MRCB User Manual

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

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Contents

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.

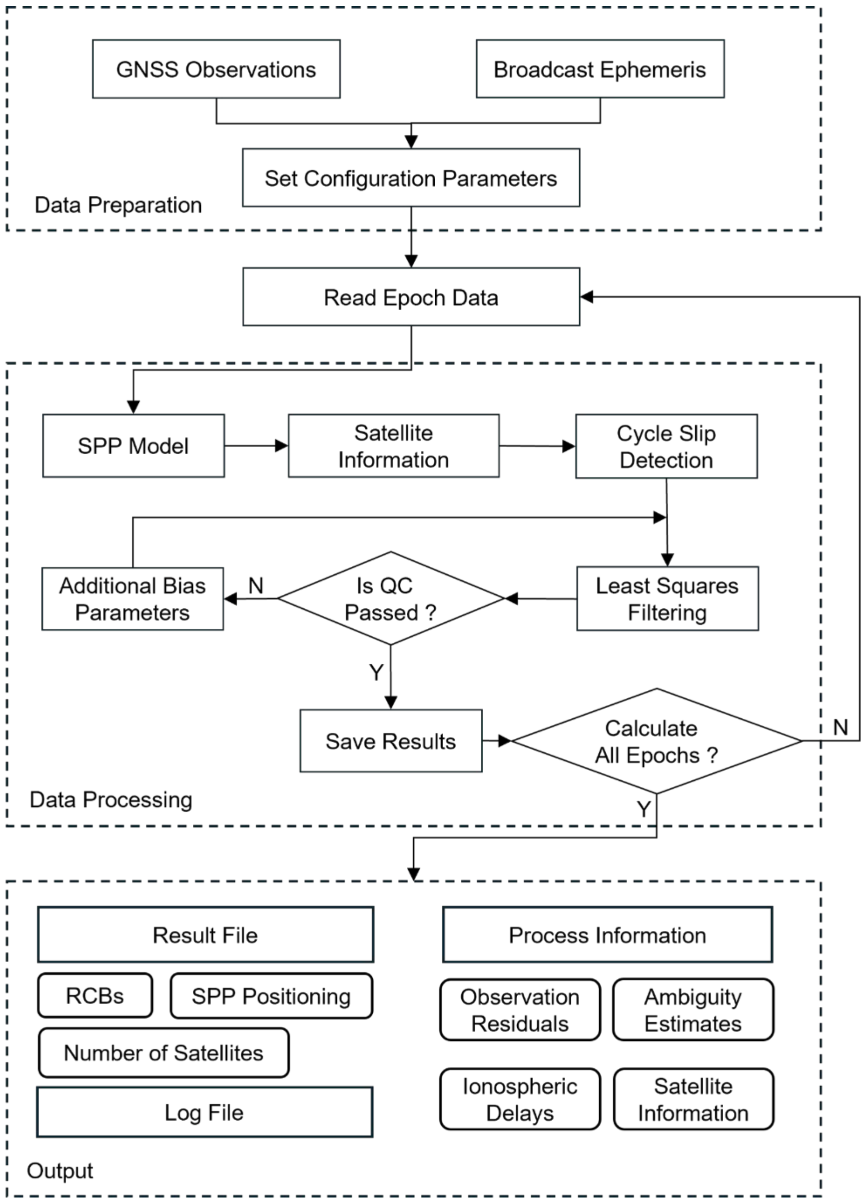


Fig. 1 The processing framework of MRCB software

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 = $\sin^2(E)$ /σ2(σ2 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

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.

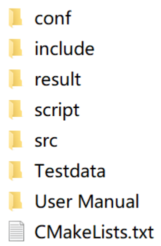


Fig. 2 File list

```
.
├── 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

```
#=================================================================
# Output File Path

OUT_PRO     =E:\open_source\result\                                          #processing information file
OUT_PATH    =E:\open_source\result\                                          #result file
OUT_LOG     =E:\open_source\result\                                          #sat Log

#=================================================================
```

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

```
#=================================================================
# Process Option1
Ephopt              =0                          # Satellite Ephemeris :0->broadcast
FiltMode            =0                          # Filting Mode        :0->Forward Mode
UseBDS2             =0                          # Is Use BDS2         :0->use bds3 , 1->use bds2
Frequency           =2                          # Frequency number
Elmask              =10                         # Satellite elevation mask
Exclsats            =C01 C02 C03 C04 C05        # prn ...
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

```
# Process Option2
Continue          =0                                              # 0->day-by-day  1->continuous processing
OBS_DIR           =E:\open_source\Testdata\continuous processing\obs\       # obs dir
NAV_DIR           =E:\open_source\Testdata\continuous processing\nav\       # nav dir

#======================================================================
```

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

conf	2025/10/16 20:18
include	2025/10/16 20:18
result	2025/10/16 20:16
src	2025/10/16 20:18
Testdata	2025/10/16 20:19
User Manual	2025/10/16 15:27
CMakeLists.txt	2025/10/16 20:28

Fig. 9 The extracted files

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

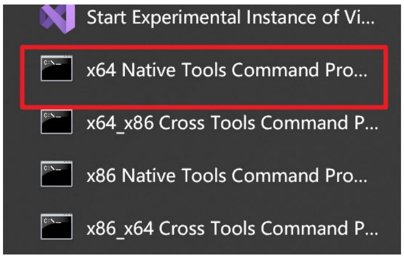


Fig. 10 Open Command Prompt

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

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

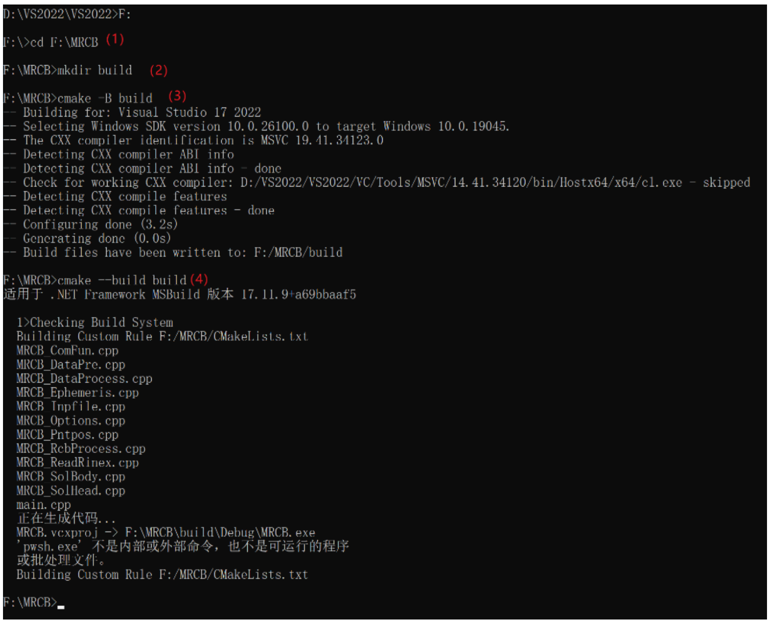


Fig. 11 Finish compile under Windows

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

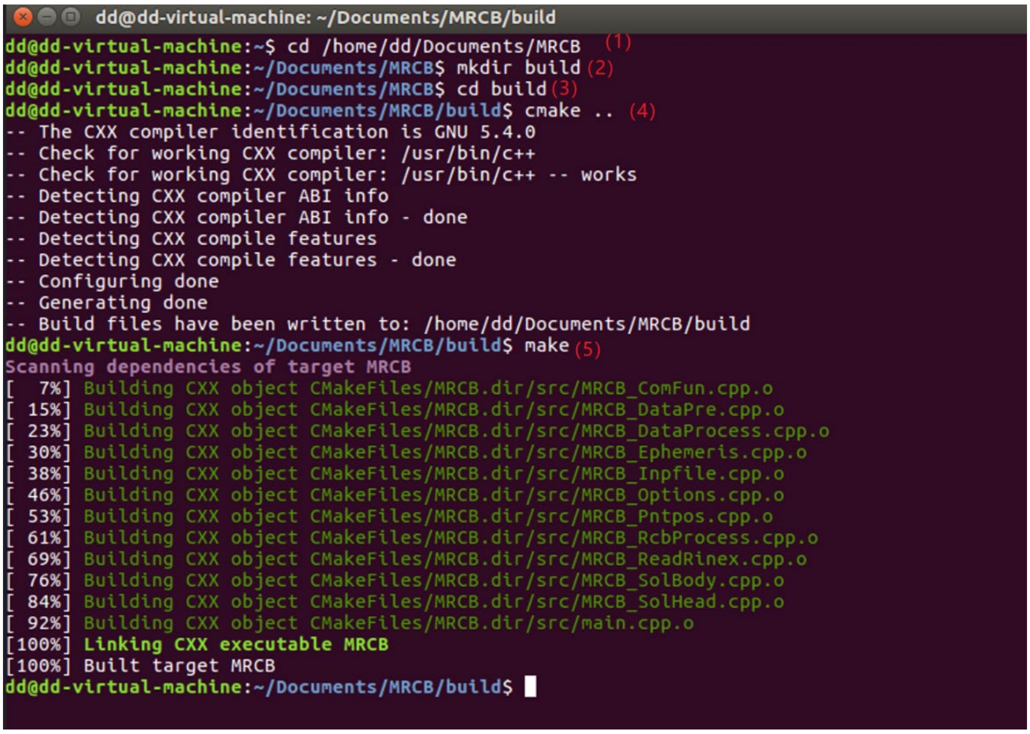


Fig. 12 Finish compile under Linux

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.

```
config.dat
# 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)

#================================================================
# Output File Path

OUT_PRO     =F:\MRCB\result\                                        #processing information file
OUT_PATH    =F:\MRCB\result\                                        #result file
OUT_LOG     =F:\MRCB\result\                                        #sat Log

#================================================================
# Process Option1
Ephopt              =0                            # Satellite Ephemeris :0->broadcast
FiltMode            =0                            # Filting Mode        :0->Forward Mode
UseBDS2             =0                            # Is Use BDS2         :0->use bds3 , 1->use bds2
Frequency           =5                            # Frequency number
Elmask              =10                           # Satellite elevation mask
Exclsats            =C01 C02 C03 C04 C05          # prn ...
System              =33                           # 1:gps+4:glo+8:gal+16:qzs+32:comp

# Process Option2
Continue            =0                                         # 0->day-by-day  1->continuous processing
OBS_DIR             =F:\MRCB\Testdata\continuous processing\obs\        # obs dir
NAV_DIR             =F:\MRCB\Testdata\continuous processing\nav\        # nav dir

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

Fig. 13 Paths Requiring Configuration

（3） Run code

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

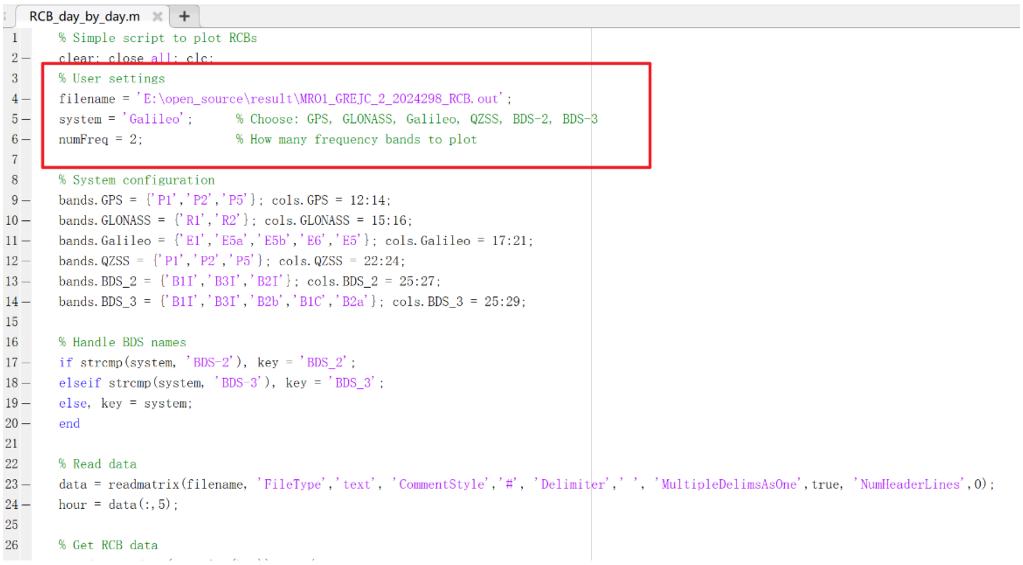
```
F:\MRCB>cd F:\MRCB\build\Debug   (1)

F:\MRCB\build\Debug>MRCB.exe   (2)
2024 10 24 00 00 00 FLOAT  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   25  99999.990
2024 10 24 00 00 30 FLOAT -0.232  0.084  0.000   0.000  0.000   0.018 -0.003  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.137  0.005  0.000  0.000  0.000   24      0.130
2024 10 24 00 01 00 FLOAT -0.253  0.058  0.000   0.000  0.000   0.199 -0.102  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.078  0.028  0.000  0.000  0.000   24      0.115
2024 10 24 00 01 30 FLOAT -0.225  0.148  0.000   0.000  0.000  -0.057 -0.130  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.008 -0.019  0.000  0.000  0.000   24      0.165
2024 10 24 00 02 00 FLOAT -0.056  0.072  0.000   0.000  0.000  -0.023 -0.138  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.054 -0.013  0.000  0.000  0.000   24      0.225
2024 10 24 00 02 30 FLOAT  0.052  0.045  0.000   0.000  0.000   0.091 -0.118  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.005  0.009  0.000  0.000  0.000   24      0.244
2024 10 24 00 03 00 FLOAT -0.022  0.078  0.000   0.000  0.000   0.030 -0.126  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.142 -0.003  0.000  0.000  0.000   24      0.152
2024 10 24 00 03 30 FLOAT  0.028  0.025  0.000   0.000  0.000   0.023 -0.083  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.076 -0.014  0.000  0.000  0.000   24      0.157
2024 10 24 00 04 00 FLOAT -0.216  0.072  0.000   0.000  0.000   0.025 -0.021  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.092 -0.019  0.000  0.000  0.000   24      0.112
2024 10 24 00 04 30 FLOAT -0.084  0.066  0.000   0.000  0.000   0.000 -0.024  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.050 -0.002  0.000  0.000  0.000   24      0.123
2024 10 24 00 05 00 FLOAT -0.132  0.193  0.000   0.000  0.000   0.056 -0.093  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.005  0.046  0.000  0.000  0.000   24      0.134
2024 10 24 00 05 30 FLOAT -0.206  0.047  0.000   0.000  0.000   0.235 -0.117  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.078  0.071  0.000  0.000  0.000   24      0.110
2024 10 24 00 06 00 FLOAT  0.066  0.013  0.000   0.000  0.000   0.080 -0.070  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.028  0.033  0.000  0.000  0.000   24      0.109
2024 10 24 00 06 30 FLOAT -0.107  0.042  0.000   0.000  0.000  -0.044 -0.043  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.074  0.006  0.000  0.000  0.000   24      0.193
2024 10 24 00 07 00 FLOAT -0.234  0.168  0.000   0.000  0.000   0.127 -0.093  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.075 -0.004  0.000  0.000  0.000   24      0.130
2024 10 24 00 07 30 FLOAT -0.079  0.074  0.000   0.000  0.000   0.097 -0.178  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.002 -0.020  0.000  0.000  0.000   24      0.208
2024 10 24 00 08 00 FLOAT -0.195  0.174  0.000   0.000  0.000   0.087 -0.169  0.000  0.000  0.000   0.000   0.000  0.000  0.000   0.090 -0.001  0.000  0.000  0.000   24      0.254
2024 10 24 00 08 30 FLOAT -0.159 -0.030  0.000   0.000  0.000   0.078 -0.044  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.064  0.026  0.000  0.000  0.000   24      0.099
2024 10 24 00 09 00 FLOAT -0.053  0.144  0.000   0.000  0.000   0.126 -0.131  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.087  0.034  0.000  0.000  0.000   23      0.104
2024 10 24 00 09 30 FLOAT -0.134 -0.036  0.000   0.000  0.000   0.127 -0.134  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.097  0.009  0.000  0.000  0.000   23      0.191
2024 10 24 00 10 00 FLOAT -0.111  0.005  0.000   0.000  0.000   0.150 -0.090  0.000  0.000  0.000   0.000   0.000  0.000  0.000  -0.080  0.015  0.000  0.000  0.000   23      0.133
```

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.



```matlab
RCB_day_by_day.m
% Simple script to plot RCBs
clear; close all; clc;
% User settings
filename = 'E:\open_source\result\MR01_GREJC_2_2024298_RCB.out';
system = 'Galileo';       % Choose: GPS, GLONASS, Galileo, QZSS, BDS-2, BDS-3
numFreq = 2;              % How many frequency bands to plot

% System configuration
bands.GPS = {'P1','P2','P5'}; cols.GPS = 12:14;
bands.GLONASS = {'R1','R2'}; cols.GLONASS = 15:16;
bands.Galileo = {'E1','E5a','E5b','E6','E5'}; cols.Galileo = 17:21;
bands.QZSS = {'P1','P2','P5'}; cols.QZSS = 22:24;
bands.BDS_2 = {'B1I','B3I','B2I'}; cols.BDS_2 = 25:27;
bands.BDS_3 = {'B1I','B3I','B2b','B1C','B2a'}; cols.BDS_3 = 25:29;

% Handle BDS names
if strcmp(system, 'BDS-2'), key = 'BDS_2';
elseif strcmp(system, 'BDS-3'), key = 'BDS_3';
else, key = system;
end

% Read data
data = readmatrix(filename, 'FileType','text', 'CommentStyle','#', 'Delimiter',' ', 'MultipleDelimsAsOne',true, 'NumHeaderLines',0);
hour = data(:,5);

% Get RCB data
```

Fig. 15 Visualizes RCBs for a single day

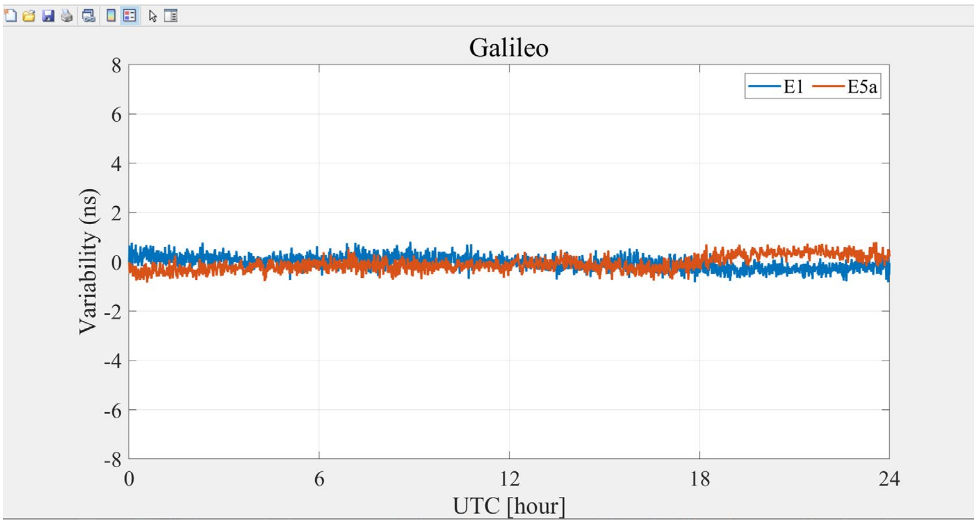


Fig. 16 Visualization Results

6.2.2 continuous processing

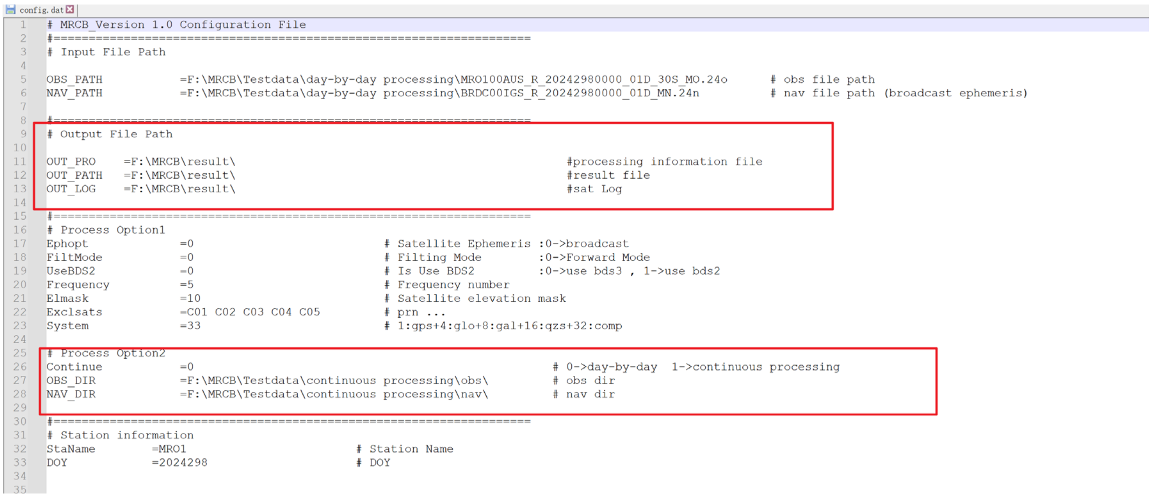
（1）Compile code

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:



```
# 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)

#=================================================================
# Output File Path

OUT_PRO     =F:\MRCB\result\                                        #processing information file
OUT_PATH    =F:\MRCB\result\                                        #result file
OUT_LOG     =F:\MRCB\result\                                        #sat Log

#=================================================================
# Process Option1
Ephopt             =0                            # Satellite Ephemeris :0->broadcast
FiltMode           =0                            # Filting Mode        :0->Forward Mode
UseBDS2            =0                            # Is Use BDS2         :0->use bds3 , 1->use bds2
Frequency          =5                            # Frequency number
Elmask             =10                           # Satellite elevation mask
Exclsats           =C01 C02 C03 C04 C05          # prn ...
System             =33                           # 1:gps+4:glo+8:gal+16:qzs+32:comp

# Process Option2
Continue           =0                                              # 0->day-by-day  1->continuous processing
OBS_DIR            =F:\MRCB\Testdata\continuous processing\obs\    # obs dir
NAV_DIR            =F:\MRCB\Testdata\continuous processing\nav\    # nav dir

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

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.

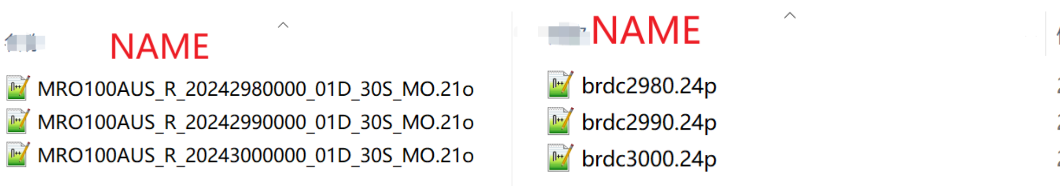


Fig. 18 Example of Correct File Organization

(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.

```
RCB_Continues.m
% Simple script to plot RCBs
clear; close all; clc;
% User settings
filename = 'E:\open_source\result\MRO1_GREJC_2_Continues_RCB.out';
system = 'Galileo';       % Choose: GPS, GLONASS, Galileo, QZSS, BDS-2, BDS-3
numFreq = 2;              % How many frequency bands to plot

% System configuration
bands.GPS = {'P1','P2','P5'}; cols.GPS = 12:14;
bands.GLONASS = {'R1','R2'}; cols.GLONASS = 15:16;
bands.Galileo = {'E1','E5a','E5b','E6','E5'}; cols.Galileo = 17:21;
bands.QZSS = {'P1','P2','P5'}; cols.QZSS = 22:24;
bands.BDS_2 = {'B1I','B3I','B2I'}; cols.BDS_2 = 25:27;
bands.BDS_3 = {'B1I','B3I','B2b','B1C','B2a'}; cols.BDS_3 = 25:29;

% Handle BDS names
if strcmp(system, 'BDS-2'), key = 'BDS_2';
elseif strcmp(system, 'BDS-3'), key = 'BDS_3';
else, key = system;
end

% Read data
data = readmatrix(filename, 'FileType','text', 'CommentStyle','#', 'Delimiter',' ', 'MultipleDelimsAsOne',true, 'NumHeaderLines',0);
hour = data(:,4);
```

Fig. 19 Visualizes RCBs for continues day

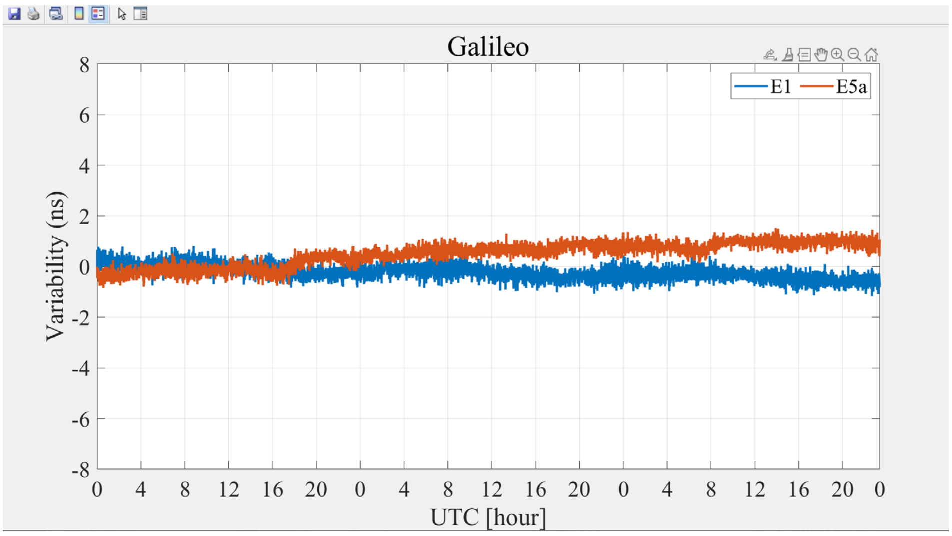


Fig. 20 Visualization Results

6.2.3 Linux Run

If you want run on the Linux system.

Execute these commands in sequence: ./MRCB

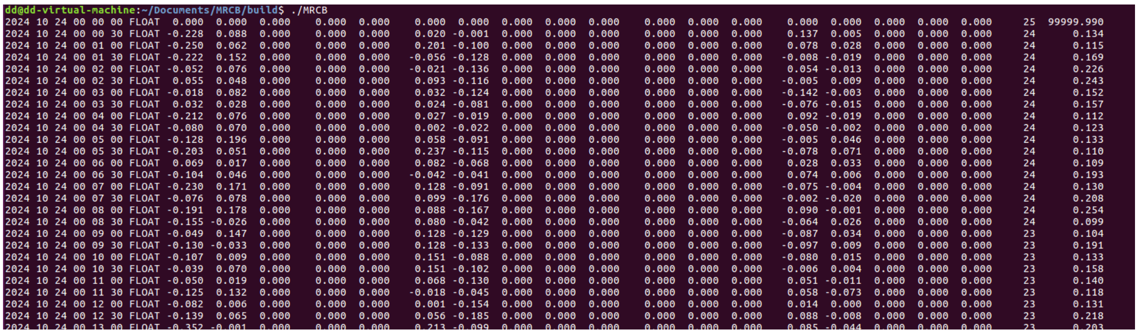


Fig. 21 Run on Linux

7 Output file format description

7.1 Result File

Name: XXXX_GEC_2_YYYYDOY_RCB.out

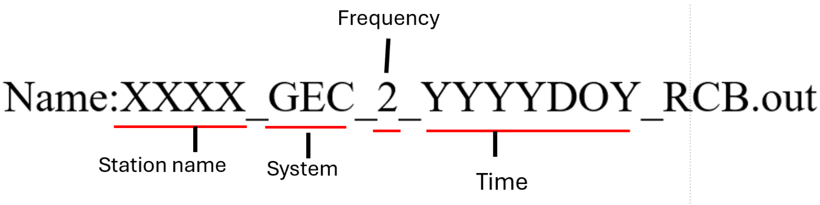


Fig. 22 Structure of output file name

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
GPS Time-varying RCB	P1	double	86-91
	P2	double	95-100
	P5	double	104-109
GLONASS Time-varying RCB	R1	double	115-120
	R2	double	124-130

Galileo Time-varying RCB	E1	double	136-141
	E5a	double	146-151
	E5b	double	157-162
	E6	double	167-172
	E5	double	177-182
QZSS Time-varying RCB	P1	double	190-195
	P2	double	199-204
	P5	double	208-213
BDS-3 Time-varying RCB	B1I	double	218-223
	B3I	double	230-235
	B2b	double	242-248
	B1C	double	255-260
	B2a	double	266-271
BDS-2 Time-varying RCB	B1I	double	218-223
	B3I	double	230-235
	B2I	double	242-248

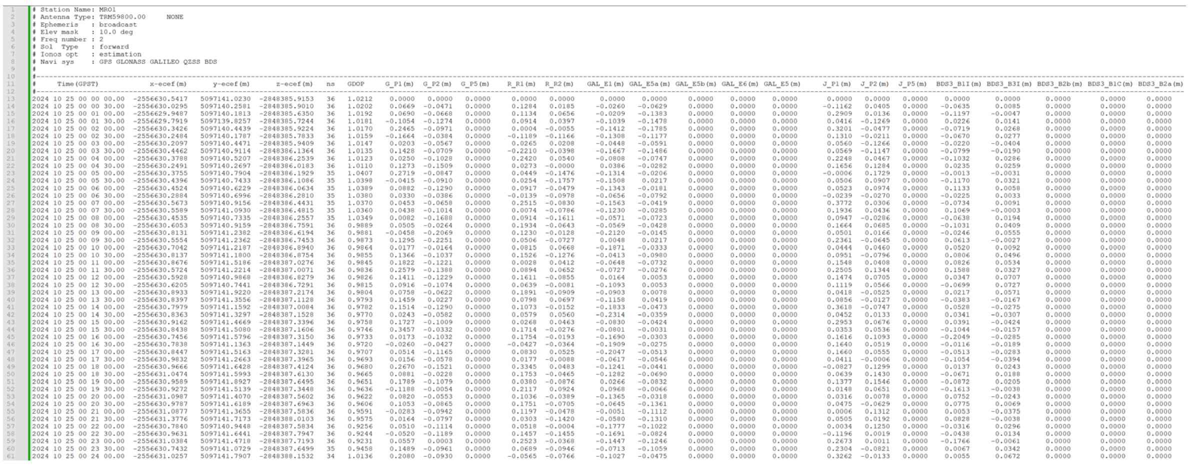


Fig. 23 Screenshot of RCBs result file

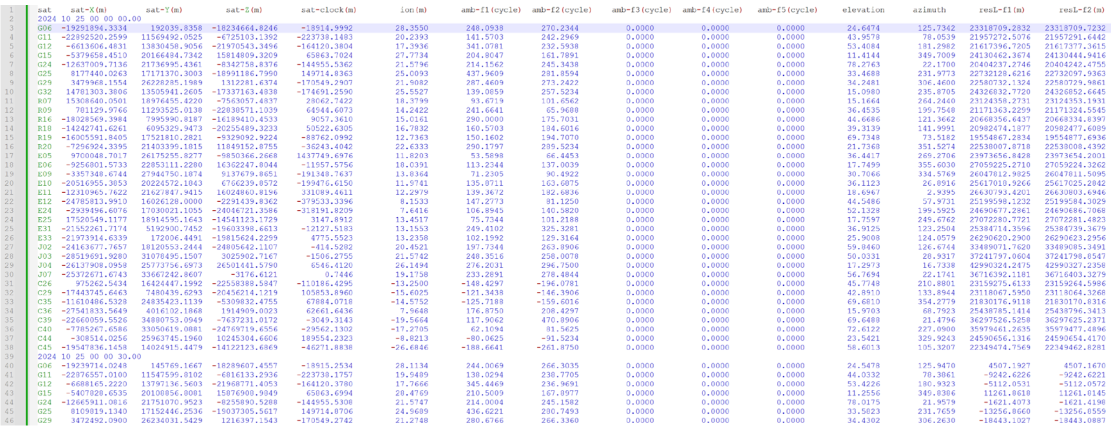
7.2 Process Information File

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
Ambiguity	F1 (cycle)	double	91-99

	F2 (cycle)	double	107-115
	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



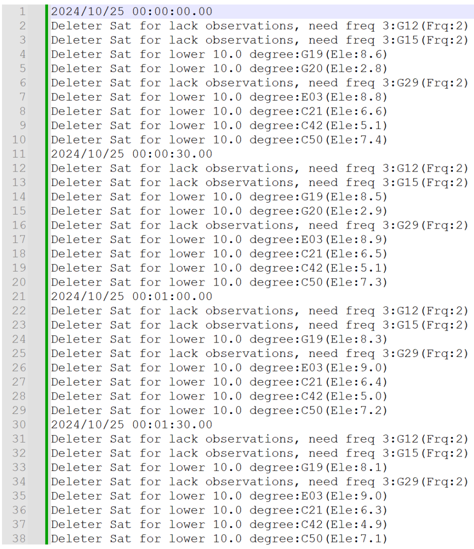
sat	sat-X(m)	sat-Y(m)	sat-Z(m)	sat-clock(m)	ion(m)	amb-f1(cycle)	amb-f2(cycle)	amb-f3(cycle)	amb-f4(cycle)	amb-f5(cycle)	elevation	azimuth	resL-f1(m)	resL-f2(m)
2024 10 25 00 00 00.00														
G06	-19291894.3334	192039.8358	-18234664.8246	-18914.9992	28.3550	248.0938	270.2344	0.0000	0.0000	0.0000	24.6474	125.7342	23318709.2832	23318709.7232
G11	-22892520.2599	11569492.0525	-6725103.1392	-223738.1483	20.2393	141.5703	242.2969	0.0000	0.0000	0.0000	43.9578	78.0539	21957272.5076	21957291.6442
G12	-6613606.4831	13830458.9056	-21970543.3496	-164120.3804	17.3936	341.0781	232.5938	0.0000	0.0000	0.0000	53.4084	181.2982	21617396.7205	21617377.3615
G15	-5379658.4510	20166484.7342	15814809.3209	65863.7024	27.7734	204.8047	161.7891	0.0000	0.0000	0.0000	11.4144	349.7009	24130462.3674	24130444.9416
G24	-12637009.7136	21736995.4361	-8342758.8376	-144955.5362	21.5796	214.1562	245.3438	0.0000	0.0000	0.0000	78.2763	22.1700	20404237.2746	20404242.4755
G25	8177440.0263	17171370.3003	-18991186.7990	149714.8363	25.0093	437.9609	281.8594	0.0000	0.0000	0.0000	33.4688	231.9773	22732128.6216	22732097.9363
G29	3479968.1554	26228285.1989	1312281.6374	-170549.2907	21.9082	287.4609	273.2422	0.0000	0.0000	0.0000	34.2481	306.4600	22580732.1324	22580729.9861
G32	14781303.3806	13505941.2605	-17337163.4838	-174691.2590	25.5527	139.0859	257.5234	0.0000	0.0000	0.0000	15.0980	235.8705	24326832.7720	24326852.6645
R07	15308640.0501	18976455.4220	-7563057.4837	28062.7422	18.3799	93.6719	101.6562	0.0000	0.0000	0.0000	15.1664	264.2440	23124358.2731	23124353.1931
R09	781129.9766	11293525.0138	-22838571.1039	64944.6073	14.2422	241.6641	65.9688	0.0000	0.0000	0.0000	36.4535	199.7548	21171363.2299	21171324.5545
R16	-18028569.3984	7995990.8187	-16189410.4533	9057.3610	15.0161	290.0000	175.7031	0.0000	0.0000	0.0000	44.6686	121.3662	20668356.6437	20668334.8397
R18	-14242741.6261	6095329.9473	-20255489.3233	50522.6305	16.7832	160.5703	184.6016	0.0000	0.0000	0.0000	39.3139	141.9991	20982474.1877	20982477.6089
R19	-16005591.8405	17521810.2821	-9329092.9224	-88762.0992	12.7363	150.1602	194.7070	0.0000	0.0000	0.0000	69.7348	73.5182	19554867.2834	19554877.6936
R20	-7296924.3395	21403399.1815	11849152.8755	-36243.4042	22.6333	290.1797	289.5234	0.0000	0.0000	0.0000	21.7368	351.5274	22538007.8718	22538008.4392
E05	9700048.7017	26175255.8277	-9850366.2668	1437749.6976	11.8203	53.5898	66.4453	0.0000	0.0000	0.0000	36.4417	269.2706	23973656.8428	23973654.2001
E06	-9256801.5733	22853111.2280	16362247.8044	-11957.5756	18.0391	113.2344	137.0039	0.0000	0.0000	0.0000	17.7499	355.6030	27059225.2710	27059224.3262
E09	-3357348.6744	27944750.1874	9137679.8651	-191348.7637	13.8364	71.2305	90.4922	0.0000	0.0000	0.0000	30.7066	334.5769	26047812.9825	26047811.5095
E10	-20516955.3853	20224572.1843	6766239.8572	-199476.6150	11.9741	135.8711	163.6875	0.0000	0.0000	0.0000	36.1123	26.8916	25617018.9266	25617025.2842
E11	-12310965.7622	21627847.9415	16024860.8196	331089.4611	12.2979	139.3672	182.6836	0.0000	0.0000	0.0000	18.6967	2.9395	26630793.4201	26630803.6946
E12	-24785813.9910	16026128.0000	-2291439.8362	-379533.3396	8.1533	147.2773	81.1250	0.0000	0.0000	0.0000	44.5486	57.9731	25199598.1232	25199584.3029
E24	-2939496.6076	17030021.1055	-24046721.3586	-318191.8209	7.6416	106.8945	140.5820	0.0000	0.0000	0.0000	52.1328	199.5925	24690677.2861	24690686.7068
E25	17520549.1177	18914595.1643	-14541123.1729	3147.8912	13.4517	75.7344	101.2188	0.0000	0.0000	0.0000	17.7597	249.6762	27072280.7721	27072281.4823
E31	-21552261.7174	5192900.7452	-19603398.6613	-12127.5183	13.1553	249.4102	325.3281	0.0000	0.0000	0.0000	36.9125	123.2504	25384714.3596	25384739.3679
E33	-21973914.6339	172006.4491	-19815624.2299	4775.5523	13.2358	102.1992	129.3164	0.0000	0.0000	0.0000	25.9008	124.0579	26290620.2900	26290623.2956
J02	-24163677.7657	18120553.2444	-24805642.1107	-414.5282	20.4521	197.7344	263.8906	0.0000	0.0000	0.0000	59.8460	126.6744	33489071.7620	33489085.3491
J03	-28519691.9280	31078495.1507	3025902.7167	-1506.2755	21.5742	248.3516	258.0078	0.0000	0.0000	0.0000	50.0331	28.9317	37241797.0604	37241798.8547
J04	-26137908.0958	25773756.6973	26501441.5790	6546.4120	26.1494	276.2031	296.7500	0.0000	0.0000	0.0000	17.2973	16.7338	42990324.2475	42990327.2358
J07	-25372671.6743	33667242.8607	-3176.6121	0.7446	19.1758	233.2891	278.4844	0.0000	0.0000	0.0000	56.7694	22.1741	36716392.1181	36716403.3279
C26	975262.5434	16424447.1992	-22558388.5847	-110186.4295	-13.2500	-148.4297	-196.0781	0.0000	0.0000	0.0000	45.7748	210.8801	23159275.6133	23159264.5986
C29	-17443745.6463	7480439.6293	-20456214.1219	105853.8960	-15.6025	-121.3438	-146.3906	0.0000	0.0000	0.0000	42.8910	133.8944	23118067.5950	23118064.3268
C35	-11610486.5328	24835423.1139	-5309832.4755	67884.0718	-14.5752	-125.7188	-159.6016	0.0000	0.0000	0.0000	69.6810	354.2779	21830176.9118	21830170.8316
C36	-27541833.5649	4016102.1868	1914909.0023	62661.6436	7.9648	176.8750	208.4297	0.0000	0.0000	0.0000	15.9703	68.7923	25438785.1414	25438796.3413
C39	-22660059.5526	34880753.0949	-7637231.0172	-3049.3143	-19.5664	117.9062	470.8906	0.0000	0.0000	0.0000	69.6488	21.4796	36297526.5258	36297625.2371
C40	-7785267.6586	33050619.0881	-24769719.6556	-29562.1302	-17.2705	62.1094	81.5625	0.0000	0.0000	0.0000	72.6122	227.0900	35979461.2635	35979477.4896
C44	-308514.0256	25963745.1960	10245304.6606	189554.2323	-8.8213	-80.0625	-91.5234	0.0000	0.0000	0.0000	23.5421	329.9243	24590656.1316	24590654.4170
C45	-19547836.1458	14024915.4479	-14122123.6869	-46271.8838	-26.6846	-188.6641	-261.8750	0.0000	0.0000	0.0000	58.6013	105.3207	22349474.7569	22349462.8281
2024 10 25 00 00 30.00														
G06	-19239714.0248	145769.1667	-18289607.4557	-18915.2534	28.1134	244.0069	266.3035	0.0000	0.0000	0.0000	24.5478	125.9470	4507.1927	4507.1670
G11	-22876557.0100	11547599.8102	-6816133.2936	-223738.1757	19.9489	138.0294	238.7705	0.0000	0.0000	0.0000	44.0332	78.3861	-9242.6226	-9242.6221
G12	-6688165.2220	13797136.5603	-21968771.4053	-164120.3780	17.7666	345.4469	236.9691	0.0000	0.0000	0.0000	53.4226	180.9323	-5112.0531	-5112.0572
G15	-5407828.6535	20108856.8081	15876908.9849	65863.6994	28.4769	210.5009	167.8977	0.0000	0.0000	0.0000	11.2556	349.8386	11261.8618	11261.8145
G24	-12665911.0816	21751070.9523	-8255890.5288	-144955.5308	21.5747	214.0004	245.1582	0.0000	0.0000	0.0000	78.0175	21.9579	-1621.4073	-1621.4198
G25	8109819.1340	17152446.2536	-19037305.5617	149714.8706	24.9689	436.6221	280.7493	0.0000	0.0000	0.0000	33.5823	231.7659	-13256.8660	-13256.8559
G29	3472492.0900	26234031.5429	1216397.1543	-170549.2742	21.2748	280.6766	266.3360	0.0000	0.0000	0.0000	34.4302	306.2630	-18443.1027	-18443.0887

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
Deleter Sat for lack observations, need freq 3:G12(Frq:2)
Deleter Sat for lack observations, need freq 3:G15(Frq:2)
Deleter Sat for lower 10.0 degree:G19(Ele:8.6)
Deleter Sat for lower 10.0 degree:G20(Ele:2.8)
Deleter Sat for lack observations, need freq 3:G29(Frq:2)
Deleter Sat for lower 10.0 degree:E03(Ele:8.8)
Deleter Sat for lower 10.0 degree:C21(Ele:6.6)
Deleter Sat for lower 10.0 degree:C42(Ele:5.1)
Deleter Sat for lower 10.0 degree:C50(Ele:7.4)
2024/10/25 00:00:30.00
Deleter Sat for lack observations, need freq 3:G12(Frq:2)
Deleter Sat for lack observations, need freq 3:G15(Frq:2)
Deleter Sat for lower 10.0 degree:G19(Ele:8.5)
Deleter Sat for lower 10.0 degree:G20(Ele:2.9)
Deleter Sat for lack observations, need freq 3:G29(Frq:2)
Deleter Sat for lower 10.0 degree:E03(Ele:8.9)
Deleter Sat for lower 10.0 degree:C21(Ele:6.5)
Deleter Sat for lower 10.0 degree:C42(Ele:5.1)
Deleter Sat for lower 10.0 degree:C50(Ele:7.3)
2024/10/25 00:01:00.00
Deleter Sat for lack observations, need freq 3:G12(Frq:2)
Deleter Sat for lack observations, need freq 3:G15(Frq:2)
Deleter Sat for lower 10.0 degree:G19(Ele:8.3)
Deleter Sat for lack observations, need freq 3:G29(Frq:2)
Deleter Sat for lower 10.0 degree:E03(Ele:9.0)
Deleter Sat for lower 10.0 degree:C21(Ele:6.4)
Deleter Sat for lower 10.0 degree:C42(Ele:5.0)
Deleter Sat for lower 10.0 degree:C50(Ele:7.2)
2024/10/25 00:01:30.00
Deleter Sat for lack observations, need freq 3:G12(Frq:2)
Deleter Sat for lack observations, need freq 3:G15(Frq:2)
Deleter Sat for lower 10.0 degree:G19(Ele:8.1)
Deleter Sat for lack observations, need freq 3:G29(Frq:2)
Deleter Sat for lower 10.0 degree:E03(Ele:9.0)
Deleter Sat for lower 10.0 degree:C21(Ele:6.3)
Deleter Sat for lower 10.0 degree:C42(Ele:4.9)
Deleter Sat for lower 10.0 degree:C50(Ele:7.1)
```

Fig. 25 Screenshot of Log file

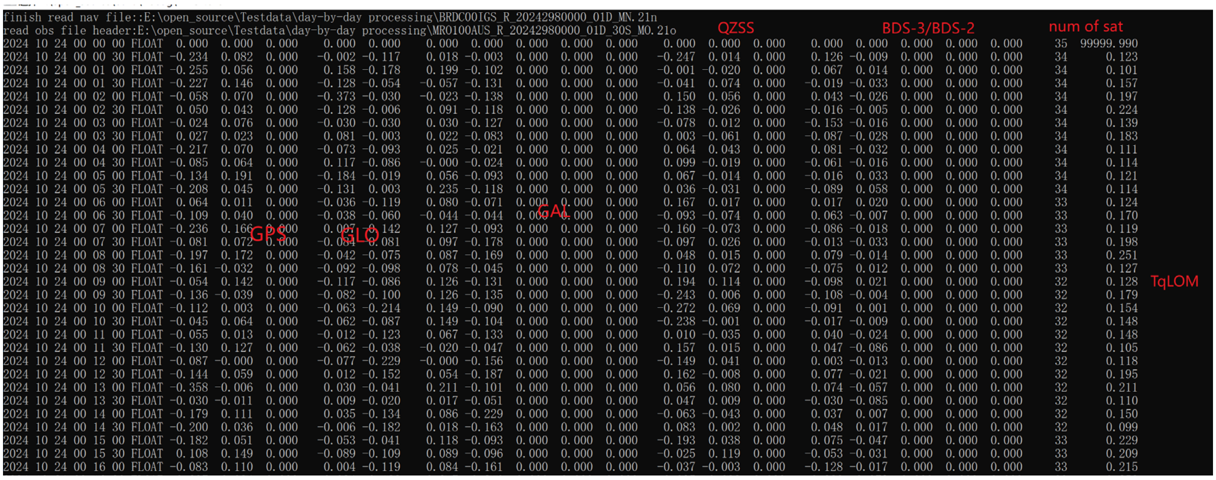
When use Continues processing, the file name become:

XXXX_GEC_2_Continues_RCB.out

XXXX_GEC_2_Continues_Inf.pro

XXXX_GEC_2_Continues_Sat.log

7.4 Execution Interface




```
finish read nav file::E:\open_source\Testdata\day-by-day processing\BRDC00IGS_R_20242980000_01D_MN.21n
read obs file header:E:\open_source\Testdata\day-by-day processing\MRO100AUS_R_20242980000_01D_30S_MO.21o
2024 10 24 00 00 00 FLOAT  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  99999.990
2024 10 24 00 00 30 FLOAT -0.234  0.082  0.000  -0.002 -0.117   0.018 -0.003  0.000  0.000  0.000  -0.247  0.014  0.000   0.126 -0.009  0.000  0.000  0.000   34      0.123
2024 10 24 00 01 00 FLOAT -0.255  0.056  0.000   0.158 -0.178   0.199 -0.102  0.000  0.000  0.000  -0.001 -0.020  0.000   0.067  0.014  0.000  0.000  0.000   34      0.101
2024 10 24 00 01 30 FLOAT -0.227  0.146  0.000  -0.128 -0.054  -0.057 -0.131  0.000  0.000  0.000  -0.041  0.074  0.000  -0.019 -0.033  0.000  0.000  0.000   34      0.157
2024 10 24 00 02 00 FLOAT -0.058  0.070  0.000  -0.373 -0.030  -0.023 -0.138  0.000  0.000  0.000   0.150  0.056  0.000   0.043 -0.026  0.000  0.000  0.000   34      0.197
2024 10 24 00 02 30 FLOAT  0.050  0.043  0.000  -0.128 -0.006   0.091 -0.118  0.000  0.000  0.000  -0.138 -0.026  0.000  -0.016 -0.005  0.000  0.000  0.000   34      0.224
2024 10 24 00 03 00 FLOAT -0.024  0.076  0.000  -0.030 -0.030   0.030 -0.127  0.000  0.000  0.000  -0.078  0.012  0.000  -0.153 -0.016  0.000  0.000  0.000   34      0.139
2024 10 24 00 03 30 FLOAT  0.027  0.023  0.000   0.081 -0.003   0.022 -0.083  0.000  0.000  0.000   0.003 -0.061  0.000  -0.087 -0.028  0.000  0.000  0.000   34      0.183
2024 10 24 00 04 00 FLOAT -0.217  0.070  0.000  -0.073 -0.093   0.025 -0.021  0.000  0.000  0.000   0.064  0.043  0.000   0.081 -0.032  0.000  0.000  0.000   34      0.111
2024 10 24 00 04 30 FLOAT -0.085  0.064  0.000   0.117 -0.086  -0.000 -0.024  0.000  0.000  0.000   0.099 -0.019  0.000  -0.061 -0.016  0.000  0.000  0.000   34      0.114
2024 10 24 00 05 00 FLOAT -0.134  0.191  0.000  -0.184 -0.019   0.056 -0.093  0.000  0.000  0.000   0.067 -0.014  0.000  -0.016  0.033  0.000  0.000  0.000   34      0.121
2024 10 24 00 05 30 FLOAT -0.208  0.045  0.000  -0.131  0.003   0.235 -0.118  0.000  0.000  0.000   0.036 -0.031  0.000  -0.089  0.058  0.000  0.000  0.000   34      0.114
2024 10 24 00 06 00 FLOAT  0.064  0.011  0.000  -0.036 -0.119   0.080 -0.071  0.000  0.000  0.000   0.167  0.017  0.000   0.017  0.020  0.000  0.000  0.000   33      0.124
2024 10 24 00 06 30 FLOAT -0.109  0.040  0.000  -0.038 -0.060  -0.044 -0.044  0.000  0.000  0.000  -0.093 -0.074  0.000   0.063 -0.007  0.000  0.000  0.000   33      0.170
2024 10 24 00 07 00 FLOAT -0.236  0.166  0.000   0.007 -0.142   0.127 -0.093  0.000  0.000  0.000  -0.160 -0.073  0.000  -0.086 -0.018  0.000  0.000  0.000   33      0.119
2024 10 24 00 07 30 FLOAT -0.081  0.072  0.000  -0.084 -0.081   0.097 -0.178  0.000  0.000  0.000  -0.097  0.026  0.000  -0.013 -0.033  0.000  0.000  0.000   33      0.198
2024 10 24 00 08 00 FLOAT -0.197  0.172  0.000  -0.042 -0.075   0.087 -0.169  0.000  0.000  0.000   0.048  0.015  0.000   0.079 -0.014  0.000  0.000  0.000   33      0.251
2024 10 24 00 08 30 FLOAT -0.161 -0.032  0.000  -0.092 -0.098   0.078 -0.045  0.000  0.000  0.000  -0.110  0.072  0.000  -0.075  0.012  0.000  0.000  0.000   33      0.127
2024 10 24 00 09 00 FLOAT -0.054  0.142  0.000  -0.117 -0.086   0.126 -0.131  0.000  0.000  0.000   0.194  0.114  0.000  -0.098  0.021  0.000  0.000  0.000   32      0.128
2024 10 24 00 09 30 FLOAT -0.136 -0.039  0.000  -0.082 -0.100   0.126 -0.135  0.000  0.000  0.000  -0.243  0.006  0.000  -0.108 -0.004  0.000  0.000  0.000   32      0.179
2024 10 24 00 10 00 FLOAT -0.112  0.003  0.000  -0.063 -0.214   0.149 -0.090  0.000  0.000  0.000  -0.272  0.069  0.000  -0.091  0.001  0.000  0.000  0.000   32      0.154
2024 10 24 00 10 30 FLOAT -0.045  0.064  0.000  -0.062 -0.087   0.149 -0.104  0.000  0.000  0.000  -0.238 -0.001  0.000  -0.017 -0.009  0.000  0.000  0.000   32      0.148
2024 10 24 00 11 00 FLOAT -0.055  0.013  0.000  -0.012 -0.123   0.067 -0.133  0.000  0.000  0.000   0.010 -0.035  0.000   0.040 -0.024  0.000  0.000  0.000   32      0.148
2024 10 24 00 11 30 FLOAT -0.130  0.127  0.000  -0.062 -0.038  -0.020 -0.047  0.000  0.000  0.000   0.157  0.015  0.000   0.047 -0.086  0.000  0.000  0.000   32      0.105
2024 10 24 00 12 00 FLOAT -0.087 -0.000  0.000  -0.077 -0.229  -0.000 -0.156  0.000  0.000  0.000  -0.149  0.041  0.000   0.003 -0.013  0.000  0.000  0.000   32      0.118
2024 10 24 00 12 30 FLOAT -0.144  0.059  0.000   0.012 -0.152   0.054 -0.187  0.000  0.000  0.000   0.162 -0.008  0.000   0.077 -0.021  0.000  0.000  0.000   32      0.195
2024 10 24 00 13 00 FLOAT -0.358 -0.006  0.000   0.030 -0.041   0.211 -0.101  0.000  0.000  0.000   0.056  0.080  0.000   0.074 -0.057  0.000  0.000  0.000   32      0.211
2024 10 24 00 13 30 FLOAT -0.030 -0.011  0.000   0.009 -0.020   0.017 -0.051  0.000  0.000  0.000   0.047  0.009  0.000  -0.030 -0.085  0.000  0.000  0.000   32      0.110
2024 10 24 00 14 00 FLOAT -0.179  0.111  0.000   0.035 -0.134   0.086 -0.229  0.000  0.000  0.000  -0.063 -0.043  0.000   0.037  0.007  0.000  0.000  0.000   32      0.150
2024 10 24 00 14 30 FLOAT -0.200  0.036  0.000  -0.006 -0.182   0.018 -0.163  0.000  0.000  0.000   0.083  0.002  0.000   0.048  0.017  0.000  0.000  0.000   32      0.099
2024 10 24 00 15 00 FLOAT -0.182  0.051  0.000  -0.053 -0.041   0.118 -0.093  0.000  0.000  0.000  -0.193  0.038  0.000   0.075 -0.047  0.000  0.000  0.000   33      0.229
2024 10 24 00 15 30 FLOAT  0.108  0.149  0.000  -0.089 -0.109   0.089 -0.096  0.000  0.000  0.000  -0.025  0.119  0.000  -0.053 -0.031  0.000  0.000  0.000   33      0.209
2024 10 24 00 16 00 FLOAT -0.083  0.110  0.000   0.004 -0.119   0.084 -0.161  0.000  0.000  0.000  -0.037 -0.003  0.000  -0.128 -0.017  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)

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

where $E(.)$ 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

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

where

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

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

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

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

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

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

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

where

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

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:

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

where

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

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

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

where

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

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)

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

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:

$$F_f^s = F_f^0 + k^s \Delta F_f \tag{12}$$

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 $|k^s| \leq 13$, $\Delta F_1/F_1^0 = 1/2848$, $\Delta F_2/F_2^0 = 1/2848$. Therefore, the wavelength λ_f^s can be expressed as:

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

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:

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

Therefore, Equation (11) can be simplified as:

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

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

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

where

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

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:

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

where

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

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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.

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