GCLK Users Guide

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1 Overview

Multi-GNSS satellite clock offset is an important prerequisite for multi-GNSS precise point positioning (PPP). Some GNSS data service organizations, such as Continuously Operating Reference System (CORS) centers in a certain country, province, or industry, still need software for multi-GNSS satellite clock offset estimation and analysis, as well as coordinate calculation of CORS stations. In this consideration, we developed and open source our software GCLK to facilitate GNSS data processing and analysis. GCLK were mainly written in Fortran language and a graphical user interface (GUI) was also developed in MATLAB environment. When users alter the core algorithm, they need to use the Intel Fortran compiler (freely available from https://www.intel.com/content/www/us/en/developer/tools/oneapi/toolkits.html) to recompile it into an executable file. If it does not involve code changes, all software functions can be achieved by operating the GUI and based on the pre-compiled executable program we provided. The features of GCLK include:

(1) Capable of multi-GNSS satellite clock offset estimation and precise positioning, including PPP and network positioning.

(2) Supports combined data processing of GPS, GLONASS, Galileo, the BeiDou Navigation Satellite System (BDS), and the Japanese Quasi-Zenith Satellite System (QZSS), and allows the selection of any two frequencies within a system to form observation values required by the software.

(3) Models in Earth-Centered, Earth-Fixed (ECEF) coordinate system, and adopts batch processed least squares estimator.

(4) Adopts prior data editing and posterior residual analysis to maximize the acquisition of clean observations.

(5) Takes measures to mitigate the effect of day boundary discontinuities (DBDs) of precise GNSS orbit products.

(6) Supports external satellite attitude products to maintain consistency with satellite orbits.

(7) Supports two execution methods: command-line (scripts) and GUI (capable of plotting and analysis).

2 Supported Platforms and License

The executable DOS commands of GCLK software for Windows was built using the Intel OneAPI toolkits (version 2024.1.0) with VS2019 on Windows 11 (64 bit). The corresponding commands for Linux was built using the Intel OneAPI toolkits (ifx version: 2024.0.2) on Ubuntu 22.04 LTS (64 bit). The MATLAB GUI was built in the MATLAB R2014a environment. When compiling the “gclk.exe” command, it is necessary to include the Intel Math Kernel Library (MKL). Certainly, the users also can use the same or similar compilers to build executable binary file on their own operating systems, including Windows, Linux, or Macintosh.

GCLK is an open-source software, which is governed by the GNU General Public License (GPL). The source code, documents, and examples can be freely available on GitHub.

3 Installation

3.1 Windows

To installation the GCLK software, you can either use the existing programs or compile them by yourself. Under the folder “GCLK_Windows”, there is a subfolder named “dos_bin” that stores the existing executable DOS commands, as well as a MATLAB figure file named “GCLK.fig”, which is the main GUI of GCLK software.

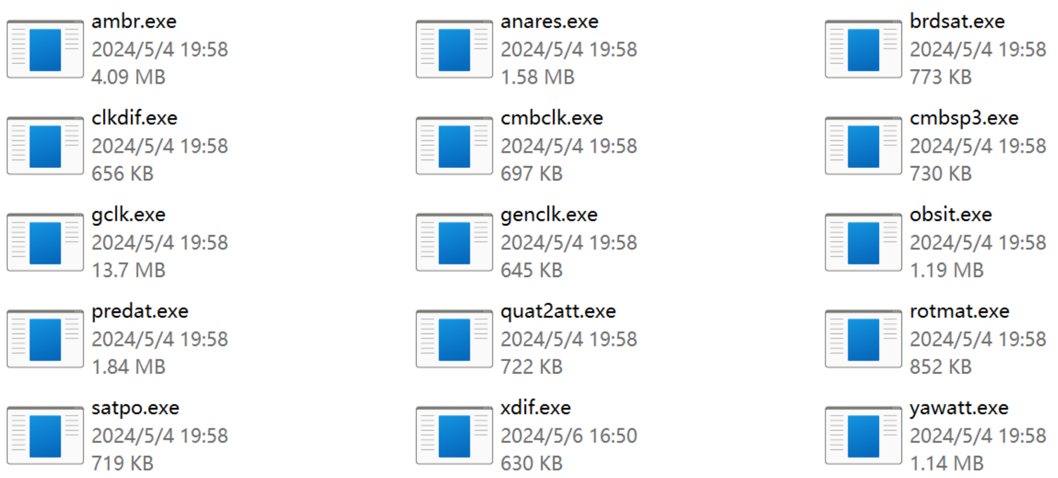

Fig.1 Executable DOS commands of GCLK software for Windows.

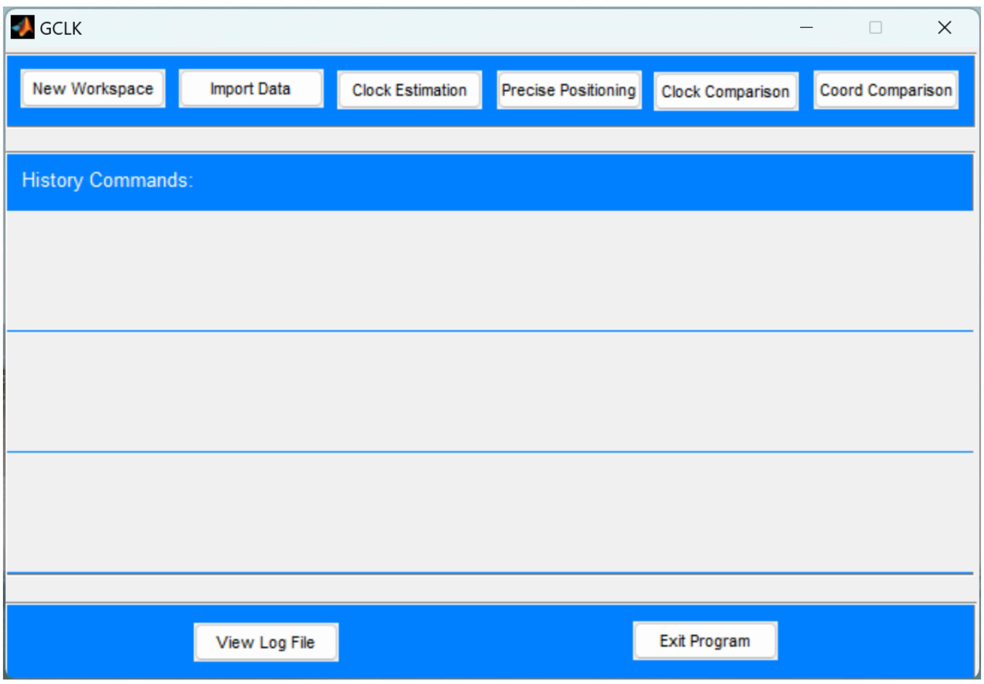

Fig.2 Main GUI of GCLK software.

Taking the "gclk.exe" command as an example, the following is the instructions for building the executable DOS commands for GCLK software.

(1) Create an empty Intel® Fortran console application project and import the source code files. The source files required for different commands can be

found in the corresponding “. sh” file in the “GCLK_Linux/ compile” folder.

(2) Modify the project properties and configure the configuration manager to “Release” configuration.

(3) Modify the project properties and add the parallel MKL library.

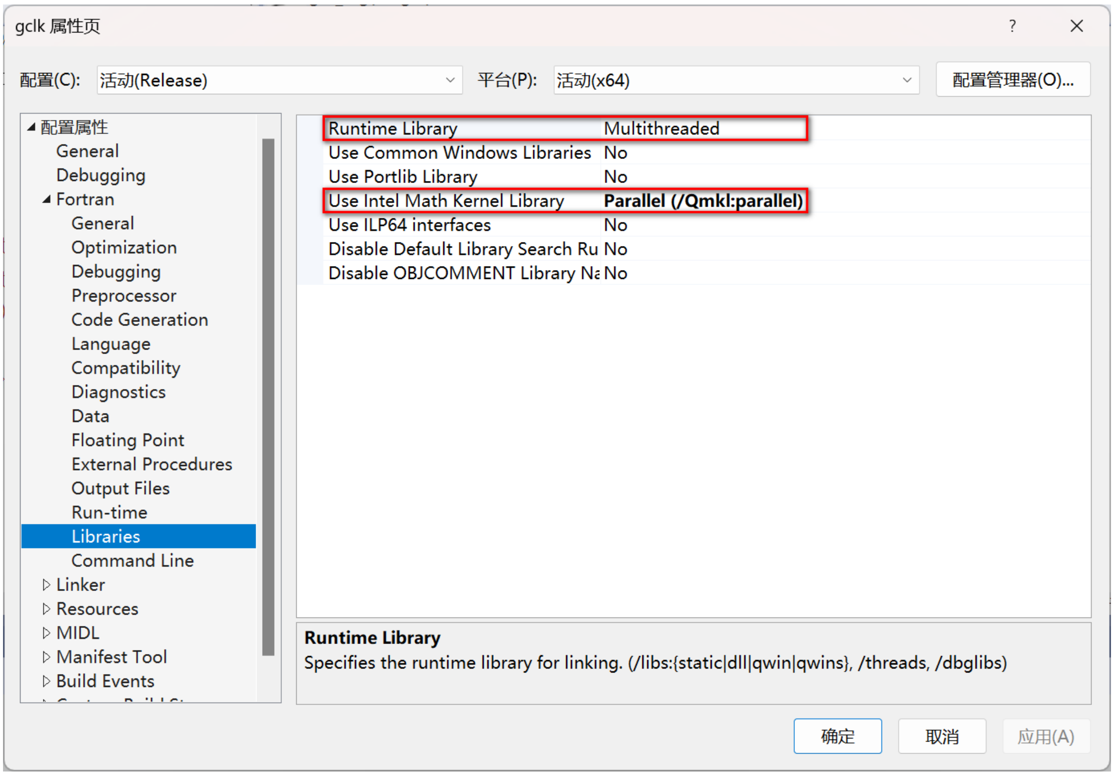

Fig.3 Adding the parallel MKL library for the project.

(4) Compile and generate the solution. Then, the executable file located in the “Release” folder under the project path.

(5) Copy the executable file to the “dos_bin” folder.

3.2 Linux

We provide installation scripts for installing GCLK software on Linux systems. For Macintosh systems, minor modifications may be required.

(1) Ensure that all files in folders “ GCLK_Linux/compile” and

“GCLK_Linux/shbin” have executable permissions.

(2) Use the terminal to enter directory “GCLK_Linux/compile” and run the “install.sh” script. Then wait for all commands to complete compilation.

```
scf@scf-Precision-3460:~/GCLK_Linux/compile$ ./install.sh
***compile ambr program success...
***compile anares program success...
***compile brdsat program success...
***compile clkdif program success...
***compile cmbclk program success...
***compile cmbsp3 program success...
***compile gclk program success...
***compile genclk program success...
***compile obsit program success...
***compile predat program success...
***compile quat2att program success...
***compile rotmat program success...
***compile satpo program success...
***compile yawatt program success...
```

Fig.4 Executing the installation script for GCLK software.

(3) Set environment variables for directory “GCLK_Linux/shbin” and directory “GCLK_Linux/bin”, and increase memory usage limits (ulimit -s <values>).

4 Operation

This section introduces how to operate GCLK software to achieve precise satellite clock offset estimation and precise positioning. In addition, some simple plotting and analysis functions are also introduced.

4.1 Data Preparation

To operate GCLK, three types of files need to be prepared: data files, table files, and configuration files. The data files need to be replaced with the processing project, the table files need to be updated when the content expires, and the configuration files need to be edited by the user according to the templates. Tables 1-3 provide descriptions for these files.

Table.1 Data files need to be prepared.

File	Format	Source
Broadcast ephemeris	RINEX	Download from the IGS data centers or source from GNSS receivers
Observation data	RINEX	Download from the IGS data centers or source from GNSS receivers
Precise ephemeris	SP3	Download from the IGS data centers or analysis centers
Satellite attitude quaternions	IGS Standard	Download from the IGS data centers or analysis centers
Precise satellite clock offset (required for precise positioning)	IGS Standard	Download from the IGS data centers or analysis centers
Station coordinates (precise coordinates are required for clock offset estimation, while approximate coordinates are sufficient for precise positioning)	GCLK defined (see Appendix)	Precise coordinates can be acquired from SINEX products, while approximate coordinates can be acquired from observation files

Table.2 Table files need to be prepared.

File	Content	Format	Source
ANTEX	Antenna corrections for satellites and receivers	IGS Standard	Download from the IGS data centers or analysis centers
EOP	Earth orientation parameters	C04	Download from http://celestrak.com/SpaceData/
Leap second	Leap seconds of UTC to TAI	GCLK defined	User edit according to the IERS bulletin
Solar ephemeris	Sun positions in GCRS	GCLK defined	Generated from JPL ephemeris
Lunar ephemeris	Moon positions in GCRS	GCLK defined	Generated from JPL ephemeris
OTL list	Ocean loading displacement for stations	BLQ	Acquired from http://holt.oso.chalmers.se/loading/index.html

Table.3 Configuration files need to be prepared.

File	Content	Format	Source
configure	Common configure file for GCLK	GCLK defined	Template (Almost no editing required)
sat_info	Satellite information	GCLK defined	Template (Minor editing when satellite information changes)
sat_used	Satellites used and constraint settings	GCLK defined	Template (Edit according to user requirements)
site_info	Station receiver and antenna information	GCLK defined	Template (Generated by the “obsit” command)
site_used	Station constraint settings	GCLK defined	Template (Edit according to user requirements)
site_list	Station used list	GCLK defined	Template (Edit according to user requirements)
site_coor/ site_appr	Station coordinates	GCLK defined	See Tab. 1
sys_freq	Frequency used settings	GCLK defined	Template (Edit according to user requirements)
model	Mathematical model settings	GCLK defined	Template (Edit according to user requirements)

4.2 Operating GCLK through GUI

The software GUI mainly implements the main functions of GCLK by calling its executable commands. The result of command execution is saved in the form of a file in the workspace (folder), while the standard output is saved in the file named “gclk.log” in the workspace. Click the "View Log File" button on the main interface of the software to view the log file. The main interface of the software will also save the last three historical commands executed. Below is a detailed introduction to the six functional modules in GUI.

4.2.1 New Workspace

Before performing other operations, a new workspace should be created first.

Namely, select a path for storage procedure or result files.

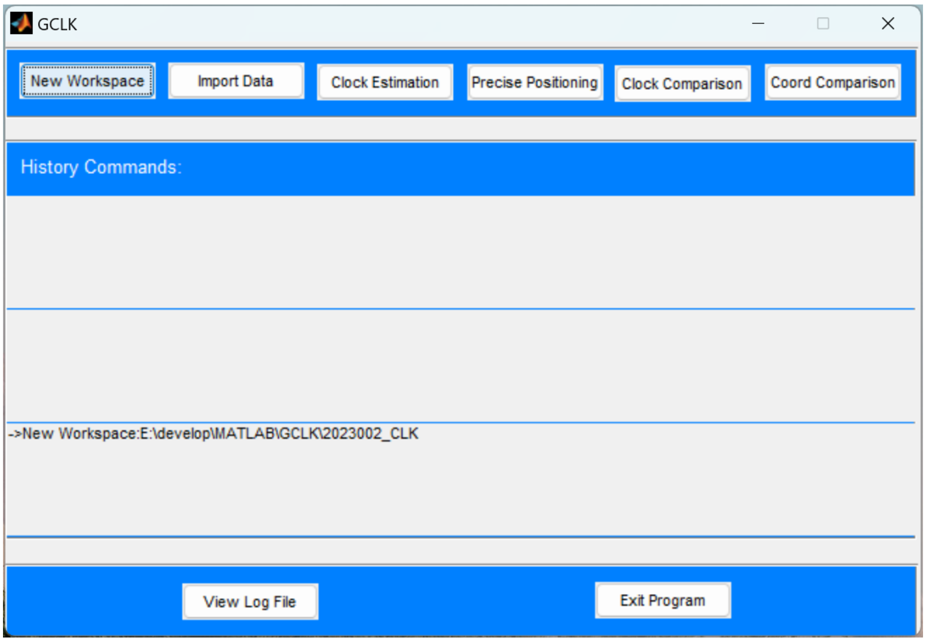

Fig.5 Create a new workspace.

4.2.2 Import Data

Before estimating clock offset and precise positioning, data needs to be imported in advance. The imported data includes broadcast ephemeris, precise ephemeris, precise clock (only precise positioning is required), and attitude quaternion. Moreover, the configure file path and observation data path also need to be set.

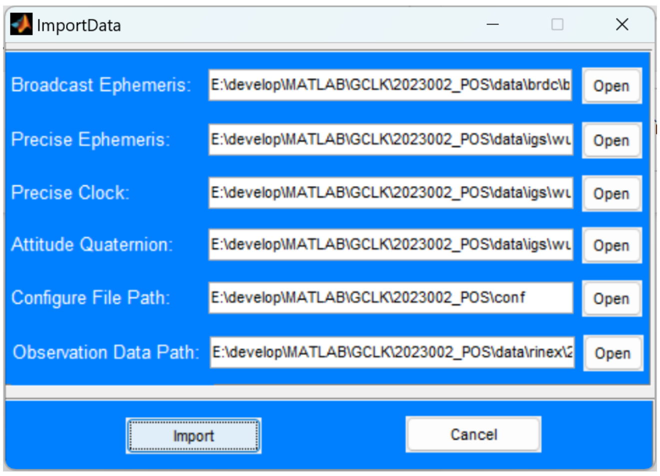

Fig.6 Import data for clock estimation and precise positioning.

4.2.3 Clock Estimation

Before clock offset estimation, the configuration files and observation files should be prepared according to section 4.1, and the file directories should be consistent with the imported data. In addition, the number of residual analysis iterations, processing date, processing interval, whether to fix ambiguity, and system combination can all be configured through the clock offset estimation GUI. The main interface of MATLAB displays the running process, and the result file is stored in the workspace path.

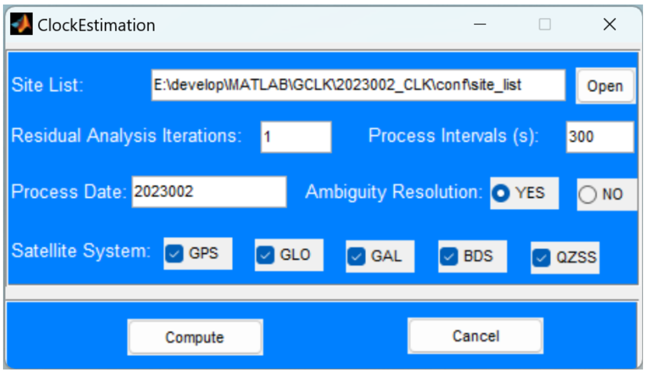

Fig.7 GUI for clock offset estimation.

4.2.4 Precise Positioning

Similar to clock offset estimation, it requires preparing configuration files and observation files, and achieving precise positioning through GUI. When the site list file only includes one station, PPP positioning is performed, and if it includes multiple stations, network positioning is performed.

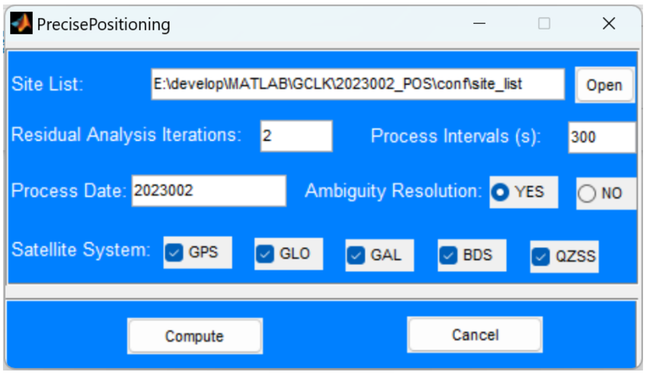

Fig.8 GUI for precise positioning.

4.2.5 Clock Comparison

After selecting two clock offset files with standard format and satellite systems through the clock offset comparison GUI, clock offset comparison can be performed. At the same time, some satellites can also be set to be excluded. The main interface of MATLAB displays comparison results and automatically completes the drawing.

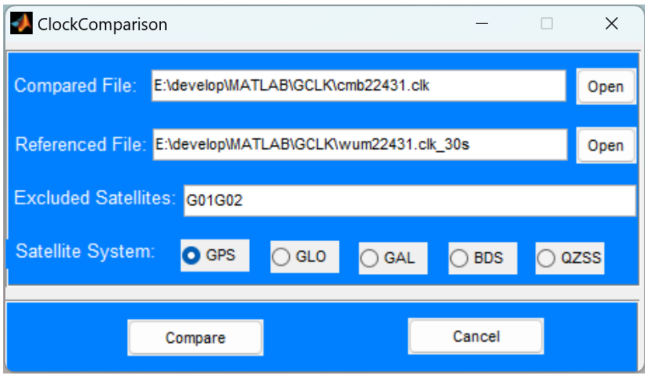

Fig.9 GUI for clock comparison.

4.2.6 Coordinate Comparison

After selecting a parameter file and a coordinate file, coordinate comparison can be performed. At the same time, some stations can also be excluded. The main interface of MATLAB displays comparison results and automatically completes the drawing.

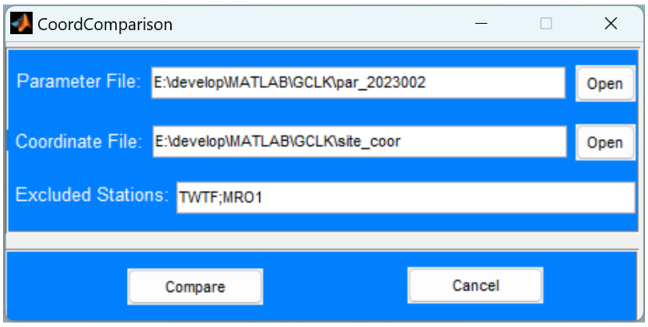

Fig.10 GUI for coordinate comparison.

4.3 Operating GCLK through Commands

In addition to operating the GUI, GCLK software's executable commands can also be run through command line to achieve software functionality. Both Windows and Linux support this operating method. We suggest combining multiple commands into a script to run. At the same time, we also provide scripts suitable for clock offset estimation and precise positioning in the example. The following describes how to operate GCLK software through commands.

4.3.1 Clock Offset Estimation

(1) Detect abnormal records in the broadcast ephemeris and generate a new, clean broadcast ephemeris file. Command: "brdsat brdm$cdoyi'0'.$yy'p' -noorb -noclk -sys $csys", where $cdoyi denotes the days of year of the data processing date, $yy denotes the last two digits of the year, $csys denotes the satellite systems to be processed, which can be any combination or non-combination of G, R, E, C, and J.

(2) Generate broadcast ephemeris orbit file (SP3 format) and broadcast ephemeris clock offset file (IGS standard format). Command: "brdsat brdc$cdoyi'0'.$yy'p' -sp3 brd$week$dow.sp3 -clk brd$week$dow.clk -fk -sys $csys -nochk", where $week denotes GPS week, $dow denotes the days of week.

(3) Calculate the rotation matrix from the Earth-fixed coordinate system to inertial coordinate system. This is mainly used for satellite attitude correction and tidal corrections. Command: "rotmat -time $yyyy $cdoyi 0 86400 -intv $intv -out rot_$yyyy$cdoyi +conf $conf_p/configure", where $yyyy denotes the year, $intv denotes data processing interval, $conf_p denotes configure file directory.

(4) Generate satellite yaw files and internal satellite attitude files (not use). Command: "yawatt brd$week$dow.sp3 -time $yyyy $cdoyi 0 86400 -intv $intv -yaw yaw_$yyyy$cdoyi -att att_$yyyy$cdoyi +conf $conf_p/configure -sys $csys".

(5) Convert external quaternion file to internal attitude file. Command:

“quat2att wum$week$dow.att_30s -intv $intv -out att_$yyyy$cdoyi -rot rot_$yyyy$cdoyi -sati $conf_p/sat_info -sys $csys”.

(6) Generate a list of observation files, before which the observation files need to be decompressed. Command: “sh_olist $yyyy $cdoyi $conf_p/site_list $rnx_p/$yyyy/$cdoyi”, where $rnx_p denotes a directory, and $rnx_p/$yyyy/$cdoyi denotes a complete directory for storing daily observation files.

(7) Generate approximate station coordinate files (not use for clock estimation) and station information files based on observation data. Command: “obsit olist”. The station information file may require further editing, such as adding missing information, replacing unsupported antenna types, etc.

(8) Observation data preprocessing site by site: “predat $f -intv 30 -freq 12 -gap 0 -sp3 brd$week$dow.sp3 -fk glonass.fk -sign $conf_p/sys_freq -sitc site_appr -sys $csys -tb -yaw yaw_$yyyy$cdoyi -leap -orb brd$week$dow.sp3”, where $f denotes the observation data file.

(9) Remove DBDs of adjacent precise ephemeris files. Commands: “cmbsp3 wum$week1$dow1.sp3 wum$week$dow.sp3 -out cmb$week1$dow1.sp3 -sys $csys -rmb 1”; “cmbsp3 cmb$week1$dow1.sp3 wum$week2$dow2.sp3 -out cmb$week$dow.sp3 -sys $csys -rmb 2”, where $week1 denotes the GPS week of the day before, $week2 denotes the GPS week of the day after, and the same is for $dow1 and $dow2.

(10) Parameter estimation: “gclk olist -clk brd$week$dow.clk -sp3 cmb$week$dow.sp3 +conf $conf_p/configure -intv $intv -fk glonass.fk -sys $csys -nopco”.

(11) Generate estimated clock offset file: “genclk pil_$yyyy$cdoyi -type ARAS”.

(12) Analyse posteriori residuals: “sh_anares olist "-gap 0"”.

(13) Repeat steps 10-12 until residual analysis is completed. Now, the “-clk” option can be replaced with “-clk pil$week$dow.clk”.

(14) Calculate satellite positions: “satpo brd$week$dow.sp3 -time $yyyy $cdoyi 0 86400 -sys $csys”.

(15) Fixed ambiguities: “ambr olist -pil pil_$yyyy$cdoyi -arc default +conf $conf_p/configure -fk glonass.fk -spo spo_$yyyy$cdoyi”.

(16) Re-parameter estimation (fixed solution): “gclk olist -clk pil$week$dow.clk -sp3 cmb$week$dow.sp3 +conf $conf_p/configure -intv $intv -amb amb_$yyyy$cdoyi -fk glonass.fk -sys $csys -nopco”.

(17) Generate the final estimated clock offset file: “genclk pil_$yyyy$cdoyi -type AS”.

4.3.2 Network Precise Positioning

(1) Detect abnormal records in the broadcast ephemeris and generate a new, clean broadcast ephemeris file. Command: “brdsat brdm$cdoyi'0'.$yy'p' -noorb -noclk -sys $csys”, where $cdoyi denotes the days of year of the data processing date, $yy denotes the last two digits of the year, $csys denotes the satellite systems to be processed, which can be any combination or non-combination of G, R, E, C, and J.

(2) Generate broadcast ephemeris orbit file (SP3 format) and broadcast ephemeris clock offset file (IGS standard format). Command: “brdsat brdc$cdoyi'0'.$yy'p' -sp3 brd$week$dow.sp3 -clk brd$week$dow.clk -fk -sys $csys -nochk”, where $week denotes GPS week, $dow denotes the days of week.

(3) Calculate the rotation matrix from the Earth-fixed coordinate system to inertial coordinate system. This is mainly used for satellite attitude correction and tidal corrections. Command: “rotmat -time $yyyy $cdoyi 0 86400 -intv $intv

-out rot_$yyyy$cdoyi +conf $conf_p/configure", where $yyyy denotes four digit year, $intv denotes data processing interval, $conf_p denotes configure file directory.

(4) Generate satellite yaw files and internal satellite attitude files (not use). Command: "yawatt brd$week$dow.sp3 -time $yyyy $cdoyi 0 86400 -intv $intv -yaw yaw_$yyyy$cdoyi -att att_$yyyy$cdoyi +conf $conf_p/configure -sys $csys".

(5) Convert external quaternion file to internal attitude file. Command: "quat2att wum$week$dow.att_30s -intv $intv -out att_$yyyy$cdoyi -rot rot_$yyyy$cdoyi -sati $conf_p/sat_info -sys $csys".

(6) Generate a list of observation files, before which the observation files need to be decompressed. Command: "sh_olist $yyyy $cdoyi $conf_p/site_list $rnx_p/$yyyy/$cdoyi", where $rnx_p denotes a directory, and $rnx_p/$yyyy/$cdoyi denotes a complete directory for storing daily observation files.

(7) Generate approximate station coordinate files and station information files based on observation data. Command: "obsit olist". The station information file may require further editing, such as adding missing information, replacing unsupported antenna types, etc.

(8) Observation data preprocessing site by site: "predat $f -intv 30 -freq 12 -gap 0 -sp3 brd$week$dow.sp3 -fk glonass.fk -sign $conf_p/sys_freq -sitc site_appr -sys $csys -tb -yaw yaw_$yyyy$cdoyi -leap -orb brd$week$dow.sp3", where $f denotes the observation data file.

(9) Remove DBDs of adjacent precise ephemeris files. Commands: "cmbsp3 wum$week1$dow1.sp3 wum$week$dow.sp3 -out cmb$week1$dow1.sp3 -sys $csys -rmb 1"; "cmbsp3 cmb$week1$dow1.sp3 wum$week2$dow2.sp3 -out cmb$week$dow.sp3 -sys $csys -rmb 2", where $week1 denotes the GPS week of the day before, $week2 denotes the GPS

week of the day after, and the same is for $dow1 and $dow2.

(10) If using external precise clock offset product, alignment processing is required. Command: “cmbclk wum$week$dow.clk_30s -sys $csys”.

(11) Parameter estimation: “gclk olist -clk cmb$week$dow.clk -sp3 cmb$week$dow.sp3 +conf $conf_p/configure -intv $intv -fk glonass.fk -sys $csys -nopco”.

(12) Analyse posteriori residuals: “sh_anares olist "-gap 0"”.

(13) Repeat steps 11-12 until residual analysis is completed.

(14) Calculate satellite positions: “satpo brd$week$dow.sp3 -time $yyyy $cdoyi 0 86400 -sys $csys”.

(15) Fixed ambiguities: “ambr olist -pil pil_$yyyy$cdoyi -arc default +conf $conf_p/configure -fk glonass.fk -spo spo_$yyyy$cdoyi”.

(16) Re-parameter estimation (fixed solution): “gclk olist -clk cmb$week$dow.clk -sp3 cmb$week$dow.sp3 +conf $conf_p/configure -intv $intv -amb amb_$yyyy$cdoyi -fk glonass.fk -sys $csys -nopco”.

4.3.3 Precise Point Positioning

Except for not requiring 14-16 steps, all other operation steps are consistent with the network precise positioning. Additionally, this process can be performed separately for one station (PPP).

4.3.4 Satellite Clock Offset Comparison

(1) Align the external precise clock offset file. Command: “cmbclk wum$week$dow.clk_30s -sys $csys -out cmb$week$dow.clk”.

(2) Compare the aligned external clock offset file with the estimated clock offset file. Command: “clkdif cmb$week$dow.clk pil$week$dow.clk -ref all -sys $csys”. We suggest comparing clock offsets system by system, as different systems may have different clock offset benchmarks.

4.3.5 Station Coordinate Comparison

We provide a script for comparing estimated station coordinates with known coordinates. Command: “pardif.sh par_$yyyy$cdoyi $conf_p/site_coor”.

4.4 Result Analysis and Plotting

The GCLK software provides a plotting function for clock offset comparison and coordinate comparison. After completing clock offset comparison or coordinate comparison by operating the MATLAB GUI, the comparison results are automatically drawn. Figures 11 and 12 are examples of the plotting.

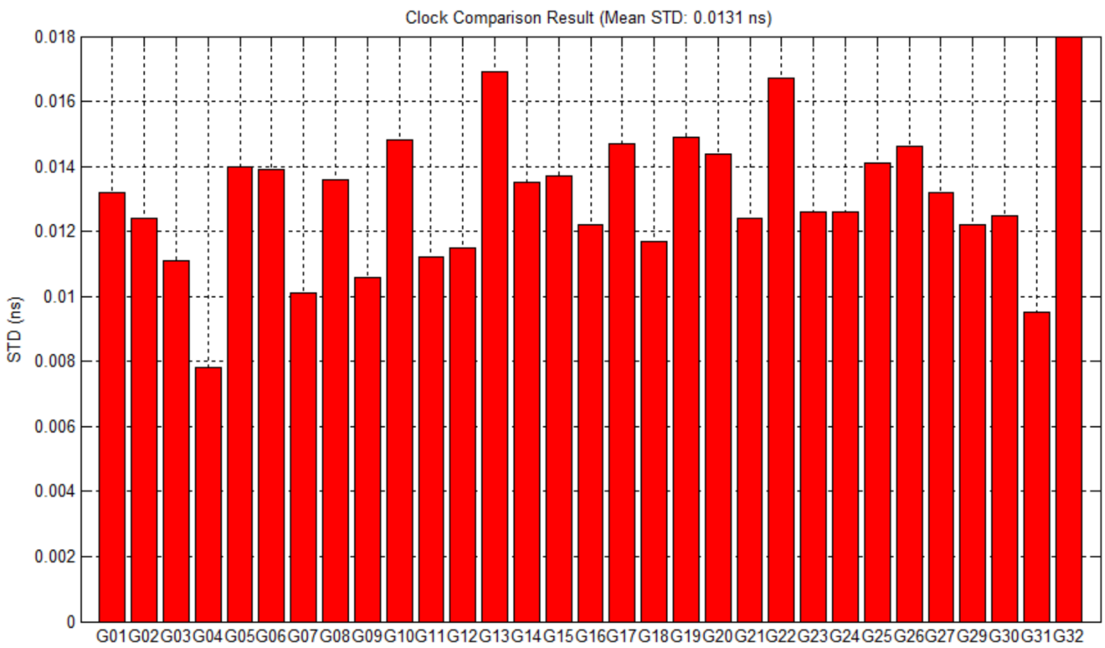

Fig.11 Plotting of clock offset comparison result.

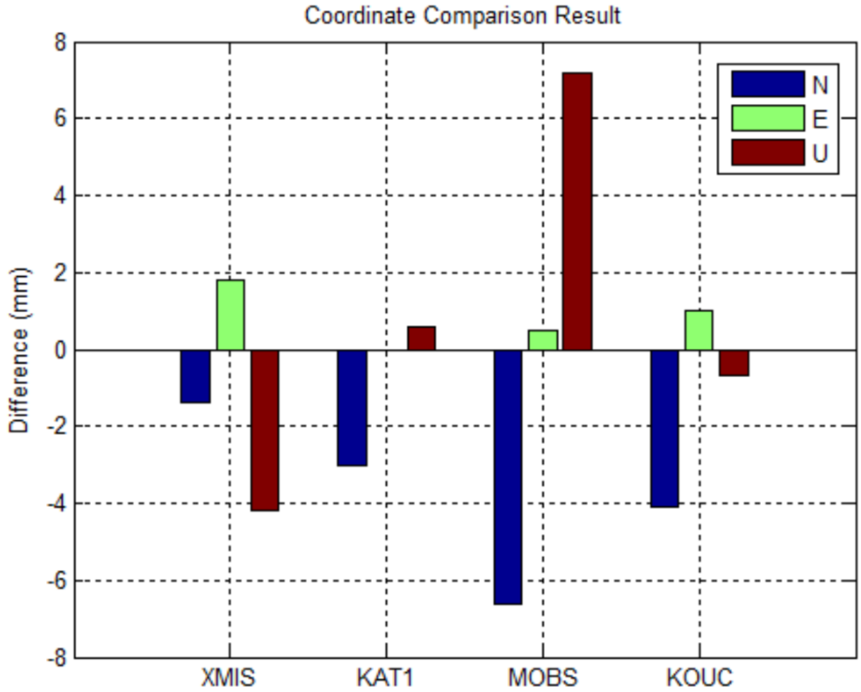

Fig.12 Plotting of station coordinate comparison result.

5 Support

Any suggestions, corrections, and comments about ***GCLK*** are sincerely welcomed and could be sent to:

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It is recommended to acknowledge *GCLK* when you find it useful!

Appendix A Command Description

Table 4 shows the functions of GCLK software commands and some scripts. Detailed information can be viewed in the terminal through "command or script name + enter" to display help information.

Table.4 Descriptions of GCLK software commands and scripts.

Name	Type	Main Function
ambr	Command	Implementing double differenced ambiguity resolution on un-differenced IF ambiguities.
anares	Command	Analyzing posteriori residuals to detect cycle slips and gross errors.
brdsat	Command	Obtaining initial satellite clock offsets and GLONASS frequency number from broadcast ephemerides.
clkdif	Command	Comparing two clock offset files.
cmbclk	Command	Combining precise clock offset files of adjacent days, and checking clock offset consistency.
cmbsp3	Command	Combining precise ephemeris files of adjacent days, and removing the day boundary discontinuities.
gclk	Command	Modeling raw measurements, and estimating the unknown parameters according to the least square criterion.
genclk	Command	Generating clock offset file in standard format.
obsit	Command	Get station information and approximate coordinates from observation file header.
predat	Command	Preprocessing raw measurements based on the “TurboEdit” algorithm, and defining observation arcs.
quat2att	Command	Converting satellite attitude quaternion file to internal attitude file.
rotmat	Command	Calculating the rotation matrix from Earth-fixed coordinate system to inertial coordinate system.
satpo	Command	Calculating GNSS satellite positions and velocities based on sp3 format file.
yawatt	Command	Satellite yaw detection and attitude Calculation.

pardif.sh	Script	Comparing the coordinates in the par file and site_coor file.
sh_anares	Script	Batch script for posteriori residual analyzing.
sh_olist	Script	Get a list of observation files based on site_list file and observation file path.

Appendix B File Description

Below are examples and content explanations of GCLK custom format files.

(1) Leap second file: “leap_sec”. The data contained in this file includes year, month, day, and leap seconds.

```
1999 01 01 32
2006 01 01 33
2009 01 01 34
2012 07 01 35
2015 07 01 36
2017 01 01 37
```

Fig.13 Example of leap second file.

(2) Lunar coordinate file: “lun.eph”. The data contained in this file includes modified Julian day (MJD) and lunar coordinates in Geocentric Celestial Reference System (GCRS).

```
Moon Ephemeris (GCRS) From JPL DE405
From  57023.00 To  64328.00 MJD(TT OR TDB) GCRS(m) 0.5 Days
57023.00D0    244199682.402253D0    278511444.057444D0     99592996.594724D0
57023.50D0    209622560.197029D0    304806197.019987D0    107599455.143372D0
57024.00D0    172258826.410397D0    327126850.457152D0    114207681.991827D0
57024.50D0    132630527.345706D0    345239508.987342D0    119352165.531663D0
57025.00D0     91275609.286824D0    358969951.461792D0    122987697.794763D0
57025.50D0     48740462.379193D0    368203418.399977D0    125089116.268896D0
57026.00D0      5572777.584319D0    372883615.930725D0    125650792.746251D0
57026.50D0    -37685188.899443D0    373010987.913188D0    124685888.732941D0
57027.00D0    -80502850.661059D0    368640325.615545D0    122225402.812920D0
```

Fig.14 Example of lunar coordinate file.

(3) Solar coordinate file: “sol.eph”. The data contained in this file includes MJD and solar coordinates in GCRS.

```
Sun Ephemeris (GCRS) From JPL DE405
From  57023.00 To  64328.00 MJD(TT OR TDB) GCRS(m) 1.0 Days
57023.00D0     25605944946.242D0   -132904112313.576D0    -57616130474.932D0
57024.00D0     28177272636.955D0   -132462946887.484D0    -57424965017.462D0
57025.00D0     30739722456.960D0   -131980759010.504D0    -57215998301.455D0
57026.00D0     33292548923.343D0   -131457711731.051D0    -56989298342.989D0
57027.00D0     35835009947.750D0   -130893970231.820D0    -56744935205.053D0
57028.00D0     38366364616.293D0   -130289702557.606D0    -56482981297.091D0
57029.00D0     40885871412.989D0   -129645080773.112D0    -56203511805.982D0
57030.00D0     43392786966.572D0   -128960282379.057D0    -55906605199.202D0
57031.00D0     45886365319.803D0   -128235491794.790D0    -55592343736.140D0
```

Fig.15 Example of solar coordinate file.

(4) Satellite information file: “sat_info”. The meaning of the data in the file refers to the data header. If the first character of each line in the file is not empty, it will be used as a comment line.

```
*Valid Until 2022 09 18
*PRN _SV_ SYS ORB CK _______TYPE_______ _MASS(G)_ B YAW_RATE YEAR MO DY HR MN - YEAR MO DY HR MN
xG01 G032 GPS MEO XX BLOCK IIA             930000 U   0.1211 1992 11 22 00 00 - 1994 06 06 00 00
xG01 G032 GPS MEO XX BLOCK IIA             930000 Y   0.1211 1994 06 06 00 00 - 1995 03 26 00 00
xG01 G032 GPS MEO XX BLOCK IIA             930000 P   0.1211 1995 03 26 00 00 - 1995 03 27 17 29
xG01 G032 GPS MEO XX BLOCK IIA             930000 N   0.1211 1995 03 27 17 29 - 1995 09 24 05 24
 G01 G032 GPS MEO XX BLOCK IIA             930000 P   0.1211 1995 09 24 05 24 - 2008 10 17 00 00
 G01 G037 GPS MEO XX BLOCK IIA             930000 P   0.1269 2008 10 23 00 00 - 2009 01 07 00 00
 G01 G049 GPS MEO XX BLOCK IIR-M          1080000 U   0.2000 2009 03 24 00 00 - 2011 05 07 00 00
 G01 G035 GPS MEO XX BLOCK IIA             930000 P   0.1180 2011 06 02 00 00 - 2011 07 13 00 00
 G01 G063 GPS MEO XX BLOCK IIF            1633000 N   0.1100 2011 07 16 00 00 - 2100 01 01 00 00
xG02 G013 GPS MEO XX BLOCK II              843000 U   0.1339 1989 06 10 00 00 - 1993 01 01 00 00
xG02 G013 GPS MEO XX BLOCK II              843000 Y   0.1339 1993 01 01 00 00 - 1995 07 04 00 00
xG02 G013 GPS MEO XX BLOCK II              843000 P   0.1339 1995 07 04 00 00 - 1995 07 05 01 10
xG02 G013 GPS MEO XX BLOCK II              843000 N   0.1339 1995 07 05 01 10 - 1995 11 17 00 00
 G02 G013 GPS MEO XX BLOCK II              843000 P   0.1339 1995 11 17 00 00 - 2004 05 13 00 00
 G02 G061 GPS MEO XX BLOCK IIR-B          1080000 U   0.2000 2004 11 06 00 00 - 2100 01 01 00 00
```

Fig.16 Example of satellite information file.

(5) Satellite used file: “sat_used”. The meaning of the data in the file refers to the data header. If the first character of each line in the file is not empty, it will be used as a comment line. “ALL” represents all the satellites below; “FIX” represents fixed corresponding parameters; “CLK” represents estimating satellite clock offset; “REF” indicates setting it as a reference clock; “XXX” indicates that the value will be replaced by the following value.

```
+SYSTEMS USED
 G:GPS
 C:BDS
 R:GLONASS
 E:Galileo
 J:QZSS
-SYSTEMS USED

+SATELITES USED
*PRN CLK _CLK_ _VEL_ ORB ___SRP___ __X__ __Y__ __Z__ __VX_ __VY_ __VZ_
*ALL FIX 0.000 0.000 FIX BERN9     0.000 0.000 0.000 .0000 .0000 .0000
*ALL CLK 0.050 0.005 ORB BERN9     0.050 0.050 0.050 .0005 .0005 .0005
*ALL CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
*ALL CLK 100.0 0.100 POS BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 ALL XXX 100.0 0.100 FIX XXXXX     10.00 10.00 10.00 0.100 0.100 0.100
*G01 REF 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G01 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G02 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G03 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G04 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G05 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
 G06 CLK 100.0 0.100 ORB BERN9     10.00 10.00 10.00 0.100 0.100 0.100
```

Fig.17 Example of satellite used file.

(6) Site coordinate file: “site_coor” or “site_appr”. The meaning of the data in the file refers to the data header. If the first character of each line in the file is not empty, it will be used as a comment line.

```
*Site Coordinates File : From SNX : Frame ITRF2014
*Name __Begin_ __Stop__ _____X(m)_____ _____Y(m)_____ _____Z(m)_____ _Vx(m/y)_ _Vx(m/y)_ _Vx(m/y)_ __Time__
 BJFS 0000 000 9999 999 -2148744.52312  4426641.16567  4044655.80380 000.00000 000.00000 000.00000 2010 001
 ABMF 0000 000 9999 999  2919785.78137 -5383744.96822  1774604.84335 000.00000 000.00000 000.00000 2010 001
 URUM 0000 000 9999 999   193030.18339  4606851.27909  4393311.52420 000.00000 000.00000 000.00000 2010 001
```

Fig.18 Example of site coordinate file.

(7) Site information file: site_info”. The meaning of the data in the file refers to the data header. If the first character of each line in the file is not empty, it will be used as a comment line.

```
*Site Information File
*NAME YEAR DOY HR MN SC - YEAR DOY HR MN SC ______REC_NUM_______ ______REC_TYP_______ ______REC
_VER_______ ______ANT_NUM_______ ____ANT_TYP_____ DOME ANT_DELTA_H(m) ANT_DELTA_E(m) ANT_DELTA_
N(m)
 ABER 2019 001 00 00 00 - 2019 001 23 59 30 5229K50655           TRIMBLE NETR9        5.01
           5249360782           TRM59900.00      SCIS         3.9650         0.0000         0.
0000
```

Fig.19 Example of site information file.

(8) Site used file: “site_used”. The meaning of the data in the file refers to the data header. If the first character of each line in the file is not empty, it will

be used as a comment line. “FIX” represents fixed corresponding parameters; “CLK” represents estimating receiver clock offset; “REF” indicates setting it as a reference clock; “POS” represents estimating position parameters; “XXXX” represents other stations except for the following.

```
+SITES USED
*NAME CLK _CLK_ POS __N__ __E__ __U__ __VN_ __VE_ __VU_
*XXXX FIX 0.000 FIX 0.000 0.000 0.000 .0000 .0000 .0000
*XXXX CLK 100.0 POS 10.00 10.00 10.00 0.100 0.100 0.100
*BJFS REF 100.0 POS 0.020 0.020 0.050 .0020 .0020 .0020
 XXXX CLK 100.0 POS 0.020 0.020 0.050 .0020 .0020 .0020
 ALIC REF 100.0 POS 0.020 0.020 0.050 .0020 .0020 .0020
 WROC REF 100.0 POS 0.020 0.020 0.050 .0020 .0020 .0020
#
-SITES USED
```

Fig.20 Example of site used file.

(9) System frequency file: “sys_freq”. The data of each system includes frequency band, frequency (MHz), and frequency number.

```
*Freq  G:GPS           R:GLONASS       E:Galileo       C:BDS           J:QZSS
 1     L1   1575.42  1 G1   1602.    1 E1   1575.42  1 B1-2 1561.098 2 L1   1575.42  1
 2     L2   1227.60  2 G2   1246.    2 E5a  1176.45  5 B3   1268.52  6 L2   1227.60  2
 3     L5   1176.45  5 G3   1202.025 3 E5b  1207.140 7 B2b  1207.140 7 L5   1176.45  5
```

Fig.21 Example of system frequency file.

(10) Satellite attitude file: “att_$yyyy$doy”. Binary files generated by the “yawatt” command.

(11) Satellite position file: “spo_$yyyy$doy”. Binary files generated by the “satpo” command.

(12) Satellite yaw file: “yaw_$yyyy$doy”. Generated by the “yawatt” command along with the satellite attitude file.

```
#59946     0.00  59947     0.00    30.00
# 74 G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20
#    G21 G22 G23 G24 G25 G26 G27 G29 G30 G31 G32 C01 C02 C03 C04 C05 C06 C07 C08 C09
#    C10 C11 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C32 C33
#    C34 C36 C37 C38 C39 C40 C41 C42 C43 C44 C45 C46 C59 C60
G01 G063 BLOCK IIF          N  1
 59946     0.00 59947     0.00   0.1100  -0.7000  0
G02 G061 BLOCK IIR-B        U  1
 59946     0.00 59947     0.00   0.2000   0.0000  0
G03 G069 BLOCK IIF          N  7
 59946     0.00 59946  3930.00   0.1100  -0.7000  0
 59946  3960.00 59946  6930.00   0.1100  -0.7000  1
 59946  6960.00 59946 26910.00   0.1100  -0.7000  0
 59946 26940.00 59946 27030.00   0.1100  -0.7000  2
 59946 27060.00 59946 47070.00   0.1100  -0.7000  0
 59946 47100.00 59946 50040.00   0.1100  -0.7000  1
 59946 50070.00 59947     0.00   0.1100  -0.7000  0
```

Fig.22 Example of satellite yaw file.

(13) Double differenced ambiguity file: “amb_$yyyy$doy”. The data contained in this file includes ambiguity type, site number 1, satellite number 1, site number 2, satellite number 2, starting epoch, end epoch, wide lane (WL) ambiguity, sigma of WL ambiguity, narrow lane (NL) ambiguity, sigma of NL ambiguity, and LC ambiguity.

```
59946     0.00  59946 86385.00    300.00  10312    828    178
108 ABPO AC24 ALIC AREG ASCG BAKO BILL BOAV BOGT BRST BSHM BUCU CAS1 CEDU CHPG CHTI
    CKIS CMUM COCO CPVG DAEJ DARW DAV1 DGAR DJIG DUMG DUND ENAO FAIR FALK GAMB GLPS
    GUAM HKWS HOB2 HOFN HOLB HRAO IISC INEG JFNG KARR KERG KIT3 KOKB KOUG LAUT LCK3
    LMMF MAC1 MAL2 MAR6 MAS1 MAW1 MAYG MBAR MCHL MDO1 MIZU MRC1 NIST NIUM NKLG NLIB
    NNOR NOT1 NRMD NTUS NYA2 P389 PADO PALM PARK PGEN POAL POHN POL2 POLV POVE PTAG
    QAQ1 SALU SAVO SCOR SCTB SGOC SHLG SOLO STHL STJ3 THTG THU2 TOPL TOW2 TUVA UCAL
    ULAB UNBD URUM USCL VACS WARK WIND WROC WSRT YEL2 YKRO ZAMB
 69 G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20
    G21 G22 G23 G24 G25 G26 G27 G29 G30 G31 G32 C01 C02 C03 C04 C05 C06 C07 C08 C09
    C10 C11 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C27 C28 C29 C30 C32 C34 C36
    C37 C39 C40 C41 C42 C43 C44 C45 C46
LC   23    1   54   17     73    122        -5.0071      0.0144       10.0391      0.0500   -0.8137
LC   23    3   54   17     79    126         5.0294      0.0139        5.0105      0.0500    2.4233
LC   23   17   54   19     85    129        22.9884      0.0132       -4.9928      0.0500    8.1481
LC   23   44   54   54    109    149         9.9629      0.0106       15.0616      0.0500    6.1893
LC   23   54   54   62    110    150        -0.0645      0.0119      -31.0105      0.0500   -3.2855
LC   23   44   54   64    109    147        11.9337      0.0101        5.0642      0.0500    6.0488
LC   23   37   54   61    190    227        18.8421      0.0102       41.0687      0.0500   13.0789
LC   23    6   54   11    124    161       -32.0497      0.0190        4.0115      0.0500  -11.6504
```

Fig.23 Example of double differenced ambiguity file.

(14) Estimated parameter file: “pil_$yyyy$doy”, which contains piled parameters for all epoch, and “par_$yyyy$doy”, which contains parameters for last epoch only. The data contained in piled parameter file includes parameter name, site name (blank for parameters unrelated to site), satellite name (blank for parameters unrelated to satellite), estimated values, corrections, sigma, parameter start time (MJD and seconds of day), parameter end time, site index,

satellite index, and number of observations on this parameter.

```
#59946     0.00  59946 86385.00   300.00     14770
#108 ABPO AC24 ALIC AREG ASCG BAKO BILL BOAV BOGT BRST BSHM BUCU CAS1 CEDU CHPG CHTI
#    CKIS CMUM COCO CPVG DAEJ DARW DAV1 DGAR DJIG DUMG DUND ENAO FAIR FALK GAMB GLPS
#    GUAM HKWS HOB2 HOFN HOLB HRAO IISC INEG JFNG KARR KERG KIT3 KOKB KOUG LAUT LCK3
#    LMMF MAC1 MAL2 MAR6 MAS1 MAW1 MAYG MBAR MCHL MDO1 MIZU MRC1 NIST NIUM NKLG NLIB
#    NNOR NOT1 NRMD NTUS NYA2 P389 PADO PALM PARK PGEN POAL POHN POL2 POLV POVE PTAG
#    QAQ1 SALU SAVO SCOR SCTB SGOC SHLG SOLO STHL STJ3 THTG THU2 TOPL TOW2 TUVA UCAL
#    ULAB UNBD URUM USCL VACS WARK WIND WROC WSRT YEL2 YKRO ZAMB
# 69 G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20
#    G21 G22 G23 G24 G25 G26 G27 G29 G30 G31 G32 C01 C02 C03 C04 C05 C06 C07 C08 C09
#    C10 C11 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C27 C28 C29 C30 C32 C34 C36
#    C37 C39 C40 C41 C42 C43 C44 C45 C46
#-----------------------------------------------------------------------------------------------
POS_X    ABPO       4097216.5051        -0.0041      0.0012  59946      0.00 59946 86100.00   1   0      13236
POS_Y    ABPO       4429119.2554         0.0032      0.0013  59946      0.00 59946 86100.00   1   0      13236
POS_Z    ABPO      -2065771.1444        -0.0035      0.0007  59946      0.00 59946 86100.00   1   0      13236
POS_X    AC24      -3051338.9073        -0.0001      0.0003  59946      0.00 59946 86100.00   2   0       5788
POS_Y    AC24      -1317097.8192        -0.0076      0.0008  59946      0.00 59946 86100.00   2   0       5788
POS_Z    AC24       5425614.1058        -0.0047      0.0014  59946      0.00 59946 86100.00   2   0       5788
POS_X    ALIC      -4052052.8453         0.0164      0.0011  59946      0.00 59946 86100.00   3   0      15812
POS_Y    ALIC       4212835.9434        -0.0293      0.0012  59946      0.00 59946 86100.00   3   0      15812
POS_Z    ALIC      -2545104.4249         0.0032      0.0007  59946      0.00 59946 86100.00   3   0      15812
```

Fig.24 Example of piled parameter file.

(15) Rotation matrix file: "rot_$yyyy$doy". The meaning of the data in the file refers to the data header.

```
  MJD    SOD           ROT(1,1)                ROT(1,2)                ROT(1,3)
 ROT(2,1)                ROT(2,2)                ROT(2,3)                ROT(3,1)
   ROT(3,2)                ROT(3,3)                GMST                    XPOLE
      YPOLE            DAT
 59946      0.00  -0.190927973148710D+00  -0.981601552791426D+00   0.221373593412786D-02   0.98
1603968456925D+00  -0.190928385693880D+00   0.254154695030714D-04   0.397717163926428D-03   0.
217786450213445D-02   0.999997549360631D+00   0.176804793386820D+01   0.284869357689287D-06
0.977122584840375D-06 37
```

Fig.25 Example of rotation matrix file.

(16) Arc file: "*.arc". '*' denotes observation file. The data contained in this file includes arc identification, satellite name, start epoch, end epoch, identification, and accumulated receiver clock jumps for two frequencies.

```
%Start Time(mjd sod):  59946      0.00
%E n d Time(mjd sod):  59946  86100.00
%Inteval(seconds): 300
%Cutoff(degree):   7.00
%SAT  BadNum  JmpNum  ObsNum  UseNum  Percent(%)
%G04       1       1     110     108     98.18
%G11       0       0      81      81    100.00
%G14       3       0      69      66     95.65
%G18       0       1     107     107    100.00
%G23       0       0      70      70    100.00
%SUM       4       2     437     432     98.86
%End of Header
ARC  G04       2       54  ARC         0.000         0.000
ARC  G04      81      135  ARC         0.000         0.000
ARC  G11     118      120  ARC         0.000         0.000
ARC  G11     121      198  ARC         0.000         0.000
ARC  G14      65      130  ARC         0.000         0.000
ARC  G18       1       23  ARC         0.000         0.000
ARC  G18      24       30  ARC         0.000         0.000
ARC  G18     182      241  ARC         0.000         0.000
ARC  G18     272      288  ARC         0.000         0.000
ARC  G23     196      265  ARC         0.000         0.000
```

Fig.26 Example of arc file.

(17) Residual file: "*.res". The first line in this file includes site number, satellite number, start time (MJD and second of day), and intervals. From second line, the data in this file includes epoch number, site name, satellite name, observation type, residual value, and observation weight.

```
  1  31   59946      0.00000   300.00000
288 MRC1 G30 L    -0.00412     1.00000
288 MRC1 G30 P    -0.45348     0.00010
288 MRC1 G21 L     0.00549     1.00000
288 MRC1 G21 P     1.78002     0.00010
288 MRC1 G19 L     0.01693     0.36922
288 MRC1 G19 P     1.82293     0.00004
288 MRC1 G17 L    -0.00098     1.00000
288 MRC1 G17 P     0.23893     0.00010
288 MRC1 G14 L     0.00565     1.00000
288 MRC1 G14 P    -0.90919     0.00010
288 MRC1 G13 L    -0.01936     0.20894
288 MRC1 G13 P    -1.61155     0.00002
288 MRC1 G08 L     0.00021     0.22129
288 MRC1 G08 P    -1.97463     0.00002
288 MRC1 G07 L    -0.01166     1.00000
288 MRC1 G07 P    -1.48861     0.00010
288 MRC1 G01 L     0.00350     1.00000
288 MRC1 G01 P    -0.99387     0.00010
```

Fig.27 Example of residual file.