT	0.085 0.064 0.000 0.117 -0.086 0.000	-0.024 0.000 0.000 0.000 0.000 0.000	0.099 -0.019 0.000 0.000 0.000 0.000	-0.061 -0.016 0.000 0.000 0.000 0.000	34 0.114
2024 10 24 00 05 FLOT	-0.134 0.191 0.000 -0.184 -0.019 0.050	-0.093 0.000 0.000 0.000 0.000 0.000	0.067 -0.014 0.000 0.000 0.000 0.000	-0.016 0.033 0.000 0.000 0.000 0.000	34 0.121
2024 10 24 00 05 30 FLOT	-0.208 0.045 0.000 -0.131 0.003 0.235	-0.118 0.000 0.000 0.000 0.000 0.000	-0.034 -0.031 0.000 0.000 0.000 0.000	-0.089 0.058 0.000 0.000 0.000 0.000	34 0.114
2024 10 24 00 06 FLOT	0.064 0.011 0.000 -0.036 -0.119 0.080	-0.071 0.000 0.000 0.000 0.000 0.000	0.167 0.017 0.000 0.000 0.000 0.000	0.017 0.028 0.000 0.000 0.000 0.000	33 0.124
2024 10 24 00 06 30 FLOT	-0.109 0.040 0.000 -0.038 -0.060 0.044	-0.070 0.000 0.000 0.000 0.000 0.000	-0.093 -0.074 0.000 0.000 0.000 0.000	0.063 -0.007 0.000 0.000 0.000 0.000	33 0.170
2024 10 24 00 07 FLOT	-0.230 0.169 0.000 0.000 0.000 0.000	0.000 0.000 0.000 0.000 0.000 0.000	-0.160 -0.073 0.000 0.000 0.000 0.000	-0.086 -0.018 0.000 0.000 0.000 0.000	33 0.119
2024 10 24 00 07 30 FLOT	0.081 0.072 0.000 -0.064 0.081 0.069	-0.091 -0.178 0.000 0.000 0.000 0.000	-0.091 -0.026 0.000 0.000 0.000 0.000	-0.013 -0.033 0.000 0.000 0.000 0.000	33 0.198
2024 10 24 00 08 FLOT	0.197 0.172 0.000 0.042 -0.075 0.078	-0.075 0.169 0.000 0.000 0.000 0.000	0.049 -0.015 0.000 0.000 0.000 0.000	0.034 -0.014 0.000 0.000 0.000 0.000	33 0.251
2024 10 24 00 08 30 FLOT	0.032 0.062 0.000 -0.029 -0.003 0.078	-0.045 0.155 0.000 0.000 0.000 0.000	0.10 -0.011 0.000 0.000 0.000 0.000	0.075 -0.021 0.000 0.000 0.000 0.000	33 0.127
2024 10 24 00 09 FLOT	0.054 0.142 0.000 0.117 -0.086 0.126	-0.131 0.000 0.000 0.000 0.000 0.000	0.194 0.114 0.000 0.000 0.000 0.000	0.099 -0.024 0.000 0.000 0.000 0.000	32 0.179
2024 10 24 00 09 30 FLOT	-0.136 -0.039 0.000 -0.082 -0.100 0.126	-0.135 0.000 0.000 0.000 0.000 0.000	-0.243 0.006 0.000 0.000 0.000 0.000	-0.108 -0.004 0.000 0.000 0.000 0.000	32 0.179
2024 10 24 00 10 FLOT	0.112 0.003 0.000 -0.063 -0.214 0.149	-0.090 0.000 0.000 0.000 0.000 0.000	-0.272 0.069 0.000 0.000 0.000 0.000	-0.091 0.001 0.000 0.000 0.000 0.000	32 0.154
2024 10 24 00 10 30 FLOT	-0.045 0.064 0.000 -0.062 -0.087 0.149	-0.104 0.000 0.000 0.000 0.000 0.000	-0.238 -0.001 0.000 0.000 0.000 0.000	-0.017 -0.009 0.000 0.000 0.000 0.000	32 0.148
2024 10 24 00 11 FLOT	0.055 0.013 0.000 -0.012 -0.123 0.067	-0.133 0.000 0.000 0.000 0.000 0.000	0.010 -0.035 0.000 0.000 0.000 0.000	0.040 -0.024 0.000 0.000 0.000 0.000	32 0.148
2024 10 24 00 11 30 FLOT	-0.130 0.127 0.000 -0.062 -0.038 0.020	-0.047 0.000 0.000 0.000 0.000 0.000	0.157 0.015 0.000 0.000 0.000 0.000	0.047 -0.086 0.000 0.000 0.000 0.000	32 0.105
2024 10 24 00 12 FLOT	-0.087 -0.000 0.000 -0.077 -0.229 0.000	-0.156 0.000 0.000 0.000 0.000 0.000	-0.149 0.041 0.000 0.000 0.000 0.000	0.003 -0.013 0.000 0.000 0.000 0.000	32 0.118
2024 10 24 00 12 30 FLOT	0.144 0.059 0.000 0.012 -0.152 0.054	-0.187 0.000 0.000 0.000 0.000 0.000	0.162 -0.008 0.000 0.000 0.000 0.000	0.077 -0.021 0.000 0.000 0.000 0.000	32 0.195
2024 10 24 00 13 FLOT	0.358 -0.006 0.000 0.030 -0.041 0.211	-0.101 0.000 0.000 0.000 0.000 0.000	0.056 0.080 0.000 0.000 0.000 0.000	0.074 -0.057 0.000 0.000 0.000 0.000	32 0.211
2024 10 24 00 13 30 FLOT	-0.030 -0.011 0.000 0.009 -0.020 0.017	-0.051 0.000 0.000 0.000 0.000 0.000	0.047 0.009 0.000 0.000 0.000 0.000	-0.030 -0.085 0.000 0.000 0.000 0.000	32 0.110
2024 10 24 00 14 FLOT	0.179 0.111 0.000 0.035 -0.134 0.086	-0.029 0.000 0.000 0.000 0.000 0.000	-0.063 -0.043 0.000 0.000 0.000 0.000	0.037 0.007 0.000 0.000 0.000 0.000	32 0.150
2024 10 24 00 14 30 FLOT	-0.200 0.036 0.000 -0.006 -0.182 0.018	-0.163 0.000 0.000 0.000 0.000 0.000	0.083 0.002 0.000 0.000 0.000 0.000	0.048 0.017 0.000 0.000 0.000 0.000	32 0.099
2024 10 24 00 15 FLOT	0.182 0.051 0.000 -0.053 -0.041 0.118	-0.093 0.000 0.000 0.000 0.000 0.000	-0.193 0.038 0.000 0.000 0.000 0.000	0.075 -0.047 0.000 0.000 0.000 0.000	33 0.229
2024 10 24 00 15 30 FLOT	0.108 0.149 0.000 -0.089 -0.109 0.080	-0.096 0.000 0.000 0.000 0.000 0.000	-0.025 0.119 0.000 0.000 0.000 0.000	-0.053 -0.031 0.000 0.000 0.000 0.000	33 0.209
2024 10 24 00 16 FLOT	-0.083 0.110 0.000 0.004 -0.119 0.084	-0.161 0.000 0.000 0.000 0.000 0.000	-0.037 -0.003 0.000 0.000 0.000 0.000	-0.128 -0.017 0.000 0.000 0.000 0.000	33 0.215

Fig. 26 Runtime Display RCBs

Appendix

(1) CDMA RCB Function Model

We commence with the undifferenced and uncombined GNSS observation equations, which are written as (Teunissen and Montenbruck, 2017)

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f \cdot I_{r,1}^s(i) + b_{r,f} - b_f^s \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f \cdot I_{r,1}^s(i) + \lambda_f \alpha_{r,f}^s \end{cases} \quad (1)$$

where $E(\cdot)$ denotes the expectation operator. $P_{r,f}^s$ and $L_{r,f}^s$ represent observed-minus-calculated code and phase observations of a satellite s tracked by a receiver r on the frequency f at the epoch i , respectively. The frequency-independent parameters in this, including the range, receiver clock offsets, satellite clock offsets, and tropospheric delays, were combined into a single parameter $\rho_r^s(i)$. the first-order slant ionospheric delay $I_{r,1}^s(i)$ on the first frequency linked to other frequencies by the coefficient $\mu_f = \lambda_f^2 / \lambda_1^2$ with λ_f being the wavelength, the RCB $b_{r,f}$ and its satellite counterpart b_f^s , and the float ambiguity $\alpha_{r,f}^s = N_{r,f}^s + \delta_{r,f} - \delta_f^s$ containing the receiver phase bias (RPB) $\delta_{r,f}$, the satellite phase bias δ_f^s , and the integer ambiguity $N_{r,f}^s$. We consider the parameters with an epoch index i as time-varying quantities and assume the parameters without the epoch index to be time constant.

Departing from the time-constant assumption of the RCB, we consider it a time-varying parameter and rewrite Eq. (1) as

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f \cdot I_{r,1}^s(i) + b_{r,f}(1) + \tilde{b}_{r,f}(i) - b_f^s \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f \cdot I_{r,1}^s(i) + \lambda_f \alpha_{r,f}^s \end{cases} \quad (2)$$

where

$$\tilde{b}_{r,f}(i) = b_{r,f}(i) - b_{r,f}(1) \quad (3)$$

denotes the time-differenced receiver bias between epoch i and the first epoch, but

parameters in Eq. (2) are not uniquely estimable due to the rank deficient problem. For this issue, we turn to the S-system theory (Baarda, 1973; Teunissen, 1985), which constraints a minimum set of parameters and formulates a full-rank model estimating the linear functionals of the original parameters. To make it clear, we first decompose the receiver and satellite code biases on the first two frequencies as

$$(\cdot)_{r,f} = (\cdot)_{r,IF} + \mu_f (\cdot)_{r,GF} \quad (4)$$

where the geometry-free combination of a frequency-dependent quantity is defined as

$$(\cdot)_{GF} = \frac{1}{\mu_2 - \mu_1} [(\cdot)_2 - (\cdot)_1] \quad (5)$$

Inserting Eq. (4) into the code observations equation in Eq. (2) yields

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f I_{r,1}^s(i) + b_{r,IF}(1) + \mu_f b_{r,IF}(1) - \mu_f b_{r,GF}^s + \tilde{b}_{r,f}(i) + \bar{b}_{r,f>2}^s \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f I_{r,1}^s(i) + \lambda_f \alpha_{r,f}^s \end{cases} \quad (6)$$

where

$$\bar{b}_{r,f>2}^s = [b_{r,f}(1) - b_{r,IF}(1) - u_f \cdot b_{r,GF}(1)] - (b_{r,f}^s - u_f \cdot b_{r,GF}^s)$$

denotes the combination of receiver and satellite code biases on the third frequency and above. The rank deficiency elimination for Eq. (6) becomes straightforward, as we can lump the parameters that have common coefficients:

$$E[P_{r,f}^s(i)] = \bar{\rho}_r^s(i) + \mu_f \bar{I}_{r,1}^s(i) + \tilde{b}_{r,f}(i) + \bar{b}_{r,f>2}^s \quad (7)$$

where

$$\begin{cases} \bar{\rho}_r^s(i) = \rho_r^s(i) + b_{r,IF}(1) \\ \bar{I}_{r,1}^s(i) = I_{r,1}^s(i) + b_{r,GF}(1) - b_{r,GF}^s \end{cases} \quad (8)$$

denote the frequency-independent parameter and ionospheric delays, respectively. When dealing with the phase observations in Eq. (2), we first replace $\rho_r^s(i)$ and $I_{r,1}^s(i)$ with $\bar{\rho}_r^s(i)$ and $\bar{I}_{r,1}^s(i)$, resulting in additional code biases. By lumping these biases with ambiguities, we

obtain the full-rank observation equations as

$$\begin{cases} E[P_{r,f}^s(i)] = \bar{\rho}_r^s(i) + \mu_f \bar{I}_{r,1}^s(i) + \tilde{b}_{r,f}(i) + \bar{b}_{r,f>2}^s \\ E[L_{r,f}^s(i)] = \bar{\rho}_r^s(i) - \mu_f \bar{I}_{r,1}^s(i) + \lambda_f \bar{\alpha}_{r,f}^s \end{cases} \quad (9)$$

where

$$\bar{\alpha}_{r,f}^s = \alpha_{r,f}^s + [b_{,IF}^s - b_{r,IF}(1)]/\lambda_f - \mu_f \cdot [b_{,GF}^s - b_{r,GF}(1)]/\lambda_f \quad (10)$$

denote the estimable parameters contain the RCB at the first epoch.

(2) FDMA RCB Function Model

GLONASS raw code and carrier phase observation equations as (Teunissen, 2019)

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f^s \cdot I_{r,1}^s(i) + b_{r,f} - b_f^s + k^s \Delta b_{r,f} \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f^s \cdot I_{r,1}^s(i) + \lambda_f^s (\alpha_{r,f}^s + k^s \Delta \delta_{r,f}) \end{cases} \quad (11)$$

different from CDMA observation equations, there exist receiver code and phase biases that are linear functions of the satellite frequency channel number, $\Delta b_{r,f}$ and $\Delta \delta_{r,f}$, respectively. The meanings of the remaining parameters are the same as in Eq. (1).

In particular, GLONASS satellites have different wavelengths, expressed as λ_f^s . Furthermore, the coefficients of the ionospheric parameters μ_f^s are also satellite-dependent. To simplify the coefficients of the ionospheric parameters, they are defined based on the frequency of each GLONASS R1 and R2 satellite as follows:

$$F_f^s = F_f^0 + k^s \Delta F_f \quad (12)$$

where F_f^0 is the center frequency, ΔF_f is the frequency offset, $\Delta F_1 = 9/16$, $\Delta F_2 = 7/16$, k^s is the frequency channel number of satellite s , and they satisfy $|k^s| \leq 13$, $\Delta F_1/F_f^0 = 1/2848$, $\Delta F_2/F_f^0 = 1/2848$. Therefore, the wavelength λ_f^s can be expressed as:

$$\lambda_f^s = \frac{c}{F_f^0 + k^s \Delta F_f} = \frac{\lambda_f^0}{1 + \frac{k^s \Delta F_f}{F_f^0}} = \frac{2848 \lambda_f^0}{2848 + k^s} \quad (13)$$

where $\lambda_f^0 = c/F_f^0$ is the wavelength corresponding to the center frequency. According to Equation (13), the coefficients of the ionospheric parameters can be written as:

$$\mu_f^s = \left(\frac{\lambda_f^s}{\lambda_1^s} \right)^2 = \left(\frac{2848\lambda_f^0}{2848 + k^s} \cdot \frac{2848 + k^s}{2848\lambda_1^0} \right)^2 = \mu_f \quad (14)$$

Therefore, Equation (11) can be simplified as:

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f \cdot I_{r,1}^s(i) + b_{r,f} - b_f^s + k^s \Delta b_{r,f} \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f \cdot I_{r,1}^s(i) + \lambda_f^s(\alpha_{r,f}^s + k^s \Delta \delta_{r,f}) \end{cases} \quad (15)$$

Departing from the time-constant assumption of the RCB, we consider it a time-varying parameter and rewrite Eq. (14) as:

$$\begin{cases} E[P_{r,f}^s(i)] = \rho_r^s(i) + \mu_f \cdot I_{r,1}^s(i) + b_{r,f}(1) + \tilde{b}_{r,f}(i) - b_f^s + k^s \Delta b_{r,f}(1) + k^s \Delta \bar{b}_{r,f}(i) \\ E[L_{r,f}^s(i)] = \rho_r^s(i) - \mu_f \cdot I_{r,1}^s(i) + \lambda_f^s(\alpha_{r,f}^s + k^s \Delta \delta_{r,f}) \end{cases} \quad (16)$$

where

$$\begin{cases} \tilde{b}_{r,f}(i) = b_{r,f}(i) - b_{r,f}(1) \\ \Delta \bar{b}_{r,f}(i) = \Delta b_{r,f}(i) - \Delta b_{r,f}(1) \end{cases} \quad (17)$$

Note that, apart from the IFBs, the structure of the GLONASS equations is entirely consistent with that of CDMA systems. Therefore, following the rank deficiency elimination procedure used for CDMA, the following equations are obtained:

$$\begin{cases} E[P_{r,f}^s(i)] = \bar{\rho}_r^s(i) + \mu_f \bar{I}_{r,1}^s(i) + \tilde{b}_{r,f}(i) + k^s \Delta \bar{b}_{r,f}(i) \\ E[L_{r,f}^s(i)] = \bar{\rho}_r^s(i) - \mu_f \bar{I}_{r,1}^s(i) + \lambda_f^s(\bar{\alpha}_{r,f}^s + k^s \Delta \delta_{r,f}) \end{cases} \quad (18)$$

where

$$\begin{cases} \bar{\rho}_r^s(i) = \rho_r^s(i) + b_{r,IF}(1) - b_{,IF}^s + k^s \Delta b_{r,IF}(1) \\ \bar{I}_{r,1}^s(i) = I_{r,1}^s(i) + b_{r,GF}(1) - b_{,GF}^s + k^s \Delta b_{r,GF}(1) \\ \bar{\alpha}_{r,f}^s = \alpha_{r,f}^s + k^s \Delta \delta_{r,f} + \frac{[b_{,IF}^s - b_{r,IF}(1) - k^s \Delta b_{r,IF}(1)]}{\lambda_f^s} - \frac{\mu_f \cdot [b_{,GF}^s - b_{r,GF}(1) - k^s \Delta b_{r,GF}(1)]}{\lambda_f^s} \end{cases}$$

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Contact author

Any suggestions, corrections, and comments on MRCB are sincerely welcomed; please contact us. MRCB will be updated frequently, I hope numerous people can participate in the next update.

Email: dusx0829@163.com

Address: No. 340 Xudong Street, Wuhan City, Hubei Prov. China 430077

References

1. Teunissen P. J. G., Montenbruck O (eds) (2017) Springer handbook of global navigation satellite systems. Springer International Publishing, Cham
2. Baarda W (1973) S-transformations and criterion matrices. Netherlands Geodetic Commission
3. Teunissen P. J. G. (1985) Zero order design: generalized inverses, adjustment, the datum problem and S-transformations. In: Optimization and design of geodetic networks. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 11–55
4. Teunissen, P. J. G. (2019). A new glonass fdma model. GPS solutions, 23(4), 100.