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# PRIDE PPP-AR III

## MANUAL

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**Multi-GNSS Precise Point Positioning with Ambiguity Resolution**

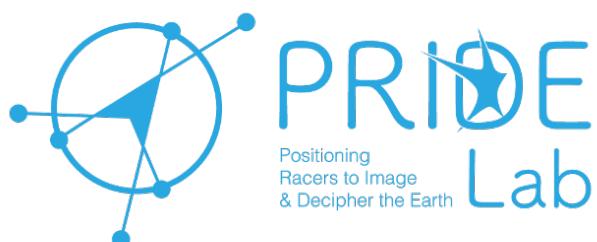
by

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2023-11-24

GNSS Research Center, Wuhan University

**Dedicated to those  
who are devoted to high-precision GNSS**



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# 1 Introduction

## 1.1 Acknowledge

PRIDE PPP-AR (Precise Point Positioning with Ambiguity Resolution) originates in Dr. Maorong Ge's efforts on PPP-AR and later developed by Dr. Jianghui Geng's team. It is an open-source software package which is based on many GNSS professionals' collective work in GNSS Research Center, Wuhan University. We would like to thank them all for their brilliant contributions to this software. No proprietary modules are used anymore in the software. We make this package open source with the goal of benefiting those professionals in their early career, and also advocate the geodetic and geophysical applications of PPP-AR. Especially, we hope that this package can contribute to high-precision applications in geosciences such as crustal motion and troposphere sounding studies. The entire open-source project is funded by the National Natural Science Foundation of China (No. 42025401) and is under the auspices of IAG SC 4.2 "Positioning and Applications".

The open-source software PRIDE PPP-AR introduced in this article can be downloaded from the website <https://github.com/PrideLab/PRIDE-PPPAR>. The precise products required for the software can be downloaded at <ftp://igs.gnsswhu.cn/pub/whu/phasebias/>. Latest updates for Support, Training courses and FAQ can be found at <https://pride.whu.edu.cn>. The copyright of this package is protected by GNU General Public License (version 3). Relevant publications are

- [Geng J, Zhang Q, Li G, et al. Observable-specific phase biases of Wuhan multi-GNSS experiment analysis center's rapid satellite products\[J\]. Satellite Navigation, 2022, 3\(1\): 1-15. doi:10.1186/s43020-022-00084-0](#)
- [Geng J, Wen Q, Zhang Q, Li G, Zhang K \(2022\). GNSS observable-specific phase biases for all-frequency PPP ambiguity resolution. Journal of Geodesy, 96\(11\):1-18. doi:10.1007/s00190-022-01602-3](#)
- [Geng J, Chen X, Pan Y, Zhao Q \(2019\). A modified phase clock/bias model to improve PPP ambiguity resolution at Wuhan University. Journal of Geodesy, 93\(10\):2053-2067. doi:10.1007/s00190-019-01301-6](#)
- [Geng J, Chen X, Pan Y, Mao S, Li C, Zhou J, Zhang K \(2019\). PRIDE PPP-AR: an open-source software for GPS PPP ambiguity resolution. GPS Solutions, 23\(91\):1-10. doi:10.1007/s10291-019-0888-1](#)
- [Geng J, Yang S, Guo J \(2021\). Assessing IGS GPS/Galileo/BDS-2/BDS-3 phase bias products with PRIDE PPP-AR. Satellite Navigation, 2\(1\):1-15. doi:10.1186/s43020-021-00049-9](#)
- [Geng J, Mao S. Massive GNSS network analysis without baselines: Undifferenced ambiguity resolution. J. Geophys. Res. 2021, 126\(10\), e2020JB021558. doi:10.1029/2020JB021558](#)

## 1.2 Major Features

PRIDE PPP-AR aims at post-processing of multi-GNSS data for the science community including geodesy, seismology, photogrammetry, gravimetry, etc. The major features of PRIDE PPP-AR include:

- 1) Multi-GNSS data processing with GPS, GLONASS, Galileo, BDS-2/3 and QZSS;
- 2) All-frequency PPP-AR on any dual-frequency ionosphere-free combinations of GPS, Galileo, and BDS-2/3;
- 3) High-rate GNSS data processing up to 50 Hz;
- 4) High-dynamic mobile platforms applicable for aerial photogrammetry, ship-borne gravimetry, etc;

- 5) Kinematic orbiting for LEO satellites;
- 6) Multi-day processing up to 108 days without day-boundary discontinuities;
- 7) IPPP clock estimation for time and frequency transfer;
- 8) Troposphere modeling with Vienna Mapping Function 1/3 (VMF1/VMF3);
- 9) Second-order ionospheric delay correction with GIM products;
- 10) Receiver clock jump detection and mitigation;
- 11) Adoption of the latest IGS conventions: Bias-SINEX, IGS20 reference frame, ORBEX, RINEX 4, etc.;
- 12) User-friendly operation and visualization for early-career researchers with lite-version GUI;
- 13) Ambiguity-float PPP with backward compatibility from 1994 when selective availability (SA) was on;
- 14) Timely data processing with rapid (RAP) products and real-time archived (RTS) products.

## 1.3 Contact Us

If you encounter any issues during the software usage, you can contact us by sending an email to report **bugs** and seek assistance.

**Email:** pride@whu.edu.cn

**Website:** pride.whu.edu.cn

For Chinese users, we have established a QQ communication group for discussing software-related usage questions. Group Number: **971523302**. Leave your organization and name when applying for admission.

## 2 Version modifications

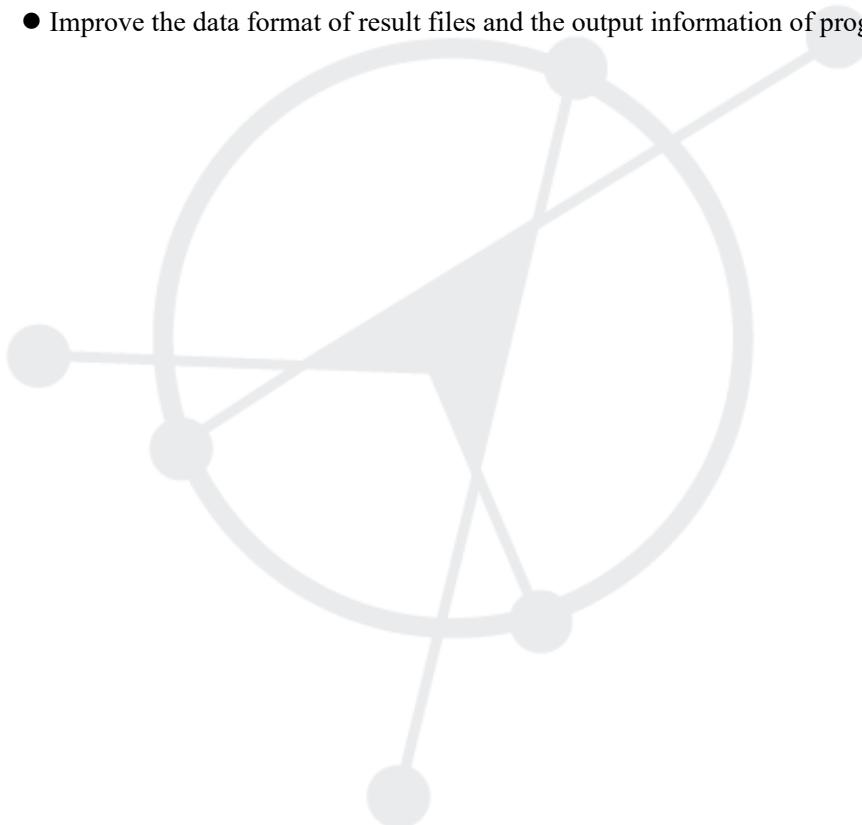
1. 2019-03-21 (v1.0)
  - Release of PRIDE-PPPAR v1.0
2. 2019-04-03 (v1.1)
  - RINEX-3 support
  - Fixed bug for high-rate computation
  - Support Linux-32 system (src/lib/shard/linux-32)
  - Support Mac OS system (src/lib/shard/mac)
3. 2019-05-01 (v1.2)
  - Support VMF1
4. 2019-05-23 (v1.3)
  - Auto-selection of IGS ATX
  - Change SP3 from COD to WHU since 2020
5. 2019-06-01 (v1.3)
  - Add src/utils/xyz2enu
6. 2019-07-12 (v1.3)
  - Support rapid phasebias product
7. 2019-07-16 (v1.4)
  - Add function: receiver clock jump check & recover
  - Print table valid time by pride\_pppar
  - Compatibility fixing for pride\_pppar.sh
8. 2019-09-05 (v1.4)
  - pride\_pppar.sh: small bugs fixed
  - table: igs14.atx updated
9. 2019-12-15 (v1.4)
  - install.sh: add install tips for src/lib/libpridepppar.so
  - pride\_pppar.sh: fix known bugs & add error replay for debug
  - table: jpleph\_de405 updated (valid until 2040-007)
  - table: update IGS14.atx (igs14\_2082.atx)
10. 2021-05-21 (v2.0)
  - Release of PRIDE PPP-AR v2.0
11. 2021-09-06 (v2.1)
  - support quaternions
12. 2022-04-07 (v2.2)
  - Batch script name changed from “pride\_pppar” to “pdp3”, corresponding command line input parameters also changed;
  - Support multi-day processing;
  - Support for quaternion products;
  - No more DCB products required;
  - The default products after 2020 changed to the multi-GNSS satellite orbit, clock, bias, quaternion and ERP (Earth Rotation Parameter) products, which are computed and released by Wuhan University;
  - The table file “leap.sec” needs to be downloaded now, and the “glonass\_chn” table file is

removed and replaced by the “sat\_parameters” table file;

- GUI version of PRIDE PPP-AR with additional plotting functions;

13. 2023-11-24 (v3.0)

- Enable “all-frequency PPP-AR” on any dual-frequency ionosphere-free combinations
- Employ the latest rapid all-frequency phase clock/bias products from Wuhan University to resolve ambiguities on new signals (L5/E6/E5b/E5/B1C/B2a/B2)
- Support orbit determination in kinematic mode for GRACE/GRACE-FO LEO satellites
- Enhance multi-day processing capability and long-term consistency, providing solutions without day-boundary discontinuities
- Offer more estimation models for parameters and command-line options
- Increase compatibility with the latest IGS data and product extensions, including RINEX 4
- Improve the data format of result files and the output information of program runs



## 3 Fundamentals

PPP (Precise Point Positioning) is a technology that uses external precise products (e.g., satellite orbit/clock), comprehensively considers and meticulously models various errors, processes single GNSS (Global Navigation Satellites System) receiver's observation by undifferenced calculation. It was put forward to reduce the huge computing burden of GNSS network solutions due to massive data, it has ushered in rapid development and application. Compared to the relative positioning, the popularity of PPP is that no nearby reference stations are required, the user can achieve high accuracy positioning with only a single receiver. Besides, compared to the SPP (Standard Point Positioning) based on broadcast ephemeris and pseudo-range, PPP takes advantage of utilizing both pseudo-range observations and carrier phase observations, and more precise satellite-related parameters.

PPP integrates the advantage of GNSS SPP and GNSS relative positioning and overcomes their disadvantages to some extent. However, PPP does not eliminate or weaken the influence of various observation errors by difference, so all error terms must be finely considered and corrected. And the number of parameters to be solved is so large that external files need to be introduced. Moreover, the phase bias caused by hardware delay from satellite ends and receiver ends will be absorbed in the ambiguity, the corresponding ambiguity will not be an integer. Therefore, the difficulty of PPP is to separate the phase bias from ambiguity to achieve ambiguity resolution (AR).

### 3.1 Mathematical model of PPP

For GNSS dual-frequency observations from station  $r$  to satellite  $s$ , the raw observation equation for original pseudorange and carrier-phase of the  $i$ -th frequency ( $i = 1, 2$ ) in the unit of length is

$$\begin{cases} P_{r,i}^s = \rho_r^s + c(\delta t_r - \delta t^s) + \frac{A}{f_i^2} + d_{r,i} - d_i^s \\ L_{r,i}^s = \rho_r^s + c(\delta t_r - \delta t^s) - \frac{A}{f_i^2} + \lambda_i N_{r,i}^s + b_{r,i} - b_i^s \end{cases} \quad (3-1)$$

where,  $P_{r,i}^s$  are pseudo-range observations;  $L_{r,i}^s$  are carrier-phase observations;  $\rho_r^s$  is the station-satellite geometric distance;  $c$  is the speed of light in vacuum;  $\delta t_r$  and  $\delta t^s$  are the receiver and satellite clock errors, respectively;  $\frac{A}{f_i^2}$  denotes the impact of the first-order ionosphere delays;  $f_1$

and  $f_2$  are the frequencies of  $L_1$  and  $L_2$ ;  $\lambda_1$  and  $\lambda_2$  are the corresponding wavelength;  $N_1$  and  $N_2$  are integer ambiguities;  $d_{r,i}$  and  $d_i^s$  denote the pseudo-range bias of the  $i$ -th frequency, which is caused by the hardware delay of the receiver and the satellite;  $b_{r,i}$  and  $b_i^s$  denote the phase bias of the  $i$ -th frequency, which is caused by the hardware delay of the receiver and the satellite; for simplicity, high-order ionospheric delay, tropospheric delay, multipath effect and random noise are omitted.

The geometric distance from the satellite to the receiver in equation (3-1) can be expressed as

$$\rho_r^s = |\mathbf{X}^s(t_s) - \mathbf{X}_r(t_r)| \quad (3-2)$$

where,  $t_s$  and  $t_r$  are signal transmission time and signal reception time respectively;  $\mathbf{X}^s(t_s)$  and  $\mathbf{X}_r(t_r)$  is the satellite coordinate vector at the signal transmitting time and the receiver coordinate vector at the signal receiving time respectively;  $|\cdot|$  represents the vector module length.

The first-order ionospheric delay in equation (3-1) can be eliminated by the difference between

the product of the dual-frequency observations and their frequency squares, while the difference between the two frequency squares is divided by the above equation to keep the geometric distance constant. The ionosphere-free observation equation is then formed

$$\begin{cases} P_{r,0}^s = \alpha P_{r,1}^s - \beta P_{r,2}^s \\ \quad = \rho_r^s + c(\delta t_r - \delta t^s) + d_{r,0} - d_0^s \\ L_{r,0}^s = \alpha L_{r,1}^s - \beta L_{r,2}^s \\ \quad = \rho_r^s + c(\delta t_r - \delta t^s) + \alpha \lambda_1 N_{r,1}^s - \beta \lambda_2 N_{r,2}^s + b_{r,0} - b_0^s \end{cases} \quad (3-3)$$

where

$$\begin{cases} \alpha = \frac{f_1^2}{f_1^2 - f_2^2} \\ \beta = \frac{f_2^2}{f_1^2 - f_2^2} \\ \alpha - \beta = 1 \end{cases}$$

and

$$\begin{cases} d_{r,0} = \alpha d_{r,1} - \beta d_{r,2} \\ d_0^s = \alpha d_1^s - \beta d_2^s \\ b_{r,0} = \alpha b_{r,1} - \beta b_{r,2} \\ b_0^s = \alpha b_1^s - \beta b_2^s \end{cases}$$

$P_{r,0}^s$  and  $L_{r,0}^s$  are the ionosphere-free pseudo-range observation and carrier-phase observation, respectively. Correspondingly,  $d_{r,0}$  and  $d_0^s$  are the ionosphere-free pseudo-range bias at the receiver end and the satellite end,  $b_{r,0}$  and  $b_0^s$  are the ionosphere-free combination phase bias at the receiver end and the satellite end respectively.

## 3.2 Error correction of PPP

As mentioned above, PPP uses undifferenced data processing and does not eliminate or weaken the impact of various observation errors through difference. Hence all error terms must be considered finely and corrected as much as possible. Usually, there are two types of error correction: (1) model correction is used for errors that can be finely modeled, such as the correction of satellite antenna PCO/PCV (Phase Center Offset/Variation); (2) for the errors that cannot be accurately modeled, they can be estimated as parameters or eliminated by using combined observations. For example the tropospheric delay after model correction still needs to be estimated by adding parameters, and the low-order term of ionospheric delay error can be eliminated by using dual-frequency combined observations.

In PPP, the main error sources can be divided into three categories: (1) errors related to satellites, (2) errors related to signal propagation paths, and (3) errors related to receivers and stations.

### 3.2.1 Errors related to satellites

#### (1) Satellite ephemeris error and clock error

Satellite ephemeris error refers to the discrepancy between the orbit represented by the satellite ephemeris and the real orbit. For the satellite coordinate vector  $X^s(t_s)$  in equation (3-2), the nominal accuracy of the post precise ephemeris product of IGS (International GNSS Service) is better than 2.5cm. The user can use Lagrange interpolation to calculate the satellite coordinates at the time of signal transmission. The calculation formula of signal transmission time is:

$$t_s = t^r + \delta t_r - \tau \quad (3-4)$$

where  $\tau$  is the signal propagation time. It can be calculated by the geometric distance between the

satellite and the observation station after correcting various errors, and the geometric distance is related to the satellite coordinates, so iterative calculation is required in this process.

Satellite clock error can be eliminated or weakened by utilizing precise satellite clock error products, that is, it can be substituted into the observation equation as a known value. At present, the precision of IGS legacy clock error products has reached 75ps, which can fully meet the needs of PPP.

## (2) Earth rotation correction

Because the earth-fixed coordinate system is rotating with the rotation of the earth, the earth-fixed coordinate system corresponding to the satellite signal transmitting time and the receiver signal receiving time is different. Therefore, it is necessary to consider this correction to calculate the geometric distance from the satellite to the receiver in the earth-fixed coordinate. Set  $\omega$  as the earth rotation angular velocity, and the resulting satellite coordinate change is

$$\mathbf{X}^{s'} = \mathbf{R} \cdot \mathbf{X}^s \quad (3-5)$$

where,  $\mathbf{R}$  is the rotation matrix

$$\mathbf{R} = \begin{bmatrix} \cos\omega\tau & \sin\omega\tau & 0 \\ -\sin\omega\tau & \cos\omega\tau & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The correction of corresponding geometric distance is

$$\Delta\rho = \frac{\omega}{c} [\mathbf{Y}^s(\mathbf{X}_r - \mathbf{X}^s) - \mathbf{X}^s(\mathbf{Y}_r - \mathbf{Y}^s)] \quad (3-6)$$

## (3) Relativistic effects

The relativistic effect is caused by the different states (motion speed and gravity potential) of the satellite clock and the receiver clock. The change of clock frequency caused by different velocities is called the special relativity effect, and the change of clock frequency caused by different gravity potentials is called the general relativity effect. Under the combined influence of the special relativity effect and the general relativity effect, the relative clock error occurs between the satellite clock and the receiver clock, and the satellite clock moves faster than the receiver clock. Its constant part can reduce its standard frequency when producing satellite clock. However, the frequency difference between the satellite clock and the receiver clock is related to the operating speed of the satellite and its distance from the earth center, so there are still residuals after the above correction, which can be corrected by the following formula:

$$\Delta\rho_{rel} = -\frac{2}{c} \mathbf{X}^s \cdot \dot{\mathbf{X}}^s \quad (3-7)$$

where  $\mathbf{X}^s$  is the coordinate vector of the satellite and  $\dot{\mathbf{X}}^s$  is the velocity vector of the satellite. In addition to the frequency drift of satellite clock, the effect of general relativity also includes the delay of the geometric distance caused by the earth's gravitational field, which is called gravitational delay. The corresponding correction can refer to relevant paper.

## (4) PCO/PCV for satellite

PCO of satellite antenna refers to the deviation between satellite center of mass and satellite antenna phase center. The satellite orbit products used in PPP are based on the satellite center of mass and the signal observations are ranging from the phase center of the satellite antenna. For a satellite, PCO can be regarded as a fixed deviation vector.

Because the phase center changes with time during the actual transmission and reception of signals, there is a deviation compared with the average phase center, which is called PCV. It is

necessary to correct the change of phase center in high-precision applications.

#### (5) Phase wind-up

GNSS satellite signal adopts polarization wave. When the satellite antenna or receiver antenna rotates around its longitudinal axis, the carrier phase observation value will change, and its value can be up to one cycle. When the relative rotation occurs between the transmitting antenna and the receiver antenna, the carrier phase observation value will include error. In positioning, after the antenna pointing of the receiver changes, its error will be automatically absorbed into the receiver clock error, so there is no need to consider it. Since the solar panel on the satellite needs to be always aligned with the sun, the satellite antenna will rotate slowly. After entering the eclipse period, the satellite will accelerate the rotation, resulting in the error of carrier phase observation. The influence of phase wind-up on PPP is very obvious, and this error must be taken into account.

### 3.2.2 Errors related to signal propagation path

#### (1) Ionospheric delay

The ionosphere is a dispersive medium, mainly located in the atmospheric area about 70km to 1000km above the earth's surface. In this region, some neutral gas molecules are ionized, producing a large number of electrons and positive ions, thus forming an ionized region. In dispersive media, the propagation velocity of wave is a function of wave frequency. The phase velocity of electromagnetic wave propagation in the ionosphere (the phase velocity of electromagnetic wave with single frequency) will exceed the group velocity (the propagation velocity of a group of electromagnetic wave signals with different frequencies as a whole). Therefore, in the GNSS signal, the pseudo-range code is delayed and the carrier phase is advanced.

As mentioned above, to eliminate and weaken the influence of ionospheric delay, ionospheric correction models and ionospheric grid models can be adopted. In addition, dual-frequency correction can be adopted to eliminate ionospheric delay error through linear combination of observations. After using the dual-frequency observations to eliminate the first-order ionospheric influence, the influence of the remaining high-order terms is very small and can be ignored.

#### (2) Tropospheric delay

The troposphere is the lower part of the atmosphere and is non-dispersive at frequencies above 15 GHz. Tropospheric delay can be divided into dry component and wet component. The common method of tropospheric delay correction in PPP is to correct the tropospheric delay by using the model as a priori value, estimate the residual tropospheric delay as piecewise constant or random walk noise, and map it to the direction of satellite signal propagation path through mapping function. Tropospheric delay can be expressed as:

$$\Delta\rho_{trop} = ZTD_{dry} \cdot M_{dry} + ZTD_{wet} \cdot M_{wet} \quad (3-8)$$

where,  $ZTD_{dry/wet}$  is the zenith tropospheric dry/wet component delay and  $M_{dry/wet}$  is the dry/wet component mapping function.

#### (3) Multi-path effect

The multi-path effect means that if the satellite signal (reflected wave) reflected by the reflector near the measured station enters the receiver antenna, it will interfere with the signal (direct wave) directly from the satellite, to make the observed value deviate from the true value. Multi-path errors vary greatly, depending on the receiver environment, satellite elevation angle, receiver signal processing method, antenna gain type, and signal characteristics.

At present, there is no more effective solution to the multipath effect. The main measures to

weaken the multipath error are: selecting an appropriate station site, equipping the receiver with a diameter suppression plate or circle, appropriately prolonging the observation time, estimating additional parameters, etc. Because the satellite signal with low elevation is more likely to produce multi-path effect, the cut-off elevation can also be set during data preprocessing, and the impact of multi-path effect on precise point positioning can be weakened through long-time observation and smoothing.

### 3.2.3 Errors related to receivers and stations

#### (1) Receiver clock error

Because the receiver generally adopts quartz clock, its stability is worse than satellite clock, so the polynomial fitting method is generally not applicable. Instead, the receiver clock of each observation epoch is treated as an unknown parameter. In the process of processing, the receiver clock error is usually regarded as a group of white noise. It should be noted that unlike the calculation of satellite position, the receiver clock error in equation (3-1) of the original observation method needs to be closely estimated, because in the calculation of satellite position, the measurement error is multiplied by the satellite operating speed of 3.9km/s, and the influence of measurement error on geometric distance needs to be multiplied by the vacuum speed of light.

#### (2) Tidal correction

Under the gravitational action of the moon and the sun, the elastic earth surface will produce periodic changes, which is called solid tide. It lengthens the earth in the connecting direction between the earth's center and the celestial body, and tends to be flat in the vertical direction. The influence of earth tide on stations includes long-term migration related to latitude and short-term term mainly composed of daily period and sub-daily period. For the daily solution of PPP, although the periodic error can be basically eliminated, the residual effect can reach 5cm in the horizontal direction and 12cm in the vertical direction.

Ocean loading results from the load of the ocean tides on the underlying crust. The displacement due to the ocean loading is one order of magnitude smaller than the earth tide. In the daily solution of PPP, the impact is mm, when the station is more than 1000km away from the coastline, the impact is negligible. The influence on a single epoch can reach 5cm.

#### (3) PCO/PCV for receiver

When GNSS receiver is used for measurement, the measured position of antenna phase center, and the antenna height is generally measured to the position of ARP (Antenna Reference Point). These two points generally do not coincide. This deviation is called receiver antenna PCO, and the PCO is also inconsistent for signals of different frequencies. It must be considered in PPP data processing.

The phase center of the receiver antenna is not fixed, and its instantaneous phase center changes with the elevation angle, azimuth angle and signal strength of the received signal. Similarly, the difference between the instantaneous phase center and the average phase center of the receiver antenna is called the antenna phase center change, correction is also required, just like the satellite-side PCV.

## 3.3 Undifferenced ambiguity resolution

The hardware delay term in equation (3-1) includes two parts which are the time-invariant part and the time-varying part, i.e.,

$$\begin{cases} d_{r,*} = \Delta d_{r,*} + \delta d_{r,*} \\ d_*^S = \Delta d_*^S - \delta d_*^S \\ b_{r,*} = \Delta b_{r,*} - \delta b_{r,*} \\ b_*^S = \Delta b_*^S - \delta b_*^S \end{cases} \quad (3-9)$$

where, \* is a wildcard character representing observations of different frequencies and their combination.

Another commonly used combined observation in PPP is Melbourne-Wübbena combination.

$$\begin{aligned} L_{r,m}^S &= \lambda_w \left( \frac{L_{r,1}^S}{\lambda_1} - \frac{L_{r,2}^S}{\lambda_2} \right) - \lambda_n \left( \frac{P_{r,1}^S}{\lambda_1} - \frac{P_{r,2}^S}{\lambda_2} \right) \\ &= \lambda_w \left( N_{r,w}^S + \frac{b_{r,1} - b_1^S}{\lambda_1} - \frac{b_{r,2} - b_2^S}{\lambda_2} \right) - \lambda_n \left( \frac{d_{r,1} - d_1^S}{\lambda_1} + \frac{d_{r,2} - d_2^S}{\lambda_2} \right) \end{aligned} \quad (3-10)$$

$\lambda_w = \frac{c}{f_1 - f_2}$  and  $\lambda_w = \frac{c}{f_1 - f_2}$  are the wide-lane wavelength and narrow-lane wavelength

respectively;  $N_{r,w}^S = N_{r,1}^S - N_{r,2}^S$  is the ambiguity of wide-lane. M-W combination eliminates ionospheric delay, geometric distance from satellite to receiver, satellite clock and receiver clock. It is only affected by multipath effect, measurement noise and hardware delay. Because the wide-lane wavelength  $\lambda_w$  is up to 86cm, it is easy to determine its integer ambiguity, that is, the wide lane ambiguity is solved through M-W combination  $L_{r,m}^S$ . The corresponding receiver phase deviation and satellite phase deviation are

$$\begin{cases} b_{r,w} = \lambda_w \left( \frac{b_{r,1}}{\lambda_1} - \frac{b_{r,2}}{\lambda_2} \right) - \lambda_n \left( \frac{d_{r,1}}{\lambda_1} + \frac{d_{r,2}}{\lambda_2} \right) \\ b_w^S = \lambda_w \left( \frac{b_1^S}{\lambda_1} - \frac{b_2^S}{\lambda_2} \right) - \lambda_n \left( \frac{d_1^S}{\lambda_1} + \frac{d_2^S}{\lambda_2} \right) \end{cases} \quad (3-11)$$

After the ambiguity of wide-lane is resolved through M-W combination, we can substitute  $N_{r,2}^S = N_{r,1}^S - \tilde{N}_{r,w}^S$  into ionosphere-free combination equation (3-3) which can then be transformed into

$$\begin{cases} P_{r,0}^S = \alpha P_{r,1}^S - \beta P_{r,2}^S = \rho_r^S + c(\delta t_r - \delta t^S) + d_{r,0} - d_0^S \\ \bar{L}_{r,0}^S = L_{r,0}^S - \beta \lambda_2 \tilde{N}_{r,w}^S = \rho_r^S + c(\delta t_r - \delta t^S) + \lambda_n N_{r,1}^S + b_{r,0} - b_0^S \end{cases} \quad (3-12)$$

where,  $\tilde{N}_{r,w}^S$  denotes the resolved wide-lane ambiguity; and the  $N_{r,1}^S$  in this formula is also called narrow-lane ambiguity;  $\bar{L}_{r,0}^S$  is the ionosphere-free combined carrier-phase observation after correcting the wide-lane ambiguity.

In the process of GNSS data, the ambiguity in the continuous arc is generally constrained as a constant, and the clock error is generally estimated as white noise. In this way, the constant part of the hardware delay is absorbed by the ambiguity parameter, and the time-varying part is absorbed by the clock parameter. Therefore, whether the hardware delay is constant or varies with time, the effect on the ambiguity is to introduce a constant deviation. The key to fixing the un-differenced ambiguity is to separate the constant bias from the integer ambiguity.

There are several methods to fix the undifferenced ambiguity: integer clock model, decoupled clock model, UPD (uncalibrated phase delay) model and phase clock/bias model.

### (1) Integer clock model and decoupled clock model

The basic idea of the integer clock model is to assume that the wide-lane phase bias remains stable in a single day, estimate the wide-lane ambiguity through M-W combination, extract its fractional part from the wide-lane ambiguity estimation as the wide-lane phase bias, and the integer part is the wide-lane integer ambiguity. Then the fixed wide-lane ambiguity is brought into the

ionosphere-free combination to solve the narrow-lane ambiguity. By rounding the resolved narrow-lane ambiguity, the corresponding narrow-lane phase bias is absorbed into the clock parameters. The decoupled clock model is similar to the integer clock model, except that the wide lane phase bias is estimated epoch by epoch. The positioning accuracy of integer clock model is high, but the satellite clock product is incompatible with IGS legacy clock product and DCB (Differential Code bias) product. The decoupled clock model needs to estimate two sets of clock products, which is rarely used by analysis centers and scientific research institutions.

### (2) UPD model

In UPD model, the processing of wide-lane phase bias is the same as that of integer clock model, and the calculation process of narrow-lane phase deviation is consistent with that of wide-lane phase bias. The UPD model directly uses the IGS legacy clock product, but its narrow-lane phase bias is not stable, it needs to be estimated every ten minutes empirically, and the positioning accuracy is lower than the integer clock model.

It should be noted that the IGS legacy clock product is defined as dual-frequency ionosphere-free combined clock. Therefore, in its legacy products, in addition to the real satellite clock, it also includes the hardware bias part of ionosphere-free combination. Considering the weight difference between pseudo-range observation and carrier-phase observation, the clock includes the time-invariant part of pseudo-range bias and the time-varying part of phase bias. Its theoretical form is

$$\begin{cases} \delta t_{r,F} = \delta t_r + \frac{\Delta d_{r,0} + \delta b_{r,0}}{c} \\ \delta t_F^s = \delta t^s + \frac{\Delta d_0^s + \delta b_0^s}{c} \end{cases} \quad (3-13)$$

### (3) Phase clock/bias model

The instability of narrow-lane phase bias in UPD model is considered to be due to the influence of satellite orbit/clock error and residual atmospheric error. Based on integer clock model and UPD model, phase bias/clock calculates the mean value of narrow lane ambiguity in UPD model in a single day and fixes it in subsequent data processing, then re-estimates the clock parameter, and absorbs the residual narrow-lane phase bias relative to the mean value of narrow-lane ambiguity into the clock error parameter. Therefore, the required integer ambiguity and its bias of narrow-lane are the integer part and fractional part of the mean value of narrow-lane ambiguity respectively. The re-estimated clock is the phase clock in the model. In the UPD model, the narrow-lane phase bias between the receiver and the satellite is

$$\begin{cases} b_{r,n} = \Delta b_{i,0} - \Delta d_{i,0} \\ b_n^s = \Delta b_0^s - \Delta d_0^s \end{cases} \quad (3-14)$$

After calculating the daily mean value of narrow-lane ambiguity and its phase bias based on UPD model, taking into account equation (3-13), the clock is re-estimated in the ionosphere-free combination (equation(3-12)), i.e.

$$\begin{cases} P_{r,0}^s = \rho_r^s + c(\delta t_{r,F} - \delta t_F^s) + (\delta d_{r,0} - \delta d_0^k - \delta b_{i,0} + \delta b_0^k) \\ L_{r,0}^s - \lambda n \bar{N}_{r,1}^s + \check{b}_n^s = \rho_r^s + c(\delta t_{r,F} - \delta t_F^s) + b_{r,n} \end{cases} \quad (3-15)$$

where,  $\delta t_{r,F}$  and  $\delta t_F^s$  are receiver clock error and satellite clock error to be estimated, respectively;  $(\delta d_{r,0} - \delta d_0^k - \delta b_{i,0} + \delta b_0^k)$  is the residual term, which will be absorbed into the pseudo-range residual and it can be ignored; the narrow lane phase bias at the receiver end  $b_{r,n}$  will be absorbed by the receiver clock error  $\delta t_{r,F}$ .

Accordingly, the user's mathematical model for PPP-AR using phase bias/clock model is as

follows:

$$\begin{cases} L_{r,m}^s + \hat{b}_w^s = \lambda_w N_{r,w}^s + b_{r,w} \\ P_{r,0}^s + c\hat{t}_F^s \approx \rho_r^s + ct_{r,F} \\ L_{r,0}^s + c\hat{t}_F^s - \beta\lambda_2 \tilde{N}_{r,w}^s + \hat{b}_n^s = \rho_r^s + ct_{r,F} + \lambda n N_{r,1}^s + b_{r,n} \end{cases} \quad (3-16)$$

where,  $\hat{b}_w^s$  and  $\hat{b}_n^s$  are the phase bias products of wide-lane and narrow-lane at the satellite end;  $\hat{t}_F^s$  is the satellite clock product; in equation (3-15), the  $(\delta d_{r,0} - \delta d_0^k - \delta b_{i,0} + \delta b_0^k)$  in the ionosphere-free combined pseudo-range observations is ignored here. The narrow-lane phase bias  $b_{r,n}$  at the receiver end will be absorbed by the receiver clock  $\delta t_{r,F}$ .

In the data processing, first fix the wide-lane ambiguity by M-W combination, and then wide-lane integer ambiguity, satellite clock and narrow-lane phase bias are brought into the ionosphere-free combination to fix the narrow-lane ambiguity.



# 4 Program structure and algorithm

## 4.1 Program structure

PRIDE PPP-AR software runs according the structure shown in Figure 4-1, the process procedures are divided into three modules, least-squares estimator and integer ambiguity resolution in addition to a data preparation and pre-processing module. The first part, data preparation and pre-processing, prepare table file and precise products for following data process. The **spp** (standard point positioning) module will be used in this part to calculate the prior positions of station. The function of **sp3orb** (SP3 orbit) is to transform SP3 orbit into a self-defined binary format. Then, the software can efficiently access the precise orbit products. In least-squares estimator part, **tedit** is used to make data tentative pre-processing and generate “log-file” to record the RINEX (The Receiver Independent Exchange Format) health diagnosis information. Once got the “log-file”, **lsq** (least-square adjustment) module can realize parameter estimation and output results. Then used **redig** (a posteriori residual diagnosis) module, the residuals can be processed and new “log-file” can be generated. By the iteration of **lsq** and **redig**, data cleaning is completed. If ambiguity is not fixed, the ambiguity-float solution can be obtained. Otherwise, the module named **arsig** (ambiguity resolution at a single receiver) will be used to realize wide-lane and narrow-lane ambiguities resolution. In the next round **lsq** processing, these integer ambiguities will be introduced as hard constraints to achieve ambiguity-fixed solutions.

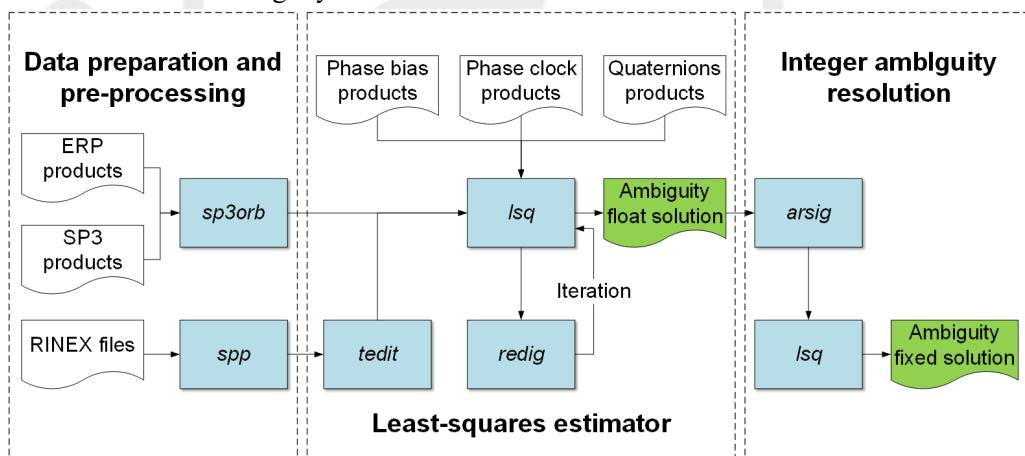


Figure 4-1 Program structure of PRIDE PPP-AR

## 4.2 Modules of PRIDE PPP-AR

The functions and usages of each module of PRIDE PPP-AR are shown below.

- **spp** is used to calculate initial positions of station, if the positioning mode is “S”, the initial position will output to the “sit.xyz” file. Otherwise, if the positioning mode is “K/P/L”, **spp** will also generate “kin\_file” to record coordinates time series. Note: If the positioning mode is “F”, the station coordinates will be fixed to the IGS daily solution.

① S/F Mode:

```
spp -elev 10 -trop saas -ts ${ts} -te ${te} -ti ${interval} ${rinexobs} ${rinexnav}
```

② K/P Mode:

```
spp -elev 10 -trop saas -ts ${ts} -te ${te} -ti ${interval} -o kin_${ydoys[0]}${ydoys[1]}_${site} ${rinexobs} ${rinexnav}
```

③ L Mode:

```
spp -elev 0 -trop non -ts ${ts} -te ${te} -int ${interval} -o kin_${ydoys[0]}${ydoys[1]}_${site}
${rinexobs} ${rinexnav}
```

Where, (Note: Symbol \${} denotes taking a value for the variable).

[-elev]	is optional, up to the elevation angle (unit: °)
[-trop]	is optional, Troposphere correction model. NON: Not correct; saas: saastamoinen model
[-ts]	is optional, start time(format:year/month/day hour:minute:second)
[-te]	is optional, end time(format:year/month/day hour:minute:second)
[-ti]	is optional, sampling rate (Unit: s)
[-o]	is optional, output file. Not specified for static calculation; specified for dynamic calculation, and the results are output to the specified file.
`\${rinexobs}`	is RINEX observation file
`\${rinexnav}`	is RINEX Broadcast Ephemeris file
[-?/-h]	is optional, output information for help

If you want to call the SPP module separately, you can input the command based on the following example.

**Example:** (Note: The folder must contain the corresponding O and N files, and the ts and te parameters should be within the time range of the observation files.)

① S/F Mode:

Input (command line):

```
spp -elev 10 -trop saas -ts 2023/06/30 00:00:00 -te 2023/06/30 23:59:59 -ti 30 abmf1810.23o
brdm1810.23p
```

Output (command line):

```
Position : 2919786.1342 -5383745.6171 1774604.6673
Duration : 2023 06 30 00 00 0.00 86370.00
```

② K/P Mode:

Input (command line):

```
spp -elev 10 -trop saas -ts 2023/06/30 00:00:00 -te 2023/06/30 23:59:59 -ti 30 abmf1810.23o
brdm1810.23p -o kin_2023181_abmf
```

Output: The file kin\_2023181\_abmf contains the calculated results for all epochs.

③ L Mode: The same as in ② K/P mode.

- **sp3orb** transforms SP3 orbit files into a self-defined binary format. Then, the software can efficiently access the precise orbit products. In addition, the reference frame is changed from an earth-fixed system into an inertial system through the ERP file.

**sp3orb \${sp3} -cfg \${ctrl\_file}**

Where, (Note: Symbol \${} denotes taking a value for the variable).

`\${sp3}`	is SP3 file
-cfg \${ctrl_file}	is configuration file

- **tedit** module is used to detect cycle jumps and receiver clock jumps, remove short piece of data and identify data gaps. This module can release the “log-file”, which can reflect the health condition of RINEX file. It should be noted that we do not repair cycle slips but just mark and record them in the ‘log’ file, for further processing.

① S/F Mode:

```
tedit ${rinexobs} -time ${ymd[*]} ${hms[*]} -len ${session} -int ${interval} -xyz ${xyz[*]} -short
1200 -lc_check only -rhd ${rhd_file} -pc_check 300 -elev ${cutoff_elev} -rnrxn ${rinexnav} -freq
${freq_cmb} -trunc_dbd ${tct_opt}
```

② K/P/L Mode:

```
tedit ${rinexobs} -time ${ymd[*]} ${hms[*]} -len ${session} -int ${interval} -xyz
kin_${year}${doy}_${site} -short 120 -lc_check no -elev ${cutoff_elev} -rhd ${rhd_file} -rnxn
${rinexnav} -freq ${freq_cmb} -trunc_dbd ${tct_opt}
```

Where, (Note: Symbol \${} denotes taking a value for the variable).

\${rinexobs}	is RINEX observation file
\${rinexnav}	is RINEX broadcast ephemeris file
[-time]	is optional, start time(format:year/month/day/hour/minute/second)
[-len]	is optional, session time of data processing (Unit:s)
[-int]	is optional, data processing interval (Unit:s)
-xyz	S/F Mode:Initial coordinates; P/K/L Mode:Initial 'kin_*' file
[-short]	is optional, data piece shorter than this value will be cut
-lc_check	is combination of cycle slips detection methods
-pc_check	checking the consistency of the receiver clock difference
[-elev]	is optional, cut-off elevation (Unit: °). The default value is 0
[-rhd]	is optional, the output RHD file
[-freq]	is optional, choose frequency combination. Default is "G12 R12 E15 C26 J12"
[-trunc_dbd]	is optional, whether to truncate ambiguities at the day-boundary. Options include "yes" or "no," with the default value being "no"

- **lsq** is the estimator based on least-squares principle. In this module, we use the ionosphere-free combination to eliminate the first-order ionospheric delay. The module of **lsq** is used to process raw measurements and estimate unknown parameters such as positions, receiver clocks, tropospheric delays and ambiguities. It is the core part of PRIDE PPP-AR, after least-squares adjustment, we can obtain “pos-file” (or “kin-file”), “rck-file”, “ztd-file”, “htg-file”, “res-file” and “amb-file”.

**lsq \${config} \${rinexobs}**

Where, (Note: Symbol \${} denotes taking a value for the variable).

\${config}	is configuration file for current project
\${rinexobs}	is RINEX observation file

- **redig** module can make new ambiguities according to the jumps within epochs. Besides, it can remove the huge residuals and remove the short periods. **redig** module updates “log-file” by reading “res-file” from lsq module. To clean the observations, the **lsq** and **redig** need to be iterated continuously.

**redig res\_\${year}\${doy} -jmp \$jump -sht \$short -pce**

Where, (Note: Symbol \${} denotes taking a value for the variable).

res_\${year}\${doy}	is residual file generated by lsq
[-jmp \$jump]	is optional, if the difference of residuals between adjacent epochs is greater than \$jump, it is marked as a new ambiguity
[-sht \$short]	is optional, if the effective time of ambiguity is less than \$short, the corresponding observation data will be deleted
[-pce]	is optional, quality control for satellite's data

- **arsig** module is used to realize wide-lane and narrow-lane ambiguity fixed. Firstly, the float wide-lane ambiguities generated from **lsq** module are fixed to the nearest integer using a bootstrapping method. Secondly, used ionosphere-free combination ambiguities and fixed wide-lane ambiguities,

float narrow-lane ambiguities can be fixed by LAMBDA (Least-squares Ambiguity Decorrelation Adjustment) method in short observation sessions or be fixed directly to their nearest integers like wide-lane. Thirdly, with the fixed wide-lane and narrow-lane ambiguities (these constraint information is written in “cst-file”), users use *Isq* module to realize ambiguities fixed PPP solutions.

**arsig \${config}**

Where, (Note: Symbol \${} denotes taking a value for the variable).

**\${conifg}**                          is configuration file for current project

## 4.3 pdp3 batch script

*pdp3* is the batch script for PPP processing by PRIDE PPP-AR, which automatically processes GNSS data according to command line parameters. The user needs to ensure that the command line parameters are entered correctly and the configuration file is modified. *pdp3* contains the information of processing procedures, you can read the script for more details.

The three basic configuration parameters in the "Basic Setting" section of the script can be modified by users as needed.

### 1. Debugging Settings

**DEBUG=NO**                          Should results files be kept in case of program execution failure.

**YES**                                  Results files are kept in case of program execution failure.

**NO(Default)**                      Results files are deleted in case of program execution failure.

### 2. Offline Settings

**OFFLINE=NO**                      Should requests for updating/downloading files be skipped to save processing time in offline mode.

**YES**                                  Skip requests, automatic downloading of broadcast ephemeris and precise products, etc., is not possible.

**NO(Default)**                     Do not skip requests, automatic downloading of broadcast ephemeris and precise products, etc., is possible.

### 3. Product Settings

**USECACHE=YES**                    Whether to use precision products and some table files under the local path

**YES(Default)**                    If there are corresponding files in the product directory/table directory, copy them to the working directory, otherwise, the corresponding files will be downloaded.

**NO**                                 Download the corresponding file directly and do not match under the local path.

- The **main()** function is the entry of the script, and its flow is as follows:

1. Analyze command line parameters, check executable programs and required system tools;
2. Define and initialize variables;
3. Output configuration information to the screen;
4. Determine the project directory structure based on the input time span;
5. Call the **ProcessSingleSession()** function based on input parameters to start the computation.

- The **ProcessSingleSession()** function is used to handle the observation data for a single session, and its flow is as follows:

1. Initialization, including variable definition and assignment, copying configuration files to the current directory, etc;
2. Call **PrepareTables()** function to prepare the required table files; call **PrepareRinexNav()** function to prepare the broadcast ephemeris; call **PrePareProducts()** to prepare the required precision products;

3. If the positioning mode is for low Earth orbit satellite tracking, then prepare the necessary low Earth orbit satellite antenna data;
4. Call sp3orb to convert the orbit product to binary;
5. Call ProcessSingleSite() for single station data processing.

● ***PrepareTables()*** for preparing table files, and its flow is as follows:

1. Link the local files in the tale directory to the current directory;
2. Prepare the leap seconds file “leap.sec”;
  - (1) Checking whether the leap seconds file in the current directory accompanies the software (marked with \* in the first line);
  - (2) Download the leap seconds file if it does not match or if the leap seconds file does not exist in the current directory;
  - (3) If the download is failed, copy the leap seconds file from the table directory to the current directory;
  - (4) If the download is successful and does not match the leap seconds file in the table directory, replace the leap seconds file in the table directory with the downloaded leap seconds file.
3. Prepare satellite parameters file “sat\_parameters”.
  - (1) Check the time lag of the satellite parameter files in the current directory;
  - (2) Download satellite parameter files if it's lagging or does not exist in the current directory;
  - (3) If the download is failed, copy the satellite parameter file from the table directory to the current directory;
  - (4) If the download is successful and does not match the satellite parameter file in the table directory, replace the satellite parameter file in the table directory with the downloaded satellite parameter file.

● ***PrepareRinexNav()*** for preparing broadcast ephemeris:

1. If processing today's data, download and merge the hourly GPS broadcast ephemeris and hourly GLONASS broadcast ephemeris;
2. If there is no broadcast ephemeris in short naming format in the data directory, match the broadcast ephemeris in long naming format starting with “BRDC00IGS\_R\_”, “BRDC00IGN\_R\_” and “BRDM00DLR\_S\_”;
3. If neither short-name format nor long-name format is available, then download the broadcast ephemeris;
  - (1) Downloading the multi-system broadcast ephemeris if it is after 2016;
  - (2) Failure of multi-system broadcast ephemeris downloads or processing of pre-2016 data, downloading of GPS and GLONASS broadcast ephemeris and merging them.
4. Checking that the required satellite systems are available in the broadcast ephemeris.

● ***PrepareProducts()*** for preparing products, and its flow is as follows:

1. Determine the directory where the precise products are located according to the “Product directory” in the configuration file, if it is not modified, i.e. Default, create a “product” directory under the year directory, where the precise products are located in the “common” subdirectory, the VMF1/VMF3 required grid files are located in the “vmf” subdirectory, the ionosphere grid files are located in the “ion” subdirectory, the SINEX files are located in the “ssc” subdirectory, and the low earth orbit satellite products are located in the “leo” subdirectory;
2. Prepare precise orbit, precise clock error and ERP products, and merge them into one file if there are multiple files;
  - (1) Copy the corresponding product from the products directory to the current directory if it is not the default product;
  - (2) If it is the default product and there are corresponding files in the products directory, copy them to the current directory;
  - (3) If it is the default product and there are no corresponding files in the products directory, download the corresponding files; the default download of Wuhan University Rapid Product (WUM0MGXRAP) product after 001 days in 2020; For 2019 and earlier, the default download is the IGS Third Reprocessing Combined Product (IGS2R03FIN);
  - (4) If the Wuhan University Rapid Product (WUM0MGXRAP) is not available, then download the Wuhan University Real-time Archive Product (WUM0MGXRTS). The update frequency for the Wuhan University Real-time Archive Product is 3 hours, which is shorter than the 24 hours for the

- Rapid Product, but it has slightly lower accuracy and does not currently provide quaternion products and phase bias products.
3. Prepare quaternions products and phase bias products, and merge them into one file if there are multiple files;
    - (1) Copy the corresponding product from the products directory to the current directory if it is not the default product;
    - (2) If it is the default product and there are corresponding files in the products directory, copy them to the current directory;
    - (3) If it is the default product and there are no corresponding files in the products directory, download the corresponding files; the default download of Wuhan University Rapid Product (WUM0MGXRAP) product after 001 days in 2020; For 2019 and earlier, the default download is the IGS Third Reprocessing Combined Product (IGS2R03FIN).
  4. Check Low Earth Orbit Attitude Files (only available in positioning mode L);
    - (1) If you are not using default products, copy the corresponding products from the product directory to the current directory;
    - (2) If you are using default products and there are corresponding files in the product directory, copy them to the current directory;
    - (3) If there are no corresponding files when processing GRACE/GRACE-FO, you need to manually invoke `prepare_leodata.sh` to download the low Earth orbit products.
  5. Prepare antenna correction files. (the Antenna Exchange Format, ANTEX);
    - (1) The antenna correction file is related to the precise product being used;
    - (2) If using standard precise products, use the ANTEX file defined in the "SYS / PCVS APPLIED" section of the clock bias header file;
    - (3) If using CODE products (COD0MGXRAP/COM) in IGS14 framework, use M14.ATX or M20.ATX;
    - (4) If none of them of (2) or (3), the latest IGS ANTEX file will be used by default.
  6. Copy or download the solution file if the positioning mode is F; copy or download the IONEX file if higher-order ionosphere correction is performed; download the atmospheric corresponding grid file if the VMF1/VMF3 mapping function is used.
  - The process of `ProcessSingleSite()` function is used to process data for a single station, and its flow is as follows:
    1. Initialization, including variable definition and assignment, getting configuration options, etc.;
    2. Call the `ComputeInitialPos()` function to calculate an initial coordinate and output the obtained coordinates to `sit.xyz`.
    3. If the positioning mode is not L, call the `xyz2blh()` function to check if the h-coordinate of the `sit.xyz` result for the station is within the range of -4km to 20km from the Earth's surface, which is the normal ground station coordinate range.
    4. Invoke `tedit` for data pre-processing based on the positioning mode and related configuration information
    5. Call `lsq` and `redig` iterations for residual editing to identify residual cycle slips until no new ambiguities and observations are censored
    6. If the command-line parameters are not specified for float solutions and signal bias products exist, call `arsig` to fix ambiguity, and then call `lsq` to adjust again; otherwise, end the calculation to get only the ambiguity-float solution.

In addition, for users who can't solve online, you can refer to the `PrepareTables()`, `PrepareRinexNav()` and `PrepareProducts()`, which has the download address of those external files. You can pick out these three functions and modify them as scripts for downloading files. Users can download and place them in the corresponding directory. See Appendix A for a brief description of these required external files.
  - Files that need to be placed in the data directory:
    1. Broadcast emphasis  
Hourly: [ftp://igs.gnsswhu.cn/pub/gps/data/hourly/](http://igs.gnsswhu.cn/pub/gps/data/hourly/)

- Daily: <ftp://igs.gnsswhu.cn/pub/gps/data/daily/> or <ftp://igs.ign.fr/pub/igs/data/>
- Files that need to be placed in the “common” subdirectory of the product directory:
    1. Software default “WUM0MGXRAP\_” and “WUM0MGXRTS\_” precise products:  
<ftp://igs.gnsswhu.cn/pub/whu/phasebias/>
  - Files that need to be placed in the “ion” subdirectory of the product directory:
    1. IONEX maps: <ftp://ftp.aiub.unibe.ch/CODE>
  - Files that need to be placed in the “vmf” subdirectory of the product directory:
    1. Tropospheric grid file  
VMF1: [http://vmf.geo.tuwien.ac.at/trop\\_products/GRID/2.5x2/VMF1/VMF1\\_OP](http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP)  
VMF3: [http://vmf.geo.tuwien.ac.at/trop\\_products/GRID/1x1/VMF3/VMF3\\_OP](http://vmf.geo.tuwien.ac.at/trop_products/GRID/1x1/VMF3/VMF3_OP)
  - Files that need to be placed in the “ssc” subdirectory of the product directory:
    1. SINEX file: <ftp://igs.gnsswhu.cn/pub/gps/products/> or <ftp://nfs.kasi.re.kr/gps/products/> or <ftp://gssc.esa.int/cddis/gnss/products/>
  - Files that need to be placed in the “leo” subdirectory of the product directory:
    1. ORBEX format low orbit attitude file named lat \${year}\${doy}\_site
    2. Precision scientific orbit (optional), used for the initial coordinate values of GRACE/GRACE-FO satellites and the drawing of orbit accuracy time series diagrams, named in pso format \${year}\${doy}\_site

*Note:* GRACE/GRACE-FO satellite products can use prepare\_leodata.sh script to download; but other low orbit satellite products need to be downloaded and prepared by yourself, and named correctly.
  - Files that need to be placed in the table directory:
    1. ANTEX file: [https://files.igs.org/pub/station/general/pcv\\_archive/](https://files.igs.org/pub/station/general/pcv_archive/)
    2. Leap second file: <ftp://igs.gnsswhu.cn/pub/whu/phasebias/table/>
    3. sat\_parameters file: <ftp://igs.gnsswhu.cn/pub/whu/phasebias/table/>

It should be noted that the default precise products start with “WUMMGXRAP\_”, in which the satellite clock products are located in the “\${year}/clock” directory, the bias products are located in the “\${year}/bias” directory, and the satellite ephemeris, attitude file and ERP file are located in the “\${year}/orbit” directory; in case of high-order ionospheric correction, the IONEX file needs to be downloaded separately; if the mapping function is VM1/VM3, the tropospheric grid files of the current day and the hour before and after need to be downloaded for interpolation; the ANTEX file matched with the default precise product is recorded in the satellite clock product file header. If other products are used, the latest IGS14 ANTEX file at the time of software release is used by default. The SINEX file needs to be downloaded in F mode.

## 4.4 Algorithms for each module

### 4.4.1 spp

*spp* is used to compute the initial coordinates of a station and is the first module called by PRIDE PPP-AR software for data processing. It is an essential step for unfolding data preprocessing tasks. *spp* can calculate the initial coordinates of a station based on user-provided observation files and broadcast ephemeris files, and it can output the calculation results to the command line or in the form of files. When using this module, if there are multiple days of observation files for the same station and corresponding broadcast ephemeris files in the same directory, the software will automatically perform standard single-point positioning for multiple days. The output result files will include results for multiple days.

Regarding the algorithm implementation of the *spp* module, it is adapted from the open-source software RTKLIB. If users are interested in the algorithm implementation, they can visit the following link: <https://github.com/tomojitakasu/RTKLIB> to learn more details. Here, we extend our

heartfelt thanks to the author, Tomoji Takasu, for their contributions.

#### 4.4.2 tedit

As the data pre-processing module of PRIDE PPP-AR, **tedit** is mainly used to check the original observation file and detect the cycle slips and outliers. The main process can be divided into two parts: firstly, check the original observation file and construct the test volume, then identify the outliers in the test volume to determine whether the cycle slips occurs. Finally, the check information is output to the log-file. The data processing flow is shown in the figure below

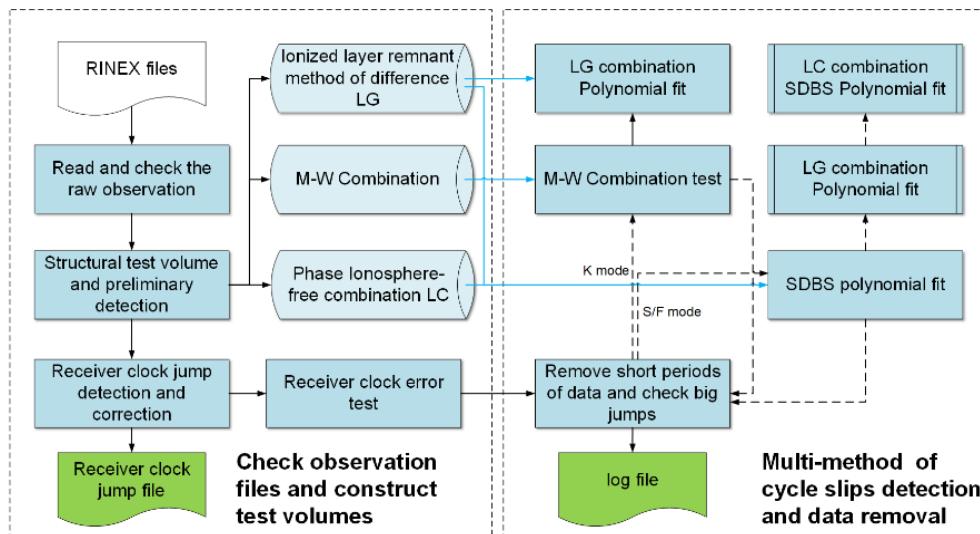


Figure 4-2 **tedit** algorithm flow. (The light blue columns indicate the constructed test volume; the blue line indicates the input of each test volume; the black dashed line indicates the running process controlled by the **pdp3** script and the process is performed only once; SDBS indicates the single difference between satellites)

##### 1. Check the observation file and construct the test volume

Read the original dual-frequency observations on an epoch-by-epoch basis. Calculate satellite elevation, distance between station and satellite, and satellite clock error based on the broadcast ephemeris. Then construct the geometry-free combination  $L_G = \frac{L_1 - L_2}{\lambda_2 - \lambda_1}$ . In this process, the  $L_G$  is initially checked for ionospheric anomalies and cycle slips are detected. Then remove data based on data availability and satellite elevation, etc.

Due to the instability of the receiver clock, the receiver clock error needs to be checked in advance, including the clock jump detection and gross error rejection. Construct the receiver clock jump test volume as follows:

$$R_{i,k} = (P_{i,k} - P_{i,k-1}) - (K_{i,k} - L_{i,k-1}) \quad (4-1)$$

where,  $i = 1, 2$  denotes the frequency number;  $k$  and  $k - 1$  denotes the adjacent non-rejected current and previous epochs. The magnitude of the clock jump check for all satellites in the current epoch is used to determine whether a receiver clock jump occurs in that epoch, and if it exists, the receiver clock jump correction is calculated to the original observation and recorded for subsequent data processing.

The receiver clock error check is required in S/F mode. The receiver clock error test volume is constructed in the following form:

$$\bar{P}_{0,k} = P_{0,k} - (\rho - c\Delta T^s) \quad (4-2)$$

where,  $\rho$  and  $\Delta T^s$  are the distance between station and satellite and the satellite clock error calculated based on the broadcast ephemeris, respectively. This test volume eliminates the geometric distance, satellite clock error, and ionospheric delay, and leaves only the receiver clock error and multi-path effects for pseudo-range, and is therefore used to check for gross error in the receiver clock error. The weighted mean value of this test volume is obtained by median-based robust estimation and compared with a given threshold value to locate and reject the gross error in receiver clock error.

The M-W combination and the phase ionosphere-free combination are constructed, and the cycle slips are initially detected based on the change rate of the M-W combination of adjacent epoch. Based on the results of the above data rejection and cycle slips detection, short piece of data or big gap of adjacent non-rejected ephemerides are identified and marked for subsequent examination.

## 2. Cycle slips detection and data rejection according to the test volume

The *pdp3* script passes different control parameters to *tedit* according to the positioning mode, and different combinations of methods are used in *tedit* for data preprocessing, with only SDBS polynomial fit in S/F mode, and only M-W combination tests in K mode.

For the SDBS polynomial fit, the fitted values are chosen from the difference between the epoch results to facilitate better positioning of the cycle slips and gross error. The process is mainly divided into two parts: firstly, we fit each satellite LG combination, calculate its fitted residuals and RMS(Root Mean Square), mark the satellites that cannot be successfully fitted, count the number of available epoch for each satellite in the fitted arc, and take the satellite with the highest number of available epoch as the reference satellite. Next, the SDBS fitting term is constructed as follows:

$$L_{c,k} = (L_{0,k}^{si} - (\rho^{si} - c\Delta T^{si})) - (L_{0,k}^{sr} - (\rho^{sr} - c\Delta T^{sr})) \quad (4-3)$$

where, *si* and *sr* indicates the current satellite and the reference satellite, respectively. The test volume eliminates the effects of receiver clock error, satellite clock error and geometric distance, leaving only tropospheric delay, ambiguity, multi-path effect and observation noise, etc. The difference between the epoch can eliminate ambiguity and weaken tropospheric delay. The residuals and RMS are calculated by fitting the difference between the epoch results, and the residuals are used to determine whether the cycle slip occurs and mark it. Finally, the fitting results are statistically calculated: (1) to determine whether the current satellite has a cycle slip based on the LC combination SDBS fitting results; (2) to determine whether the reference satellite has a cycle slip based on the LG combination fitting results and the LC combination fitting results.

When testing the M-W combination, the mean and variance of the M-W combination are calculated recursively, and the M-W combination is marked according to the magnitude of the difference between the current epoch and the mean. *tedit* also has a polynomial fitting process for the LG combination to determine whether a cycle slip has occurred according to the fitting residuals and RMS, which is not used at present.

After running the above process, the short piece of data are checked again with the adjacent available epoch with larger intervals. Finally, the detection results and data rejection results are written to the log file, including the information related to the deleted observations and the newly added ambiguity.

### 4.4.3 lsq

*lsq* is based on the generalized least squares principle of the parameter elimination-recovery method for parameter estimation. As shown in the figure below, the data processing process can be divided into three parts: (1) initialization, obtaining configuration information, variable assignment, and the number of statistical parameters; (2) construction of the function model, constructing the parity mathematical model and filling the matrix by epoch, eliminating process parameters (such as receiver clock error) and state parameters (ambiguity parameters) in this process and compressing the normal equation matrix as needed; (3) adjustment, adjustment for the non-eliminated parameters, recovering the eliminated parameters and calculating the residuals, and inputting the results to different result files

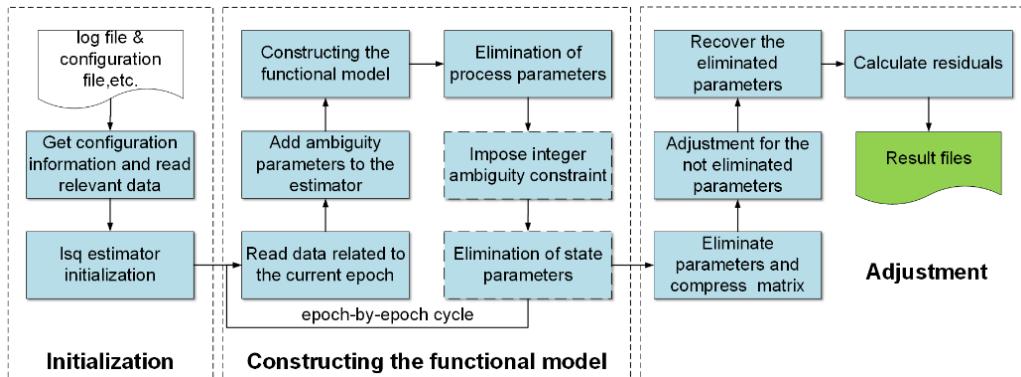


Figure 4-3 *lsq* algorithm flow. (The dashed box part is executed only when the ambiguity parameters is eliminated)

#### 1. Initialization

First, get the configuration information required for *lsq* from the configuration file, such as satellite list, a priori constraints and process noise. S/F mode reads the initial coordinates of the station from the pos\_file or “sit.xyz” file; reads the data in the relevant files, such as the PCO/PCV of the receiver and satellite, and the coordinates of the antenna reference point for the station.

Determine the information about the parameters and normal equation based on the positioning mode and relevant configuration information. The parameters are divided into three categories: constant parameters, process parameters and state parameters; the station coordinates are estimated as constant parameters in S/F mode, the process parameters include station position parameters in K mode, receiver clock error, zenith tropospheric delay parameters and horizontal tropospheric gradient parameters, and the state parameters are ambiguity parameters. If the integer ambiguity resolution method is rounding method, the ambiguity parameters need to be eliminated subsequently; otherwise, if the integer ambiguity resolution method is a search algorithm such as LAMBDA, the ambiguity parameters need to be retained before adjustment to obtain the variance-covariance matrix for integer ambiguity resolution. Thus, different matrix dimensions are assigned according to different integer ambiguity resolution strategies.

Initialize the parameter vector with the normal equation matrix. Based on the stochastic process, the state transfer matrix of STO or PWC (Piece-Wise Constant) is assigned to the unit array and the white noise state transfer matrix to the zero matrix. Based on the generalized least squares principle, the corresponding diagonal elements of the parameters in the normal equation are assigned a priori

weights, i.e.

$$N_{b,b} = \text{diag}([P_x \ P_y \ P_z \ \cdots \ 0]) \quad (4-4)$$

where the ambiguity parameter part will be filled later.

## 2. Constructing the adjustment functional model

Based on the initialized least squares estimator, construct the function model epoch by epoch and fill the corresponding matrix, and some parameters are eliminated in the estimator in this process. First, read the observation data of the current epoch and the corresponding OSB; read the log file with the deleted satellite and new ambiguity information of the corresponding epoch; if the positioning mode is K mode, read the initial coordinates of the current epoch in the kin file; if there is a receiver clock jump in the current epoch, read the receiver clock jump file generated in **tedit** and correct it in the observation value of the current epoch. Same as constant parameters and process parameters, update the information related to the ambiguity parameters of the current epoch to the estimator.

The functional model corresponding to the original observation equation is established based on the satellite constellation selected in the configuration file and existing in the observation file, including the design matrix, OMC (Observed minus calculated) and the weights corresponding to the observations. In this process, the correction of each systematic error is carried out, and the calculated receiver clock error is used as the initial value of the receiver clock error parameter. The functional model of the ionosphere-free observation equation is constructed based on the functional model of the original observation equation, and the M-W combination is composed to calculate the initial value of the wide lane ambiguity, and then calculate the initial value of the ionosphere-free combination ambiguity. Calculate the elements of the normal equation matrix and fill them into the upper triangular matrix, and calculate the OMC weighted sum of squares in the functional model of the ionosphere-free combination for calculating the residual sum of squares.

The state equation in the PPP is extended with the virtual observation equation as in equation (4-5), where the state vector is the process parameter.

$$V = X_k - \Phi X_{k-1} + \omega_k, P_w \quad (4-5)$$

The process parameters of the previous epoch are eliminated, and the information related to the process parameters of the current epoch is added to the estimator according to the state equation. If the integer ambiguity resolution method is the rounding method, the ambiguity parameter needs to be eliminated. If the *lsq* is performed after *arsig*, the SDBS ambiguity “cst\_” file generated in *arsig* is read and appended to the estimator as a strong constraint.

## 3. Adjustment

At the end of the epoch cycle, the remaining integer ambiguity constraint is attached, the process parameters are eliminated, and the remaining ambiguity parameters are also eliminated if the integer ambiguity resolution method is the rounding method, and the normal equation matrix is compressed. The non-eliminated parameters are solved, and the variance of unit weight and the posterior variance of the non-eliminated parameters are calculated.

Recover the eliminated parameters and calculate the residuals, and output the different results to the corresponding result files. S mode writes the position estimation and other information to the “pos\_” file. Count the solvable ambiguity and write it to “amb\_” file. if the integer ambiguity resolution method is LAMBDA method, write the information such as covariance matrix, residual sum of squares and degrees of freedom to “neq\_” file for LAMBDA method to fix the narrow lane ambiguity.

#### 4.4.4 redig

*redig* performs residual editing based on the “log\_” file generated in *tedit* and the “res\_” file generated in *lsq*, deletes the gross error and detects the residual small cycle slips, and its data processing flow is shown in Figure 4-4.

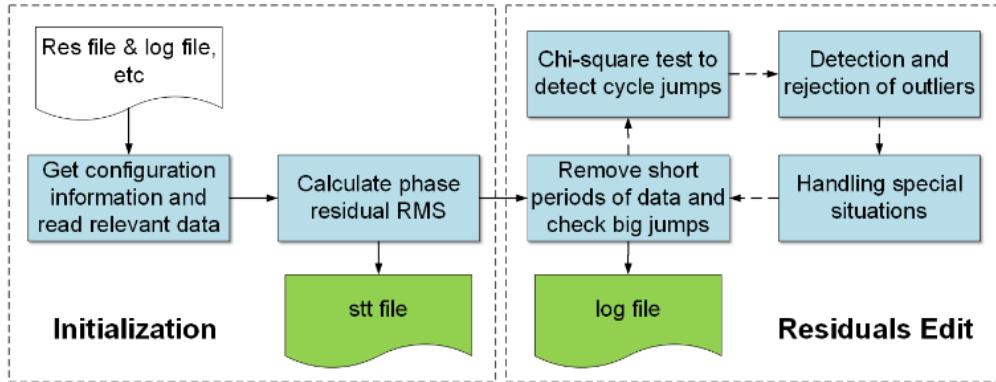


Figure 4-4 *redig* algorithm flow. The black dashed line indicates that the process is executed only once

The initialization section first obtains the configuration information required by *redig*, such as the number of ephemerides, the satellites included and the command line input parameters, etc. Next, the phase residuals in the “res\_” file are read, and the status of existing observations is identified (whether the ambiguity has been established, the observations have been deleted, etc.). The RMS of each satellite phase residual is calculated separately and written to the header of the “stt\_” file, as well as output to the screen, and the time series of each satellite phase residual is written to the “stt\_” file.

After the initialization is finished, the residuals are edited satellite by satellite, firstly checking whether there are short pieces of data and removing them. Secondly, check whether there is residual cycle slip or gross error in the residual time series: (1) calculate the residual difference between adjacent available epochs and its mean and standard deviation, and also calculate the mean and standard deviation after removing the absolute value of the maximum residual difference to detect the jump based on the above calculated value of chi-square test. Repeat the above process until it passes the chi-square test and the maximum residual difference value does not exceed the threshold; (2) if the adjacent available epochs both detect the cycle slips, distinguish the cycle slips from the gross error according to the residual difference value; (3) deal with special cases, such as the last available epoch detects the cycle slip and delete it. Finally, remove the short piece of data after residual editing and update the “log\_” file according to the residual editing result.

#### 4.4.5 arsig

*arsig* uses SDBS to eliminate the hardware delay at the receiver and resolution integer ambiguity for the wide lane and narrow lane, where the wide lane ambiguity is fixed by rounding, and the narrow lane ambiguity can be fixed by the same rounding method when the data processing period is long, otherwise it should be fixed by the LAMBDA method. Its data processing flow is shown in Figure 4-5.

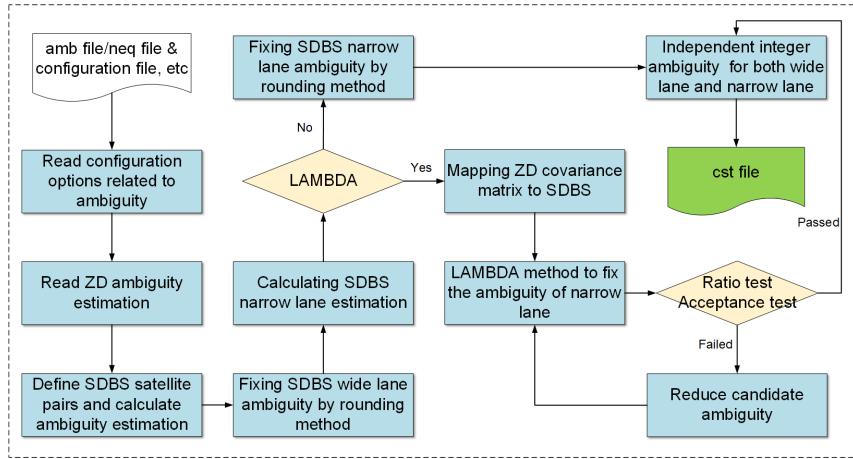


Figure 4-5. *arsig* algorithm flow. ZD indicates the zero difference

As can be seen from the figure, the key in *arsig* is the narrow-lane integer ambiguity resolution method, and all subsequent integer ambiguity resolution methods described refer to the narrow-aisle fuzziness fixation method. Firstly, initialization is performed and the parameters related to integer ambiguity resolution in the configuration file are read. If the integer ambiguity resolution method is rounding, the “amb\_” file is read; if it is the LAMBDA method, the “neq\_” file generated in lsq is read. Based on the available information, all satellite pairs are defined for SDBS, and the real values of SDBS ambiguity and its standard deviation are calculated. And calculate the standard deviation of iSDBS narrow lane ambiguity: LAMBDA method is calculated from the covariance matrix and unit weight variance, and the rounding method is empirical.

If the integer ambiguity resolution method is LAMBDA method, firstly the ZD covariance matrix is mapped to the corresponding SDBS covariance matrix. Secondly, narrow lane integer ambiguity resolution is performed according to LAMBDA algorithm, and acceptance test and ratio test are performed at the end of LAMBDA algorithm. If the test is failed, the number of candidate ambiguity is reduced and the ambiguity is fixed again until it can pass the test as well as meet a certain number of ambiguity. After the successful resolution, the information related to the narrow lane ambiguity is updated and the independent SDBS wide lane and narrow lane integer ambiguity are output to the “cst\_” file.

## 5 Technical Aspects

### 5.1 User Requirements

#### 5.1.1 System Requirements

PRIDE PPP-AR is composed of CUI Apps(Command User Interface Application Programs, CUI Apps). The executable binary CUI APs included in the package require Linux environment. All of the main codes were written in Fortran. A series of tests are conducted on different operating systems with several gfortran versions. The tests results are listed as below (Table 5-1). Note that you can also try other Linux distribution and Fortran compiler, and tell us if you have any problems.

Fortran compiler, such as gfortran needs to be installed before installing PRIDE PPP-AR.

Table 5-1 PRIDE PPP-AR test results in different operating systems.

Platform version	gfortran version	Test result	Notes
Ubuntu14.04.4 (x64)	4.8.4	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference
Ubuntu14.04.4 (x32)	4.8.4	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference
Ubuntu16.04.11 (x64)	5.4.0	pass	Test result is consistent with the reference
Ubuntu16.04.11 (x32)	5.4.0	pass	Test result is consistent with the reference
Ubuntu18.04(x64)	7.3.0	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference
Ubuntu20.04.4(x64)	4.8.4	pass	Test result is consistent with the reference
Ubuntu20.04.4(x32)	4.8.4	pass	Test result is consistent with the reference
Arch Linux (x64)	8.2.1	pass	Test result is consistent with the reference
CentOS 6.5 (x64)	4.4.7	pass	Test result is consistent with the reference
CentOS 7 (x64)	4.8.5	pass	Test result is consistent with the reference
Debian 9.6 (x64)	6.3.0	pass	Test result is consistent with the reference

Debian 8.11 (x64)	4.9.2	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference
MacOS 10.14	10.2.0	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference

## 5.1.2 License

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## 5.2 Installation Guide

### 5.2.1 Structures of PRIDE PPP-AR

The structure of PRIDE PPP-AR is as follows (Table 5-2). We provide a complete set of cases in the “example/” folder for users to execute. The program will be executed automatically, and users do not need to use the files in other folders alone. However, in order to give users a better understanding of the software content, further instructions are given below.

Table 5-2 PRIDE PPP-AR structures

Directory / File	Directory / File	Instructions
\bin		Executable program
	arsig	Ambiguity resolution

	<b>get_ctrl</b>	Get configuration parameters
	<b>lsq</b>	Least squares adjustment
	<b>pbopos</b>	Convert “pos_” files to PBO position series
	<b>redig</b>	Residual editing
	<b>sp3orb</b>	Satellite orbit format and coordinate system conversion
	<b>spp</b>	Standard single point positioning
	<b>tedit</b>	Pre-processing of observation data
	<b>xyz2enu</b>	Convert ECEF position in “kin_file” to ENU
<b>\scripts</b>	<b>Scripts that facilitate data process</b>	
	<b>lat2obx.py</b>	Convert LEO attitude products to ORBEX format
	<b>leoatx.py</b>	LEO antenna information
	<b>merge2brdm.py</b>	Merge GPS and GLONASS broadcast ephemerides to brdm file
	<b>pdp3.sh</b>	Automatic processing Shell script (Linux)
	<b>plotkin2ps0.py</b>	Python script for plotting LEO result
	<b>plotkin.py</b>	Python script for plotting Kinematic results
	<b>plotkin.sh</b>	GMT script for plotting Kinematic results
	<b>plotres.py</b>	Python script for plotting Residuals
	<b>plotres.sh</b>	GMT script for plotting Residuals
	<b>plottrack.py</b>	Python script for plotting track
	<b>plotztd.py</b>	Python script for plotting zenith troposphere delays
	<b>prepare_leodata.py</b>	Prepare the data for low orbit satellites
<b>\src</b>	<b>Source programs</b>	
	<b>arsig/</b>	Ambiguity resolution
	<b>header/</b>	Header files
	<b>lib/</b>	Library functions
	<b>lsq/</b>	Least squares adjustment
	<b>orbit/</b>	Satellite orbit format and coordinate system conversion
	<b>redig</b>	Residuals edit
	<b>spp/</b>	Standard point positioning
	<b>tedit/</b>	Pre-processing of observation data
	<b>utils/</b>	Universal tools
	<b>Makefile</b>	Compile Command
<b>\table</b>	<b>Dependent table files</b>	
	<b>config_template</b>	Configuration file template

	<b>file_name</b>	File names definition
	<b>gpt3_1.grd</b>	External grid file of meteorological parameters file ( $1^{\circ} \times 1^{\circ}$ )
	<b>leap.sec</b>	Leap seconds
	<b>oceanload</b>	Ocean tide loading file
	<b>orography_ell</b>	Global terrain file for VMF1 ( $2.5^{\circ} \times 2.5^{\circ}$ )
	<b>orography_ell_1x1</b>	Global terrain file for VMF3 ( $1^{\circ} \times 1^{\circ}$ )
	<b>sat_parameters</b>	Satellite parameters
	<b>ANTEX files</b>	Provide antenna offset data in need
<b>install.sh</b>		Installation script
<b>ChangeLog.txt</b>		Change log of the software
<b>README.md</b>		Software related information
<b>LICENSE.txt</b>		GPL3 protocol
<b>\doc</b>		<b>Document flag</b>
	<b>logo</b>	The logo printed on screen when installing successfully
	<b>Manual</b>	Manual of the software
<b>\example</b>		<b>Examples</b>
	<b>test.sh</b>	Test script
	<b>\data</b>	Data of examples
<b>\results_ref</b>		Reference results for examples

## 5.2.2 Installation and validation

**Step 1:** Make sure you have installed some essential programs in advance.

i.e. **bash, make, gfortran, wget**

**Step 2:** Run script **./install.sh** to install the program automatically. (This script executes Makefile to build CUI APs and add CUI APs to system PATH (**~/.PRIDE\_PPPAR\_BIN/\***))

If you see the prompt shown in the picture below, the installation is completed normally.

```
.....
.:.:..,. .:.,. .
.:.:.,.....:.. 1-:..,
.:.,.. .:.,.. .:.-.
-:.,. .:.,. -.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.
-:.,. .:.,. .:.

Positioning        .-   o
".,.....":.,".-. /   o
Racers to Image    :-  :-.:/ s:-:./
.....:...:...:...:.. :: ::-s o "o
& Decipher the Earth .+-.:":/-:o-`s--/-.

PRIDE-PPPAR (v3.0) installation successfully completed!
executable binaries are copy to /home/username/.PRIDE_PPPAR_BIN
/home/username/.PRIDE_PPPAR_BIN added to PATH
```

Figure 5-1 successfully installed interface

### Step 3: Input y/Y to run the example.

The script ***test.sh*** in **/example** folder is used to validate the correctness and effectiveness of the installation and execution. The examples of PPP and PPP-AR will be conducted after successfully running ***test.sh***. The data processing procedure is conducted and some information is printed on the screen. After that, results files are created. Then compare the solution files between results and reference results to make sure the software installation is correct and valid.

Five examples are conducted by script ***test.sh***. ‘**static**’ mode denotes that we regard the station as a static station, and estimate only one set of coordinates in the whole observation period. ‘**kinematic**’ denotes that we regard the station as a kinematic station, and estimate one set of coordinates every epoch. ‘**high-rate**’ denotes that we use high-frequency data, and estimate one set of coordinates every epoch. ‘**PPP-AR**’ achieves ambiguity resolution by utilizing code/phase bias products. ‘**PPP-AR LAMBDA**’ denotes the ambiguity resolution process is conducted by **LAMBDA** (Least-squares Ambiguity Decorrelation Adjustment) method.

Table 5-3 PRIDE PPP-AR test examples

Examples	Content
static-24h-fixed	Daily static solution, PPP-AR
kinematic-24h-fixed	Daily kinematic solution, PPP-AR
kinematic-1h-fixed-LAMBDA	Hourly kinematic solution, PPP-AR LAMBDA
highrate-1h-fixed-LAMBDA	High-rate solution, PPP-AR
tropo-24h-fixed	Daily tropospheric solution, PPP-AR

## 5.3 File Specifications

### 5.3.1 Solution Files

After successfully running the test script, the solution files will be moved to the “/example/result” directory, as shown in Table 5-3. The solution files of “static-24h-fixed” are shown in Figure 5-2.

For the positioning results, the static solution stores it in the ‘pos\_’ file, while the kinematic solution stores it in the ‘kin\_’ file. Other kinematic solution files are consistent with static solution.

 amb_2020001_abmf	Ambiguities
 cst_2020001_abmf	Inter ambiguities Constrain(only in fixed solution)
 htg_2020001_abmf	Horizontal troposphere gradient
 log_2020001_abmf	RINEX health diagnosis
 pos_2020001_abmf	Static station coordinate
 rck_2020001_abmf	Receiver clock offset correction
 res_2020001_abmf	Residuals for observation
 stt_2020001_abmf	Phase residual of single satellite
 ztd_2020001_abmf	Zenith tropospheric delay

Figure 5-2 Solution files of “static-fixed-24h”

The solution files header recorded the basic configuration and corresponding file content description. Users can check the corresponding configuration information.

```

abmf
Static      10.000000 10.000000 10.000000
YES
2020 1 1 0 0 0.00
2020 1 1 23 59 0.00
    30.00
    7.00
    0.30
    0.01
WUMOMGXRAP_20200010000_01D_01M_ORB.SP3
WUMOMGXRAP_20200010000_01D_30S_CLK.CLK
WUMOMGXRAP_20200010000_01D_01D_ERP.ERP
WUMOMGXRAP_20200010000_01D_30S_ATT.OBX
WUMOMGXRAP_20200010000_01D_01D_ABS.BIA
SEPT POLARX5
TRM57971.00      NONE
    0.0000      0.0000      0.0000
IGS14_2136
STO
PWC:720
NO
SOLID POLE OCEAN
YES GPS 40 GAL 24 BDS2 2 BDS3 21 QZSS 0
    600.00
    15.00
    0.20 0.15 1000.00
    0.15 0.15 1000.00
    2     4     1.80      3.00
Start Field Description
Name
Mjd
X
Y
Z
Sx
Sy
Sz
Rxy
Rxz
Ryz
Sig0
Nobs
End Field Description
□

```

	STATION
POS MODE/PRIORI	(meter)
OBS STRICT EDITING	
OBS FIRST EPOCH	
OBS LAST EPOCH	
OBS INTERVAL (sec)	
OBS MASK ANGLE (deg)	
MEASUREMENT NOISE PSEUDORANGE (1-SIGMA, meter)	
MEASUREMENT NOISE CARRIER PHASE (1-SIGMA, cycle)	
SAT ORBIT	
SAT CLOCK	
SAT ERP	
SAT ATTITUDE	
SAT BIAS	
SITE RECEIVER TYPE	
SITE ANTENNA TYPE	
SITE ANTENNA E/N/H (meter)	
TABLE ANTEX	
TROP ZENITH	
TROP GRADIENT	
IONO 2ND	
TIDES	
AMB FIXING	
AMB DURATION (sec)	
AMB CUTOFF (deg)	
AMB WIDELANE	
AMB NARROWLANE	
AMB SEARCH	
COMMENT	
STATION NAME	
MODIFIED JULIAN DAY	
X COORDINATE (meter)	
Y COORDINATE (meter)	
Z COORDINATE (meter)	
DIAGONAL COFACTOR OF X COORDINATE	
DIAGONAL COFACTOR OF Y COORDINATE	
DIAGONAL COFACTOR OF Z COORDINATE	
OFF-DIAGONAL COFACTOR OF X AND Y COORDINATES	
OFF-DIAGONAL COFACTOR OF X AND Z COORDINATES	
OFF-DIAGONAL COFACTOR OF Y AND Z COORDINATES	
SQUARE ROOT OF VARIANCE FACTOR (meter)	
NUMBER OF OBSERVATIONS	
COMMENT	
END OF HEADER	

Figure 5-3 Header of solution files

### amb file

The values of float ambiguities are recorded in ‘amb’ file. Running **arsig** will call ‘amb’ file to obtain initial value of ambiguity. The results in the ‘amb’ file are: Pseudo Random Noise code(PRN), ionosphere-free(IF) float ambiguity, wide-lane(WL) float ambiguity, MjdS, MjdE, RMS(IF/WL), mean elevation angle during the valid time.

#### ionosphere-free(IF) ambiguity

PRN	IFamb	WLamb	MjdS	MjdE	RMS(IF/WL)	SigIF	SigWL	Elev
G01	2.306695	-18.409229	58849.0000000000	58849.2135416667	0.0395	0.0092	48.1	
G07	5.622805	11.709663	58849.0000000000	58849.2194444444	0.0662	0.0073	41.3	
G08	1.508260	-30.286970	58849.0000000000	58849.1663194444	0.0813	0.0148	31.0	
G09	14.717519	4.598100	58849.0000000000	58849.1211805556	0.1138	0.0207	21.7	
G11	-5.935466	-23.334870	58849.0000000000	58849.2177083333	0.0573	0.0084	47.5	
G16	-2.598334	-40.271059	58849.0000000000	58849.0899305556	0.0742	0.0206	16.3	
G23	13.192038	12.697517	58849.0000000000	58849.0927083333	0.0837	0.0166	22.9	
G26	4.669495	-42.405466	58849.0000000000	58849.0270833333	0.0811	0.0662	9.9	
G27	0.970959	-28.319515	58849.0000000000	58849.0711805556	0.0735	0.0234	22.4	
R09	11.930558	-7.498517	58849.0000000000	58849.1850694444	0.0327	0.0124	46.2	
R16	16.718429	-34.077357	58849.0000000000	58849.0923611111	0.0462	0.0203	32.8	
R19	31.859371	-26.898176	58849.0000000000	58849.0699097222	0.0568	0.0324	37.5	
R20	-4.151642	-46.309943	58849.0000000000	58849.1555555556	0.0658	0.0152	49.1	
E01	17.832845	-51.689214	58849.0000000000	58849.2482638889	0.0289	0.0050	42.2	

PRN  
wide-lane(WL) ambiguity

mean elevation angle  
during the valid time

Figure 5-4 The ambiguities (‘amb\_’) file

### cst file

Running *arsig*, ‘cst’ file will be produced. ‘cst’ file records the values of integer ambiguity. The header records the total number of observations for each system, fixed observations for wide-lane ambiguity, fixed observations for narrow-lane ambiguity and so on. The contents in the ‘cst’ file are: single-difference(SD) satellites, begin and end time, SD WL/NL ambiguity.

Single-Difference Ambiguity Constraint abmf												COMMENT			
SD												TYPE OF CONSTRAINT			
311	308	271	40	40	40	ROUNDING						G	AMB FIXING (T/W/N)		
G16	G27	2020	1	1	0	0	0.000000	2020	1	1	1	42	30.000000	-12	36
G09	G16	2020	1	1	0	0	0.000000	2020	1	1	2	9	30.000000	45	-128
G23	G17	2020	1	1	1	22	0.000000	2020	1	1	2	13	30.000000	13	-12
G23	G22	2020	1	1	0	3	0.000000	2020	1	1	2	13	30.000000	-7	-22
G08	G09	2020	1	1	0	0	0.000000	2020	1	1	2	54	30.000000	-35	100
G08	G03	2020	1	1	1	50	0.000000	2020	1	1	3	59	30.000000	-18	74
G01	G20	2020	1	1	1	56	30.000000	2020	1	1	5	7	30.000000	-24	94
G01	G09	2020	1	1	4	12	0.000000	2020	1	1	5	7	30.000000	-22	68
G11	G06	2020	1	1	2	58	0.000000	2020	1	1	5	13	30.000000	-26	67
G11	G22	2020	1	1	0	3	0.000000	2020	1	1	5	13	30.000000	-43	71
G07	G02	2020	1	1	4	44	30.000000	2020	1	1	5	16	0.000000	-11	5
G07	G30	2020	1	1	0	49	30.000000	2020	1	1	5	16	0.000000	2	-25
G30	G05	2020	1	1	6	7	30.000000	2020	1	1	6	28	0.000000	0	19
G17	G03	2020	1	1	1	50	0.000000	2020	1	1	6	33	0.000000	12	-45

Constrained satellite  
single- difference(SD) satellites

SD WL/NL ambiguity

Figure 5-5 The integer ambiguities (‘cst\_’) file

### htg file

The parameters in the horizontal troposphere gradient (‘htg\_’) file are: start time (GPS time), end time (GPS time), initial North-South troposphere gradient (m), North-South troposphere gradient correction (m), initial East-West troposphere gradient (m), East-West troposphere gradient correction (m).

YearS	MonS	DayS	HourS	MinS	SecS	YearE	MonE	DayE	HourE	MinE	SecE	HTGCin1	HTGCor	HTGSin1	HTGScor
2020	1	1	0	0	0.000000	2020	1	1	12	0	0.000000	0.000000	0.000110	0.000000	-0.000063
2020	1	1	12	0	0.000000	2020	1	2	0	0	0.000000	0.000000	0.000351	0.000000	-0.000452

start time(GPS time)                                  end time(GPS time)

### log file

The results of RINEX health diagnosis are recorded in ‘log’ file. In the part of the file header, the comment “INTERVAL” denotes interval of the file; the comment “AMB AI DAT-BOUNDARY” denotes the disposal of ambiguity at the day boundary; the comment “AMB MAX/TOT/NEW” denotes max numbers of ambiguity for epochs, total numbers of ambiguity and newly added ambiguity numbers after posterior residual diagnosis, respectively; the comment “EPO AVA/REM/NEW” denotes available numbers of epochs, deleted numbers of epochs and newly added epoch numbers after posterior residual diagnosis, respectively; the comment “EPO AVA/REM/NEW” denotes the number of available epochs, the number of deleted epochs, and the number of newly added epochs respectively; the comment “RES TIME BEG/LEN” denotes the start time and duration of the file(unit: second); the comment “SYS / FREQUENCY BAND” denotes the navigation systems and frequencies used for position solving.

In the part of file body, the line started with “TIM” records the time of health diagnosis data.







(`~/PRIDE_PPPAR_BIN/`). Then you can use these python scripts directly in any directory.

```
cp plotkin.py ~/PRIDE_PPPAR_BIN/
```

Moreover, the python scripts require some modules of python, i.e., NumPy and Matplotlib. The GMT5 is required if you use GMT scripts.

#### Usage of pbopos

***pbopos*** is used to convert PRIDE-PPPAR pos files to PBO position series. The usage of ***pbopos*** is as follows:

```
pbopos site path [x_ref y_ref z_ref]
```

where

site

is the station name

path

is the “pos” file with path

[x\_ref y\_ref z\_ref]

is optional parameter, represent the reference coordinates

#### Usage of xyz2enu

***xyz2enu*** is used to convert the geocentric coordinate to the topocentric coordinate (unit: m). The usage of ***xyz2enu*** is as follows:

```
xyz2enu kin_fl enu_fl [x_ref y_ref z_ref]
```

where

kin\_fl

is the “kin” file

enu\_fl

is user-defined output file name

[x\_ref y\_ref z\_ref]

is optional parameter, represent the reference coordinates. If there is no input, the coordinates mean value of “kin” file will be used

#### Plots of position time series

The ***plotkin.py*** script and the ***plotkin.sh*** script are used to plot position time series of K/P mode.

```
plotkin.py kin_filename png_filename [x_ref y_ref z_ref]
```

```
plotkin.sh kin_filename png_filename [x_ref y_ref z_ref]
```

where

kin\_filename

is the “kin” file

png\_filename

is the PNG format picture name to be saved

[x\_ref y\_ref z\_ref]

is optional parameter, represent the reference coordinates. If there is no input, the coordinates mean value of ‘kin’ file will be used

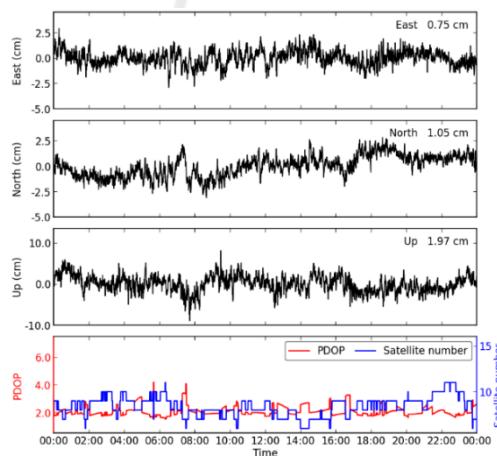


Figure 5-14 Example of *plotkin.py*

#### Plots of residuals

There is a python script and a GMT script for plotting residuals in the ‘scripts’ folder named ***plotres.py*** and ***plotres.sh***.

***plotres.py res\_filename PRN***

***plotres.sh res\_filename png\_filename***

where

***res\_filename***

denotes the “res” file

***PRN***

denotes the satellite will be plotted in *plotres.py*, and the picture will be saved as “PRN.png”

***png\_filename***

denotes the PNG format picture will be saved in *plotres.sh*, and the *plotres.sh* will plot all satellites contained in the ‘res’ file

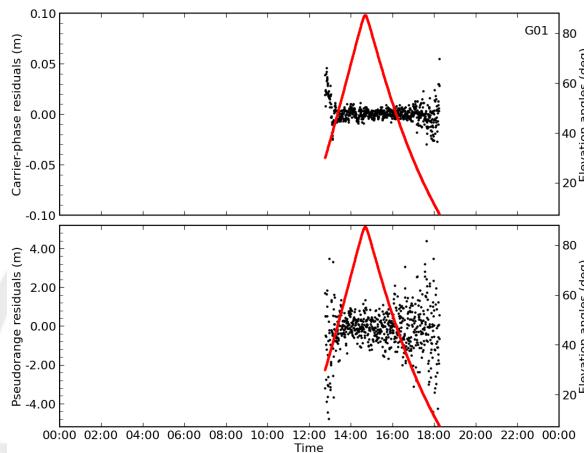


Figure 5-15 Example of *plotres.py*

### Plots of track

Trajectory can also be plotted via ‘kin’ file, i.e., through ***plottrack.py*** we can obtain the required picture.

***plottrack.py kin\_filename png\_filename***

where

***kin\_filename***

is the “kin” file

***png\_filename***

is the PNG format picture name to be saved

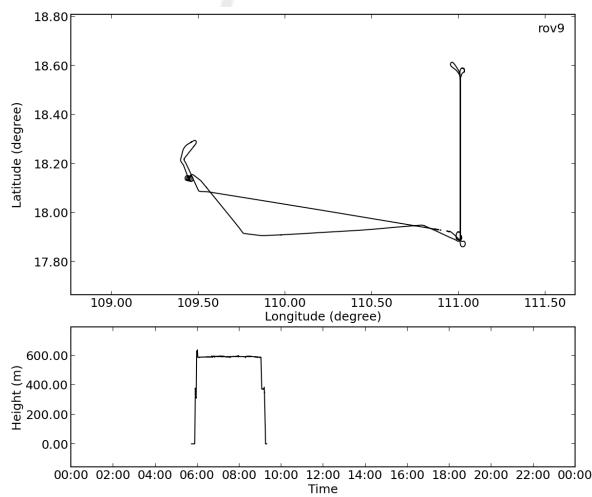


Figure 5-16. Example of *plottrack.py*

### Plots of ZTD

Another plotting script is ***plotztd.py***, the usage of ***plotztd.py*** is as follows.

```
plotztd.py ztd_filename png_filename
```

where

**ztd\_filename** is the "ztd" file

**png\_filename** is the PNG format picture name to be saved

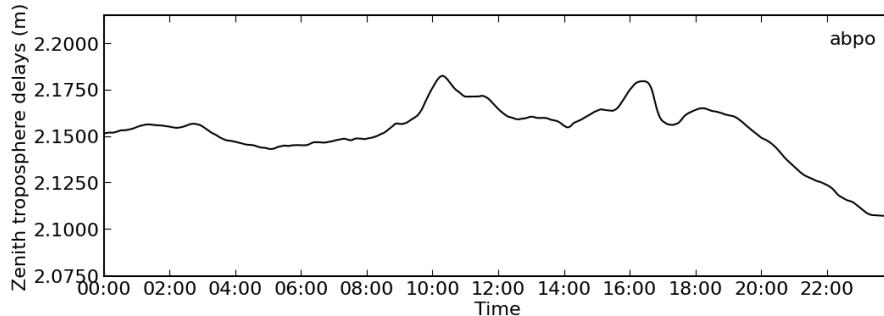


Figure 5-17 Example of *plotztd.py*

### Plots of LEO satellites positio time series

***plotkin2ps0.sh*** is used to plot the time series diagrams of the Low Earth Orbit Satellite in three directions: tangential, radial, and normal. Its usage is as follows

```
plotkin2ps0.py kin_file pso_file png_file
```

where

**kin\_file** is the "kin" file of LEO satellite

**pso\_file** is the "pso" file which records the scientific position of LEO satellite

**png\_file** is the PNG format picture name to be saved

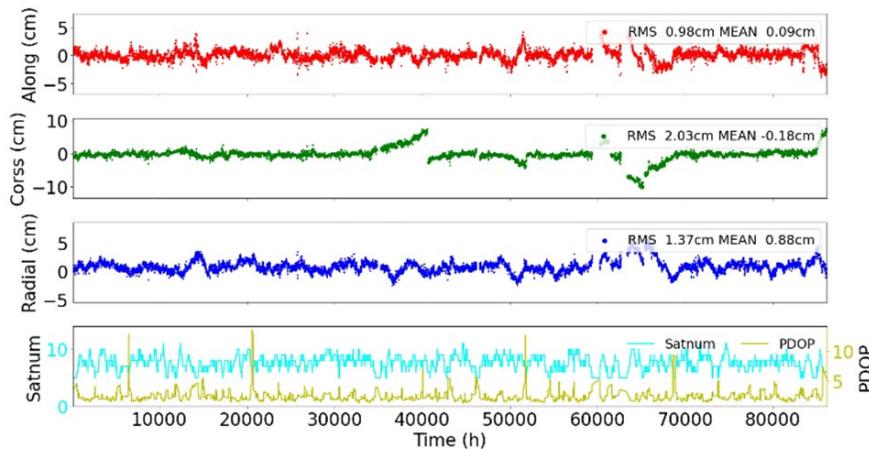


Figure 5-18 Example of *plotkin2ps0.sh*

### Prepare LEO satellites data and products

***prepare\_leodata.sh*** is used to download observation data and products of LEO satellites.

```
prepare_leodata.sh leo_name date
```

where

**leo\_name** is the name of LEO satellite, such as GRACE-FO, GRACE

**date** is the date of the downloaded data, in the format of year/month/day or year/day (day of year)

**Note:** Downloading data will use the format conversion function, and the script will call

lat2obx.py to convert the customized formats of each LEO satellite to ORBEX format. Among them, the GRACE-FO satellite files are ASCII files and do not require format conversion; The GRACE satellite files are custom binary files that need to be converted using the corresponding software (GraceReadSW\_L1-2010-03-31).

### 5.3.3 Table Files

#### Ocean Tide Loading File

In order to obtain ocean tide loading information, you can submit station coordinates to the website (<http://holt.oso.chalmers.se/loading/>) as required. Then copy the ocean-load information to your ocean tide loading file ocean-load. The station coordinates in sit.xyz can be used to calculate ocean tide loading information. The parameters and format of these files are described at the website.

#### File Name Definition File

File names of PRIDE PPP-AR are defined in file “file\_name”. The first column records keyword of output file and following it is the format of file name. In the format, YYYY denotes the year of processing and DDD denotes the day of year. SNAM denotes the station name. For example, “res\_2020001\_abmf” denotes the residual of station abmf in 1st, 2020. The format of “file\_name” is as below (Figure 5-19):

amb	amb_-YYYY--DDD-
cst	cst_-YYYY--DDD-
fcb	fcb_-YYYY--DDD-
htg	htg_-YYYY--DDD-
kin	kin_-YYYY--DDD--SNAM-
neq	neq_-YYYY--DDD-
orb	orb_-YYYY--DDD-
pos	pos_-YYYY--DDD--SNAM-
rck	rck_-YYYY--DDD-
res	res_-YYYY--DDD-
log	log_-YYYY--DDD--SNAM-
rnxo	-SNAM--DDD-0.-YY-o
rnxm	-SNAM--DDD-0.-YY-m
rnxn	auto-DDD-0.-YY-n
sck	sck_-YYYY--DDD-
stt	stt_-YYYY--DDD-
ztd	ztd_-YYYY--DDD-
vmf	vmf_-YYYY--DDD-
tec	tec_-YYYY--DDD-
rck	rck_-YYYY--DDD-
att	att_-YYYY--DDD-

Figure 5-19 Format of ‘file\_name’

#### Global Terrain File

In order to correct the effect of terrain on the results, the global terrain correction file **orography\_ell** which contains coefficients for terrain correction is used, and the grid accuracy is 2.5 degree \* 2.5 degree. The content of another file named **orography\_ell\_1x1** is similar to **orography\_ell**, but the grid precision is 1 degree \* 1 degree.

#### External Grid File

GPT3\_1 is based on a 1 degree \* 1 degree external grid file ('gpt3\_1.grd') with mean values as well as sine and cosine amplitudes for the annual and semiannual variation of the coefficients.

#### Configuration File Template

Records the data processing strategy that is the basis for the operation of the software. Please refer to section 5.4.2 for specific details of the document.

## 5.4 Quick Start and Program Execution

After the software installation is completed, the corresponding executable programs and data processing scripts will be stored in the system path `~/.PRIDE_PPPAR_BIN/*`. Considering the previous command line form of `pdp3` and configuration file is more complex, some adjustments have been made to facilitate users to use PRIDE PPP-AR , but the software is still running based on the configuration file. Before you start, you need to know some considerations:

- 1) Change the way the `pdp3` script runs, so that users can enter command line parameters according to their needs;
- 2) As described in section 5.2.2 Drawing Lines, the three configuration file templates under the software installation directory (`~/.PRIDE_PPPAR_BIN/config_template`) are used by default. If the users needs to modify the rest of the options in the configuration file, the configuration file template from the “table” directory can be used as the basis.

In this section: the package directory is path-to-software; the working directory is path-to-project; the path to the directory where the RINEX observation files and broadcast ephemeris are located is path-to-data; the path to the configuration file is path-to-config; the observation files, broadcast ephemeris and configuration files are: RINEXo, RINEXn and config respectively.

### 5.4.1 Usage of `pdp3`

The usage of `pdp3` is shown in Figure 5-20. For more detailed information, you can entering `pdp3` at the terminal.

```
Usage: pdp3 [options] <obs-file>
All character type arguments could be upper-case or lower-case

Start up:
  -V, --version           display version of this script
  -H, --help               print this help

Common options:
  -cfg <file>, --config <file>      configuration file for PRIDE PPP-AR 2
  -sys <char>, --system <char>       GNSS to be processed, select one or more from "GRC233":
  -----
  G | GPS                  | R | GLONASS
  E | Galileo              | C | BeiDou-2 and BeiDou-3
  2 | BeiDou-2 only        | 3 | BeiDou-3 only
  J | QZSS
  -----
  * default: all GNSS

  -frq <char>, --frequency <char>   frequencies to form ionosphere-free combination, select from:
  -----
  | 1 | 2 | 5 | 6 | 7 | 8 |
  -----
  G | L1 | L2 | L5 |
  R | L1 | L2 |
  E | E1 | E5a | E6 | E5b | E5
  C | B1C | B1I | B2a | B3I | B2b | B2
  J | L1 | L2 | L5 | L6 |
  -----
  input as: "G12 R12 E15 C26 J12" (default setting)

  -m <char>, --mode <char>      positioning mode, select one from "K/S/F/L":
  -----
  S | static    | K | kinematic | F | fixed    | L | LEO sat
  -----

```

Figure 5-20 `pdp3` script partial help information

Except for “**obs-file**”, all other options are optional, and the order of priority is, Command Line Parameters > Configuration File > Default Value. The option name must be entered correctly, and the input parameters can be entered in both upper and lower case, where `<>` indicates that the input parameter is required and `[ ]` indicates that the input parameter is optional. Options can be divided into three categories: (1) Mandatory options; (2) Common options; (3) Advanced options. The meaning of each option is as follows:

**(1) Mandatory options:**

- **obs-file:** RINEX observation file with path, either relative path or absolute path. Note that the broadcast ephemeris needs to be in the same directory as the RINEX observation file. For multi-day processing, all observation files are stored in the same directory, and then the observation file names for the first day are entered. Multi-day processing observation file matching methods include: (1) search for observation files in standard naming format; (2) support for observation files that are directly merged for multiple days.

**(2) Common options:**

- **-V, --version:** output software version.
- **-H, --help:** output pdp3 script help information.
- **-cfg, --config:** configuration file with path, either relative path or absolute path. If this item is not specified, the default matches the configuration file in the installation directory (~/.PRIDE\_PPPAR\_BIN/config\_template).
- **-sys <char>, --system <char>:** Select the GNSS systems involved in data processing by entering one or more of "GREC23J", which means "GPS/GLONASS/Galileo/BDS/BDS-2/BDS-3/QZSS" respectively. When this option is not entered, all satellites of these five systems will be used by default.
- **-frq <char>, --frequency <char>:** select frequency to from ionosphere-free combination. The optional frequencies for GPS system include L1/L2/L5, GLONASS system includes L1/L2, Galileo system includes E1/E5a/E6/E5b/E5, BDS system includes B1C/B1I/B2a/B3/B2b/B2, and QZSS system includes L1/L2/L5/L6. Follow the rule of "system + frequency-label 1 + frequency-label 2" when using. The corresponding relationship between frequency-label and system frequency is shown in Table 5-4.

Table 5-4 Corresponding relationship between frequency-label and system frequency

system \ label	1	2	5	6	7	8
<b>G</b>	L1	L2	L5			
<b>R</b>	L1	L2				
<b>E</b>	E1		E5a	E6	E5b	E5
<b>C</b>	B1C	B1I	B2a	B3	B2b	B2
<b>J</b>	L1	L2	L5	L6		

**Note:** When selecting frequencies, it is necessary to consider the frequency spacing of the selected frequency, which will affect the positioning performance of the linear combination composed of them. The default combination is "G12 R12 E15 C26 J12".

- **-m <char>, --mode <char>:** positioning mode. Options include "S/P/K/F/L". S for the static solution, P for the piece-wise constant solution, K for the kinematic solution, F for the station-fixed solution and L for low earth orbit satellites solution (required corresponding products). If this item is not specified and the configuration file is specified, the positioning mode in the configuration file will be read, otherwise the K mode is used by default.

**Note:** If choose L mode, due to the GRACE/GRACE-FO satellite being equipped with an ultra-stable oscillator, when solving GRACE/GRACE-FO satellite, you can add a "- r s" configuration to specify the receiver clock error as a random walk noise estimation during the calculation to improve the accuracy of the satellite orbit. If choose P mode, the default processing time is 300s. To set different segmented processing times, the unit should be seconds. If choose F mode, the prior

coordinates of the measurement station are required. If the calculation data from an IGS station, the coordinates in the SINEX file are used by default; If you want to use the fixed coordinates set by yourself, you need to create a new "sit.xyz" file in the working directory and add "stename posx posy posz" data to the file. The data meanings are "station name(with the same name as in the O file) fixed X coordinate fixed Y coordinate fixed Z coordinate".

- **-s <date [time]>, --start <date [time]>**: start time for processing, format: "yyyy/mm/dd hh:MM:ss", indicates the year, month, day and hour, minute and second, where "hh:MM:ss" is optional. And can take the form of a yyyy/doy (year and day of year). If this item is not specified, use the first epoch of the observation file as the start time.

- **-e <date [time]>, --end <date [time]>**: end time for processing, format: "yyyy/mm/dd hh:MM:ss", indicates the year, month, day and hour, minute and second, where "hh:MM:ss" is optional. And can take the form of a yyyy/doy (year and day of year). If this item is not specified, the default is to use the last epoch of the observation file as the end time.

- **-n <char>, --site <char>**: four digit and letter combinations for station name. If this item is not specified, Read the station name corresponding to "MARKER NAME" in the observation file header; If the station name is not read, take the first four characters of the observation file name (subject to the standard naming format)

- **-i <num>, --interval <num>**: processing interval. The values range from 0.02s to 30s. If this item is not specified and the configuration file is specified, the processing interval in the configuration file will be read, otherwise, the sampling rate of the observation file is used by default.

### **(3) Advanced options:**

- **-aoff, --wapc-off**: disable APC correction on the Melbourne-Wübbena combination. If this option is not entered, APC correction will be applied. Note that this correction should be consistent with the calculation strategy of the corresponding products. When using products other than "WUMMGX0RAP\_\*", try entering this parameter on the command line if you do not know the calculation strategy of the corresponding products and the fixed rate of the wide lane is low.

- **-c <num>, --cutoff-elev <num>**: The cutoff elevation angle, in the range of 0° to 60°. If this option is not entered, the default is 7°.

- **-f, --float**: No ambiguity resolution and the float solution is calculated. If this option is not entered and there are code/phase bias products the fixed solution is calculated

- **-hion, --high-ion**: use 2nd ionospheric delay model with CODE's GIM product. When this option is not entered, no higher-order ionospheric correction is performed.

- **-hoff, --htg-off**: disable horizontal tropospheric gradient (HTG) estimation. The K mode does not estimate the horizontal tropospheric gradient when this option is not entered, and the S/F mode is PWC:720 (Unit: s, estimated every 12 hours).

- **-l, --loose-edit**: disable strict editing mode, which should be used when high dynamic data quality is poor. If this option is not entered, strict editing is performed by default. Arcs shorter than ten minutes in strict edit mode will be excluded, otherwise two minutes.

- **-p <char>, --mapping-func <char>**: ZTD mapping function. Options include (1) G: GMF mapping function; (2) N: NMF mapping function; (3) V1: VMF1 mapping function; and (4) V3: VMF3 mapping function. GMF mapping function is used by default if this option is not entered.

- **-töff <char>, --tide-off <char>**: disable tide correction, enter one or more of "SOP" for solid, ocean, and polar tides. If this option is not entered, apply all tide corrections.

- **-x <num>, --fix-method <num>**: ambiguity resolution method. Options include: (1) rounding method; (2) LAMBDA method. The default Ambiguity resolution method is LAMBDA method when the processing time is less than 6 hours, otherwise it is the rounding method. The LAMBDA

method should be used when the processing time is short, otherwise the rounding method should be used.

- **-z <char[length] [num]>, --ztd <char[length] [num]>**: the zenith tropospheric delay model and the corresponding process noise parameters (optional). The zenith tropospheric delay model options include: (1) p60/P60: PWC:60, estimated every 1h, where the estimated duration (60) is customizable (needs to be greater than or equal to 60); (2) s/S: STO, stochastic walk noise. This option defaults to sto when not entered. The corresponding process noise parameters are in units of m/sqrt(s) and 0.02m/sqrt( h), the range is 0~10. STO corresponds to the default value of 0.0004 when the process noise parameter is not entered, and PWC corresponds to the default value of 0.02m/sqrt(h).

- **-r <char [num]>, --rck <char [num]>**: receiver clock offset estimation model configuration. There are two options available: S/W. S represents the receiver clock offset estimated using the random walk model, W represents the receiver clock offset estimated using the white noise model, and the default mode is white noise estimation. When selecting the S mode, the [num] option can be set to .0040, indicating that the process noise is 0.0040m/sqrt (s), otherwise the default value is 0.001m/sqrt (s).

- **-h <char [length] [num]>, --htg <char [length] [num]>**: horizontal tropospheric gradients configuration. The options are "S", "P", and "N". S represents selecting the STO model, P represents selecting the PWC model and N represents no model. The default is the PWC model. [length] represents the estimated duration, with optional values of 60 and 720. If this parameter is not set, P mode takes 720 minutes. [num] represents the process noise parameter. If this parameter is not set, P mode takes 0.002m/sqrt (h), and S mode takes 0.0004m/sqrt (s).

- **-v, --verbose**: Restore other ambiguity outputs.

**Note:** For multi-day processing, use **-s (--start)** and **-e (--end)** to specify the data processing session time, use the observation files that have not been merged for multiple days to put them in the same directory, and **obs-file** to specify the observation files for the first day. In addition, when processing highly dynamic data, due to the large amount of data, **pdp3** will be relatively time-consuming to match the relevant information at the beginning, so please be patient.

## 5.4.2 Configuration file

As mentioned above, there is a configuration file template in the “path-to-software/table” directory, which is used to record the data processing policy of PRIDE PPP-AR. The command-line parameters described in section 5.4.1 are equivalent to specifying the configuration options in the configuration file, and the users can modify the configuration information through the configuration file. If no command-line parameters are entered and a configuration file is specified, the corresponding configuration options in the configuration file will be matched. The configuration file uses the “**Keyword=Value**” format to record the various options. For enumerated values, the optional value is an enumerated label (NO, YES, etc.). The text after “!” in a line is considered a comment. The configuration file is divided into the following parts: Global processing options and file path settings, parameter model options, fixed ambiguity options, satellite list and its weights, and station processing options

### Global processing options and file path settings

The command line options corresponding to each configuration option in this section include:

- **Frequency combination = Default**

The corresponding **pdp3** command line parameter for frequency combination is **-frq** or **--**

**frequency.** Specify the frequency composition of ionospheric composite observations. Default "means using the default value" G12 R12 E15 C26 J12 ". If you want to set different frequency combinations, please refer to Table 5-4.

- **Interval** = Default

The sampling rate corresponds to the command line option **-i** or **--interval**. "Default" means that the default value, which is the corresponding sampling rate in the observation file.

- **Session time** = -YYYY- -MM- -DD- -HH- -MI- -SS- -SE-

The data processing starting time and processing duration, in order, are the year, month, day, hour, minute and second and the processing duration in seconds. Note that the modification does not take effect when using the *pdp3* script. If the user wants to specify the processing time period, enter the corresponding command line parameters, which correspond to **-s** (**--start**) and **-e** (**--end**).

- **Table directory** = /home/username/path-to-table/table/

Specify the directory where the table files are located.

**Note:** After the software installation is successful, the "**Table directory**" will be changed to the "table/" directory under the software package directory, and users do not need to modify it. Namely, **Table directory=/home/username/path to software/table/**

- **Product directory** = Default

Specify the directory where precision products are located. For the "**Product directory**" directory, if the user has not made any modifications, i.e. "Default", the "product" directory will be created under the "path to project/year" directory. For example, when processing data for 2022, it is: **Product directory=/home/username/path to project/2022/product/**

The required precision product classification is stored in a subdirectory of the "product" directory, including four subdirectories: "common", "ssc", "vmf", and "ion". These directories are the most prone to errors and are usually left with default values.

**Note:** the **Rinex directory** in the previous version's configuration file was replaced by the last option in *pdp3*, which stores the observation file and broadcast ephemeris. Therefore, users need to ensure that they enter the correct path and observation file name (they can use the Tab key to fill in the path to prevent input errors).

After that is the product name section, which are Satellite orbit, Satellite Clock, ERP, Quaternions and Code/phase bias, "Default" means use the default product, related information can refer to the end of section 4.3 and Appendix A. If you want to use other products, you need to decompress them and place them in the "**Product directory/common**" directory. Then change the corresponding product name in the configuration file from "Default" to the actual file name. If there is no quaternions product, you can change **Quaternions** to "none"; if you don't need ambiguity resolution, you don't need the code/phase bias product, and you can change **Code/phase bias** to "none". Note that multi-day processing should include all days of product filenames, separated by spaces.

### Parameter model options

There are six configuration options in this section:

- **Strict editing** = Default

Data editing mode. The corresponding command line option is **-l** or **--loose-edit**. "Default" represents the "YES". Value should be modified to "NO" when the data quality is poor, meaning a more lenient editing threshold and fewer iterations.

- **RCK model** = Default

The receiver clock offset estimation model corresponds to a command line parameter of **-r** or

**--rck.** 'Default' represents the WNO (White Noise), representing the white noise estimation model.

- **ZTD model** = Default

Zenith troposphere delay process noise model (PWC/STO). PWC:60 means piece-wise constant for 60 minutes; STO means stochastic walk noise. The corresponding command line option is **-z** or **--ztd**. "Default" means STO.

- **HTG model** = PWC:720

Horizontal troposphere gradient process noise model (PWC/NON). NON means no estimates. "Default" means PWC:720 for S/F mode and NON for K mode.

**ZTD model** and **HTG model** modification suggestions: (1) S/F model: PWC: 60 and PWC: 720; (2) K model: STO and NON.

- **Iono 2nd** = Default

Changed to YES if correcting 2-order ionospheric delays. The corresponding command line option is **-hion** or **--hgh-ion**. "Default" means NO. The residual higher-order ionospheric delay in the ionosphere-free observations has a negligible effect on the PPP and is not normally corrected. The corresponding GIM product will be stored in the "[Product directory/ion](#)" directory when this correction is performed.

- **Tides** = Default

Remove any of them to shut it down, or changed to NON if not correcting tidal errors. The corresponding command line option is **-toff** or **-tide-off**. Among them, the ocean tide correction needs to be interpolated according to the oceanload file under the [Table directory](#). If “*##warning (oceanload\_coeff): no ocean load coefficients for*” is prompted in the output *lsq* part of the screen or the head of the result file shows that the ocean tide correction is not carried out, update the oceanload file according to **step 3** of section 5.4.3 and solve again

#### Ambiguity resolution options

There are two main configuration options to note in this section, the others can be left at their default values.

- **Ambiguity co-var** = Default

Ambiguity resolution method, the corresponding command line option is **-x** or **--fix-method**. "Default" means the default value, YES when the instant length is less than 6h, use LAMBDA method for ambiguity resolution, otherwise use rounding method.

- **Ambiguity duration** =600

Single-difference satellite pair co-viewing time length required for ambiguity resolution.

- **Cutoff elevation** =15

Cut-off elevation angle required for ambiguity resolution.

- **PCO on wide-lane** = YES

PCO corrections on Melbourne-Wübbena or not. The corresponding command line option is **-aoff** or **--wapc-off**.

- **Widelane decision** = 0.20 0.15 1000.

Bias, standard deviation, and threshold in cycle for judging wide-lane ambiguity resolution.

- **Narrowlane decision** = 0.15 0.15 1000.

Bias, standard deviation, and threshold in cycle for judging narrow-lane ambiguity resolution.

- **Critical search** = 3 4 1.8 3.0

The four parameters are, the maximum number of ambiguities removed, the minimum number of ambiguities retained, the minimum value of ratio for ambiguity search and the threshold value in the LAMBDA algorithm in order. When the ambiguity of the narrow lane cannot be fixed using the LAMBDA method, i.e. “*no more can be fixed*” is output in the LAMBDA fixed rate section of **arsig**,

the first value (the maximum amount of ambiguity is eliminated) can be adjusted upward gradually and solve again.

- Truncate at midnight = YES

Whether to truncate the ambiguity at midnight to solve the discontinuity problem at the solar boundary.

- Verbose output =NO

Whether to display the fixed rate of all ambiguity of the subsystem.

#### Satellite list and its weights

The satellite list consists of the satellite PRN and the corresponding weighting factor, the larger the weighting factor, the lower the weighting. Users can disable the satellite by inserting “#” at the beginning of a single GNSS PRN, corresponding to the command line parameter **-sys** or **--system** (note that these two command line parameters indicate that all satellites of the corresponding input system are selected, and satellites of other systems will be disabled). Since the orbit accuracy of BDS-2 GEO satellites (C01-C05) is low, you can disable them if the positioning result is poor.

#### Station processing options

Leave the default values in the station list except for the configuration options corresponding to the command line parameters. Note: (1) only one line can be kept in the station list; (2) x/X in this part is a wildcard, indicating the corresponding default value; (3) if you want to make changes, pay attention to keep the same indentation as the original one.

NAME	TP	MAP	CLKm	PoDm	EV	ZTDm	PoDm	HTGm	PoDm	RAGm	PHSc	PoLns	PoXEm	PoYNm	PoZHm
xxxx X	XXX	9000	xxxxx	xx	0.20	xxxxx	.005	xxxxx	0.30	0.01	xxxxx	10.00	10.00	10.00	10.00
<hr/>															
NAME	Station name														
TP	Positioning mode														
MAP	Tropospheric projection function														
CLKm / PoDm	Receiver clock deviation prior constraint (Unit: m) and process noise (Unit: m/sqrt(s))														
EV	Elevation mask														
ZTDm / PoDm	Zenith tropospheric delay prior constraint (Unit: m) and process noise (Unit: m/sqrt(s))														
HTGm / PoDm	Horizontal tropospheric delay prior constraint (Unit: m) and process noise (Unit: m/sqrt(s))														
RAGm	Pseudo-range observation noise (Unit: m)														
PHSc	phase prior constraint (Unit: cycle)														
PoLns	Parameter duration of position parameter PWC mode (Unit: s)														
PoXEm	Priori constraint on the X coordinate (Unit: m)														
PoYNm	Priori constraint on the Y coordinate (Unit: m)														
PoZHm	Priori constraint on the Z coordinate (Unit: m)														

### 5.4.3 General operation steps

After installation and verification, let's start the PPP data processing! The general steps when using PRIDE PPP-AR for data processing are:

**Step 1:** Make sure you have the software installed. For the method of installing software, see section 5.2.2.

**Step 2:** Refer to section 5.4.1 and section 5.4.2, if you want to modify other configuration options in addition to the command line options, modify the configuration file based on the configuration file template in the “example” directory in the software package.

**Step 3:** In case of non-networked solving, it is necessary to prepare in advance the external files to be downloaded and place them in the corresponding directories. This includes precision products, partial table files and broadcast ephemeris, refer to the last part of Section 4.3 and Appendix A.

**Step 4: [Optional choice for stations offshore]** Get Ocean tide loading parameters using the coordinates in *sit.xyz* according to the website (<http://holt.oso.chalmers.se/loading/>), or you can calculate the station coordinates by *spp*, such as

```
spp -trop saas path-to-data/RINEXo path-to-data/RINEXn
```

Choose the model **FES2004** (Figure 5-21), and leave the rest of the options as default.

#### Select ocean tide model

A brief description of the ocean tide models can be found [here](#).

FES2004

Figure 5-21 Ocean tide model

Then submit a task by add station coordinates as below at the website. When you get the oceanload coefficients through your email, append them to oceanload in “Table directory” as the original format (Figure 5-22).

Name of station	Longitude (deg)	Latitude (deg)	Height (m)	OR
Name of station	X (m)	Y (m)	Z (m)	
//sala	11.9264	57.3958	0.0000	
//ruler.....b.....				
// Records starting with // are treated as comments				

Figure 5-22 Submitting the task

**Step 5:** Calling *pdp3* for data processing.

```
pdp3 [-cfg path-to-config/config .....] path-to-data/RINEXo
```

**Step 6:** After processing, check the solution files in *path-to-project/year/doy* directory.

### 5.4.4 Processing Examples

If you already know how to process data with *pdp3*, you can start processing your data. Otherwise, you can practice with the data in the “path-to-software/example” directory. Create “Practice” folder under the “example” directory for program execution (If you are familiar with Linux, you can change the directory as needed). This section illustrates the parameter selection and input for common data processing scenarios, which can be used as a reference for users to adjust the relevant processing strategies as needed when processing data. Note that a corresponding complete configuration file will be generated under the result directory (year/day-of-year directory), which can be viewed by users to check the configuration information.

#### Example 1: Static single-day solution

For static single-day solution, enter **-m** or **--mode** option to specify the positioning mode as S mode, enter **-z** or **--ztd** option to specify the ZTD model as PWC:60, and keep the rest of the default configuration.

1) Create ‘Practice1’ directory under ‘Practice’ directory.

2) Open terminal, run *pdp3* script to start data processing under ‘Practice/Practice1’ directory.

```
pdp3 -m s -z p60 ../../data/2020/001/abmf0010.20
```

3) The result files will be output in the “2020/001” directory, change directory to the “2020/001” directory.

4) For static solution, users can use ***pbo*** to convert “pos\_” file to PBO format.

```
pbo abmf pos_2020001_abmf
```

5) Plot residuals to analyze the solution.

```
plotres.py res_2020001_abmf G01
```

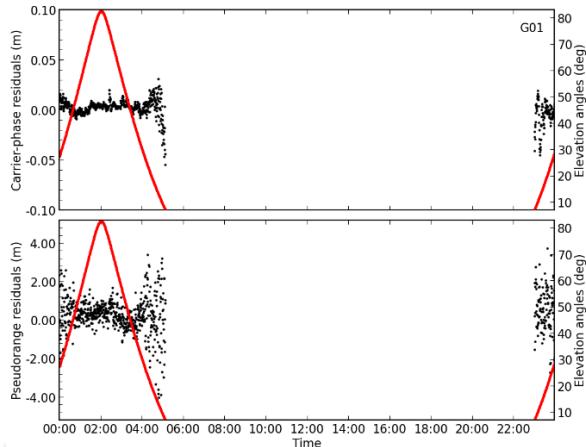


Figure 5-23 Residuals of abmf, 001 day in 2020

### Example 2: Kinematic solutions

It is sufficient to keep the default configuration parameters when processing kinematic solutions. You can enter the **-l** or **--lose-edit** parameter if the data quality is poor.

1) Back to the ‘Practice’ directory and create ‘Practice2’ directory.

2) Open the terminal and run the ***pdp3*** script to start data processing under the ‘Practice/Practice2’ directory.

```
pdp3 ../../data/2021/210/ccj22100.21o
```

3) The result files will be output in the “2021/001” directory, change directory to the “2021/210” director.

4) For kinematic solution, users can use ***xyz2enu*** to transform XYZ to ENU, If reference coordinates are empty, the coordinates mean value of “kin\_” file will be used.

```
xyz2enu kin_2021210_ccj2 enu_2021210_ccj2
```

5) Plot displacement of station.

```
plotkin.py kin_2021210_ccj2 enuts_ccj2
```

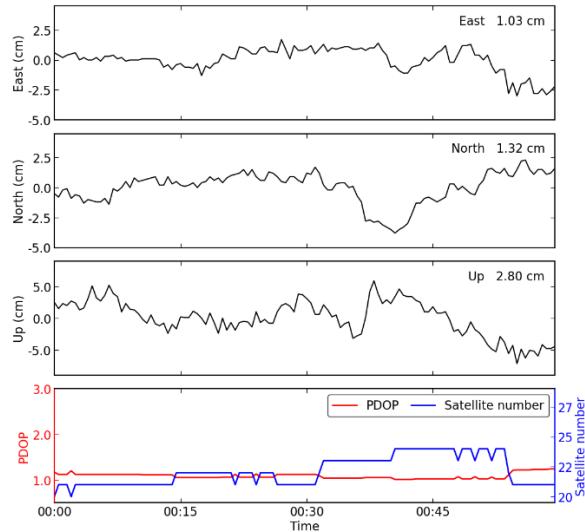


Figure 5-24 Position time series of ccj2, 210 day in 2021

### Example 3: Seismic Data

The seismic data is the same as the dynamic solution, and each configuration parameter can be kept as default.

- 1) Back to the ‘Practice’ directory and create ‘Practice3’ directory.
- 2) In this example, using data during the Alaska M8.1 earthquake, data from UNAVCO (<https://www.unavco.org>).
- 3) Open terminal, run *pdp3* script to start data processing under ‘Practice/Practice3’ directory.  
`pdp3 ../../data/2021/210/ac122100.21o`
- 4) The result files will be output in the “2021/001” directory, change directory to the “2021/210” directory.
- 5) Plot displacement of station.

```
plotkin.py kin_2021210_ac12 enuts_ac12
```

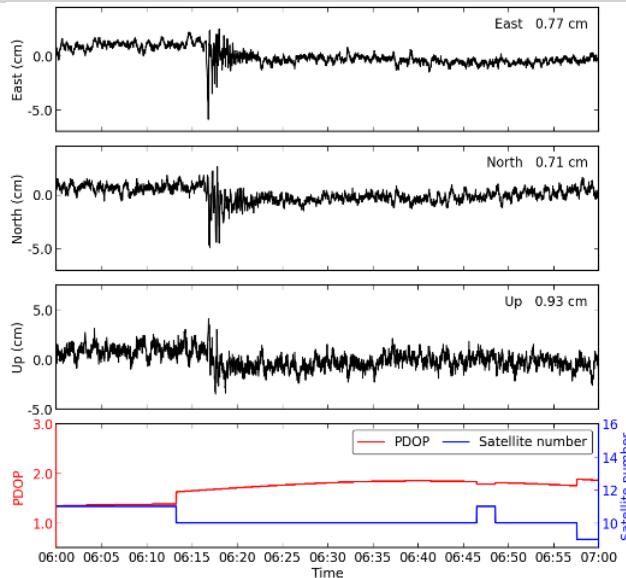


Figure 5-25 Position time series of ac12, 210 day in 2021

### Example 4: Using other products

When using other products, you should pay attention to whether to add PCO correction in the

M-W observation. If you are not sure, you can compare the parameters with and without **-aoff** or **--wape-apc**, and then choose the solution with a higher fixed rate of wide-lane. In order not to modify the original configuration file template, copy “path-to-software/example/config\_template” to the directory of this example.

- 1) Back to the ‘Practice’ directory and create ‘Practice4’ directory.
- 2) In this example, we will use the precise product released by CODE, the corresponding GPS week is 2168 and days of week is 4 , the download link is [http://ftp.aiub.unibe.ch/CODE\\_MGEX/CODE/2021/](http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/2021/).
- 3) Create the directory “2021/product/common” after the download is completed, and unzip the downloaded precise products and store them in this directory;
- 4) Switch to the 'Practice4' directory, copy the configuration file template from the “Table directory” directory to the current directory, and modify the product name in the configuration file.

<i>Satellite orbit</i>	= COM21684.EPH
<i>Satellite clock</i>	= COM21684.CLK
<i>ERP</i>	= COM21684.ERP
<i>Quaternions</i>	= COM21684.OBX
<i>Codephase bias</i>	= COM21684.BIA

**Note:** In multi-day processing you need to write all product file names with spaces as separators; or write individual merged product file names after merging them yourself, e.g.

*Satellite orbit* = COM21684.EPH COM21685.EPH

- 5) Open terminal and run the script to start data processing under the ‘Practice/Practice4’ directory.  
`pdp3 -cfg config_template -aoff ../../data/2021/210/ccj22100.21o`
- 6) The result files will be output in the “2021/210” directory, change directory to the “2021/210” directory.
- 7) Plot displacement of station.

`plotkin.py kin_2021210_ccj2 enuts_ccj2`

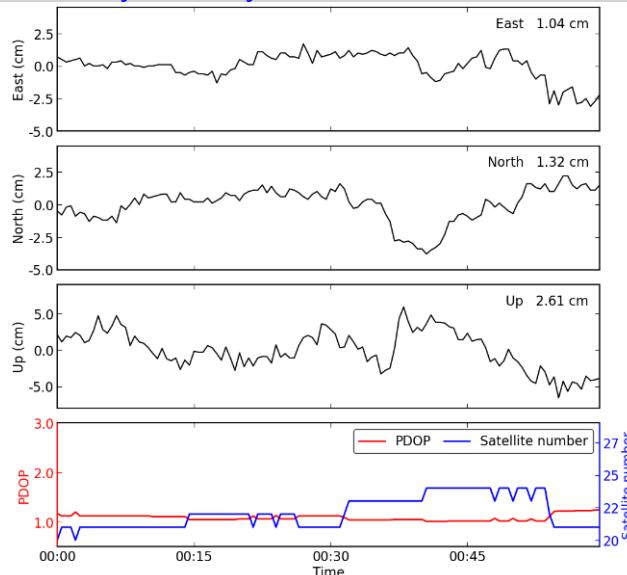


Figure 5-26 Position time series of ccj2, 210 day in 2021

#### Example 5: Preparing external files while offline

Processing data in offline mode requires prior preparation of external files, download links

refer to the end of section 4.3. As in Example 4, the downloaded precision products need to be sorted into the respective subdirectories.

#### Required external files:

- Precise products: Downloaded and stored in the “[Product directory](#)/common” directory.
- Broadcast ephemeris: downloaded and stored in the directory where the observation files are located.
- leap.sec file: Since the time interval between two leaps is long, update this file after the leap occurs, download it and store it in the “[Table directory](#)” directory.
- sat\_parameters file: This file is mainly used to read GLONASS satellite channel number, when processing data containing GLONASS satellite, you need to update this file, download it and store it in “[Table directory](#)” directory.
- ANTEX file: the record "SYS / PCVS APPLIED" in clock difference product recorded the corresponding antenna file, if the “[Table directory](#)” directory does not have the file, you need to download and store in the “[Table directory](#)” directory.

#### Optional external files:

- IGS SINEX file: required when the positioning mode is F mode, it indicates the fixed station coordinates to improve the accuracy of ZTD estimation, download and store it in “[Product directory](#)/ssc” directory.
- Tropospheric grid file: required when the mapping function is VMF1 or VMF3, downloaded and stored them in the “[Product directory](#)/vmf” directory.
- The GIM products: needed for higher-order ionospheric corrections, download and store it in the “[Product directory](#)/ion” directory.

This example takes F mode as an example and downloads the corresponding precise products, broadcast ephemeris and solution files.

- 1) Back to the ‘Practice’ directory and create ‘Practice5’ directory, Download the external files required for the F model in 2021 day 220.

Precise products: <ftp://igs.gnsswhu.cn/pub/whu/phasebias/2021>

Broadcast ephemeris:

[ftp://igs.gnsswhu.cn/pub/gps/data/daily/2021/220/21p/BRDC00IGS\\_R\\_20212200000\\_01D\\_MN.rnx.gz](ftp://igs.gnsswhu.cn/pub/gps/data/daily/2021/220/21p/BRDC00IGS_R_20212200000_01D_MN.rnx.gz)

ANTEX file: The antenna file recorded in the header of the clock difference file in this example is “igs14\_2148.atx”, [https://files.igs.org/pub/station/general/pcv\\_archive/igs14\\_2148.atx](https://files.igs.org/pub/station/general/pcv_archive/igs14_2148.atx)

Satellite parameter file: [ftp://igs.gnsswhu.cn/pub/whu/phasebias/table/sat\\_parameters](ftp://igs.gnsswhu.cn/pub/whu/phasebias/table/sat_parameters)

SINEX file: <ftp://igs.gnsswhu.cn/pub/gps/products/2170/igs21P21700.ssc.Z>

- 2) Store the corresponding external files in the corresponding directories.

- 3) Open terminal and run the script to start data processing under the ‘Practice/Practice5’ directory.

`pdp3 -m f ../../data/2021/220/BAKO00IDN_R_20212200000_01D_30S_MO.rnx`

- 4) The result files will be output in the “2021/220” directory, change directory to the “2021/220” directory.

- 5) Plot the ZTD time series.

`plotztd.py ztd_2021220_bako ztdts_2021220_bako`

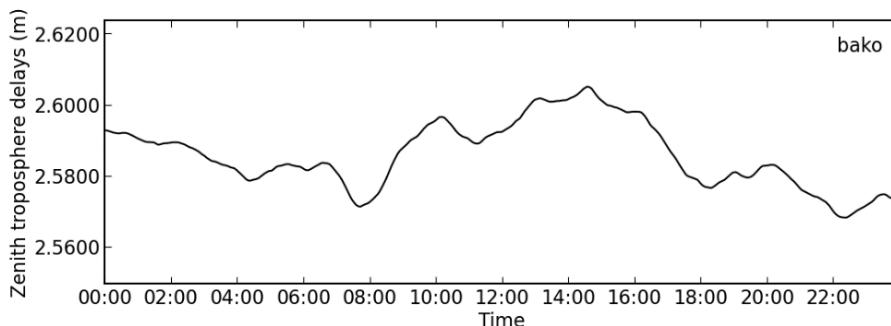


Figure 5-27 ZTD time series of bako, 220 day in 2021

### Example 6: LEO satellite orbit calculation

The orbit calculation of LEO satellites is the same as the dynamic solution, and all configuration parameters can be kept as default.

- 1) Back to the 'Practice' directory and create 'Practice6' directory.
- 2) Data preparation: Open the terminal and run the following script. The downloaded data for this script includes: Observation O files for low orbit satellites, Attitude files for low orbit satellites and Scientific orbit files for low orbit satellites.  
`prepare_leodata.sh grace-fo 2023/001`
- 3) LEO satellite position calculation: Input the following *pdp3* script and start data processing in the "Practice/Practice6" directory.  
`pdp3 -m l ./data/2023grac0010.23o`
- 4) The result file will be output to the "2023/001" directory and switched to the "2023/001" directory.
- 5) Plot radial, tangential, and normal RMS diagrams: Create a new terminal in the results folder, enter the following command to draw a positioning accuracy time series diagram, and save the results to rms\_enu.  
`potkin2ps0.py kin_2023001_grac ../product/leo/ps0_2023001_grac rms_enu`

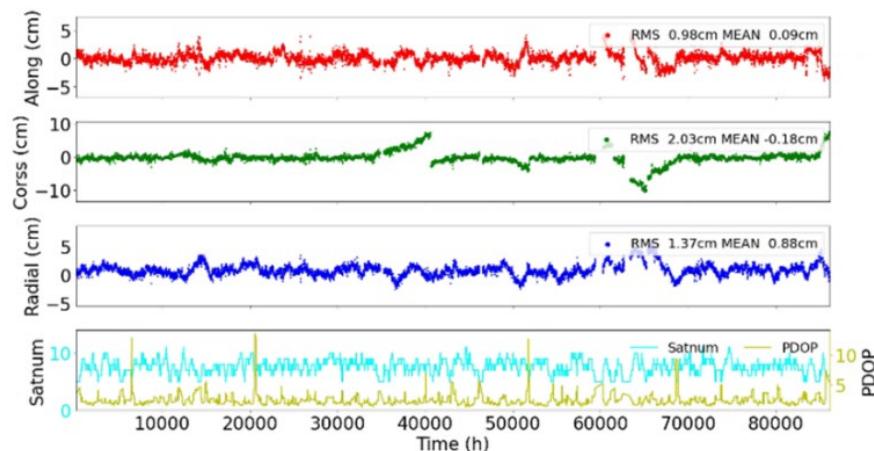


Figure 5-28 Time series diagram of grace satellite's resolution accuracy on the 1 day of 2023

# 6 PRIDE PPP-AR for GUI

## 6.1 Overview

### 6.1.1 The difference between the GUI version and the CUI version

- 1) The GUI version cannot handle high-frequency data above 1Hz.
- 2) GUI version can only recognize observation files in standard naming formats.
- 3) GUI version will not download RTS products, GLONASS broadcast ephemeris and hourly broadcast ephemeris.
- 4) For data before 2020, the GUI version can automatically download IGS's third reprocessing product for processing, but cannot download COD/COM products before 2020. If you want to test COD/COM products, users can download and modify the corresponding configuration by themselves, see section 6.3.2.
- 5) Only support for single-day processing.
- 6) Same as section 5.4.3 step3, some stations near the coast need ocean tidal correction. [Table directory](#) of the GUI version is in the installation directory.
- 7) The GUI version maintains the same software functionality as v2.2, so some new features added in version 3.0 are not applicable to the GUI version.

### 6.1.2 Software Introduction

This GUI version of PRIDE PPP-AR software is based on the Linux version. The executable files used in the software are the same as the Linux version, and the products preparation process and data processing steps are also the same as the Linux version. The software can help users to use PRIDE PPP-AR on Mac system and Windows system in a friendly way.

This software can achieve most of the functions of the Linux version, and it can process the observation data of a single station in a single day at a time. However, due to the memory limitation of Windows system, you still need to use Linux version if you need to process high frequency dynamic data with sampling frequency higher than 1Hz, continuous multi-day data processing, or large batch of observation data solving.

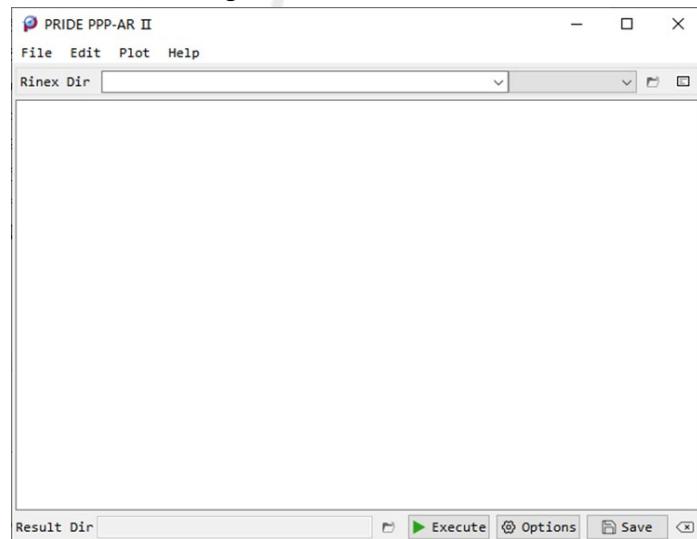


Figure 6-1. Main interface of the software PRIDE PPP-AR

### 6.1.3 Software features

PRIDE PPP-AR GUI version has the following features:

- (1) User-friendly interface for users who are not good at operating Linux systems;
- (2) Support a variety of result files' plotting, and support zoom, cursor and other auxiliary functions;
- (3) The calculation results are consistent with the Linux version, and compatible with the Linux version, such as the configuration file (config) and the result files (kin, res, etc.) can be interoperable;
- (4) Inherited most of the data processing functions of Linux version, such as hourly kinematic data processing with sampling interval greater than 1s, kinematic/static solution in a single day, etc.
- (5) Maintain the majority of solution options as Linux version, such as support for the solutions of the five systems of GRECJ, LAMBDA algorithm, a variety of tropospheric delay estimation models, a variety of AC GNSS products and so on.

### 6.1.4 Software main interface

As shown in the figure, the main interface of the software has the following main sections.

- (1) Menu bar: In the first menu bar, the “File” bar allows you to select the directory of the RINEX file where the calculation is performed, save the execution steps in the output message area, load the config file, etc.; the “Options” in the Edit bar can be used to set the parameters of the solution; the “Plot Figure” option in the “Plot” can be used for plotting after the solution; the “Help” option in “Help” can be used to go to the official website of this software.
- (2) Workspace: mainly buttons for viewing config file in item 2, controls related to directory setting in item 3 workspace, message output area in item 4, controls related to result files' directory in item 5, buttons for parameter setting and calculation in item 6, and buttons for saving or clearing output messages in item 7.

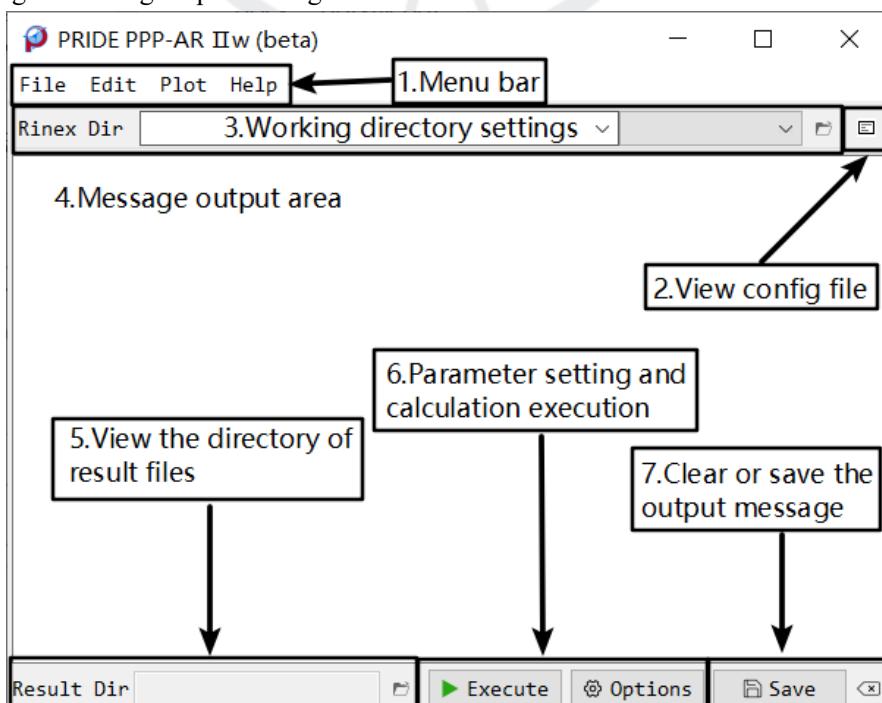
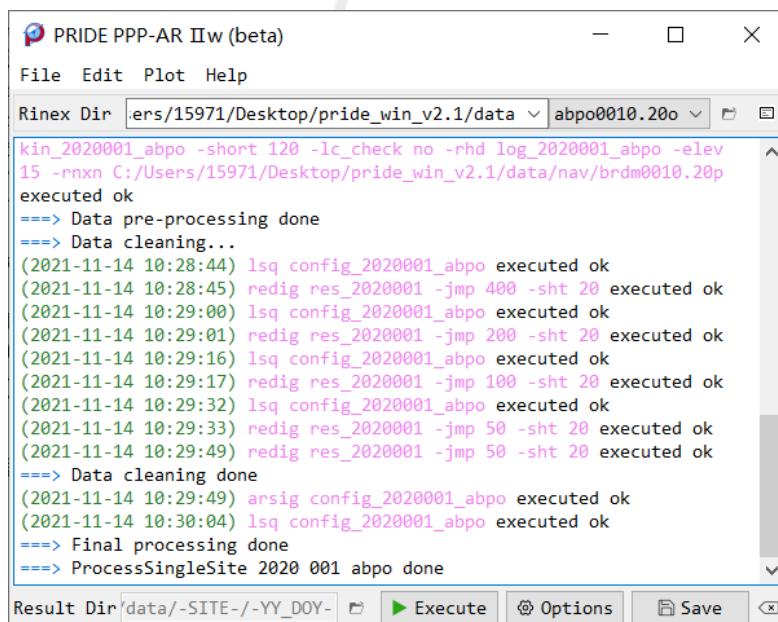


Figure 6-2 Main components of the main software interface

## 6.2 Software Operation Steps

- (1) **Select the observation file to be processed:** first click on the folder icon in the main interface and select the path where the observation file to be processed is located in the file path option dialog that pops up; then the combo box on the left side of the folder icon will have the observation file name to choose from, and select the observation file to be processed from the combo box according to the file name, or select “ALL” to process all the observation files in the working directory.
- (2) **Select the desired solution parameters:** click on the Options button and set exactly the parameters such as sampling interval, dynamic or static, ambiguity fixing strategy and satellites list involved in the solution in the Options dialog, plus other options such as tropospheric estimation parameters and product options can be modified as needed. This step generates a config file equivalent to the Linux version, which can be viewed by clicking on the icon to the right of the folder icon.
- (3) **Start solving:** Click the Execute button to perform PPP solving on the observation file selected in the first step and according to the solving parameters selected in the second step; during the solving process, this GUI version of PRIDE PPP-AR program will execute programs such as *spp*, *sp3orb*, *redig*, *tedit*, *lsq* and *arsig* in the same order as the Linux version to perform a series of PPP or PPP-AR operations. The solving process takes about tens of seconds, and during this process the middle whiteboard text box will display the solving steps simultaneously, in addition you can save the contents of the text box to a text file by using the Save button in the bottom right corner of the main interface, the button to the right of the Save button is to clear all the contents of the text box.
- (4) **To access the results file:** you can access the results folder by clicking on the folder icon directly below the main interface, or you can click on the Plot Figure option under Plot in the menu bar at the top of the main interface to plot from the results file; in addition, you can also choose to save and clear the existing contents of the text box before solving for another observation file.



The screenshot shows the PRIDE PPP-AR IIw (beta) software window. The title bar reads "PRIDE PPP-AR IIw (beta)". The menu bar includes "File", "Edit", "Plot", and "Help". The "Rinex Dir" dropdown is set to "C:/Users/15971/Desktop/pride\_win\_v2.1/data" and the "Result Dir" dropdown is set to "data/-SITE-/YY\_DOF". The central text area displays the command-line log of the solution process:

```

kin_2020001_abpo -short 120 -lc_check no -rhd log_2020001_abpo -elev
15 -rnrx C:/Users/15971/Desktop/pride_win_v2.1/data/nav/brdm0010.20p
executed ok
====> Data pre-processing done
====> Data cleaning...
(2021-11-14 10:28:44) lsq config_2020001_abpo executed ok
(2021-11-14 10:28:45) redig res_2020001 -jmp 400 -sht 20 executed ok
(2021-11-14 10:29:00) lsq config_2020001_abpo executed ok
(2021-11-14 10:29:01) redig res_2020001 -jmp 200 -sht 20 executed ok
(2021-11-14 10:29:16) lsq config_2020001_abpo executed ok
(2021-11-14 10:29:17) redig res_2020001 -jmp 100 -sht 20 executed ok
(2021-11-14 10:29:32) lsq config_2020001_abpo executed ok
(2021-11-14 10:29:33) redig res_2020001 -jmp 50 -sht 20 executed ok
(2021-11-14 10:29:49) redig res_2020001 -jmp 50 -sht 20 executed ok
====> Data cleaning done
(2021-11-14 10:29:49) arsig config_2020001_abpo executed ok
(2021-11-14 10:30:04) lsq config_2020001_abpo executed ok
====> Final processing done
====> ProcessSingleSite 2020 001 abpo done

```

The bottom of the window has buttons for "Execute", "Options", "Save", and "Clear".

Figure 6-3 Output message of the solution results

## 6.3 Options

The parameters in the Options dialog all correspond to the command line parameters and the config file parameters in the Linux version. The template config in the example in the Linux version of the software can also be used directly in this version of the software. When the software starts, the “.PRIDE\_PPPAR\_config” folder will be created under the system user folder by default, and the template config file “config\_template” will be further created under it, according to which the options parameters of Options are derived.

### 6.3.1 General Options

- (1) Interval: Sampling interval, 30s, 1s, 5s, 15s, etc. can be selected as the sampling interval of the observation data, and the user needs to select it according the actual observation file to be calculated.
- (2) Strict Editing: refined editing options, optional YES and NO.
- (3) Positioning mode: divided into Kinematic, Static and Fixed, that is, the kinematic mode calculates the position of each ephemeris station, which will be recorded in the kin file at the end; the static mode calculates the average position of each ephemeris and gives the variance, which will be recorded in the pos file at the end; the fixed position mode refers to the SNX file reference coordinates of the IGS to solve, and the final The calculation gives the mean position and variance, which is recorded in the pos file; it should be noted that only stations with IGS can be solved by the method of fixed position mode.
- (4) Satellite system: the satellite system involved in the solution.
- (5) Excluded satellites: satellites that are excluded from the list of satellites involved in the solution.
- (6) Downweighted satellites: some satellites with reduced weights in position resolution (e.g., GEO satellites).

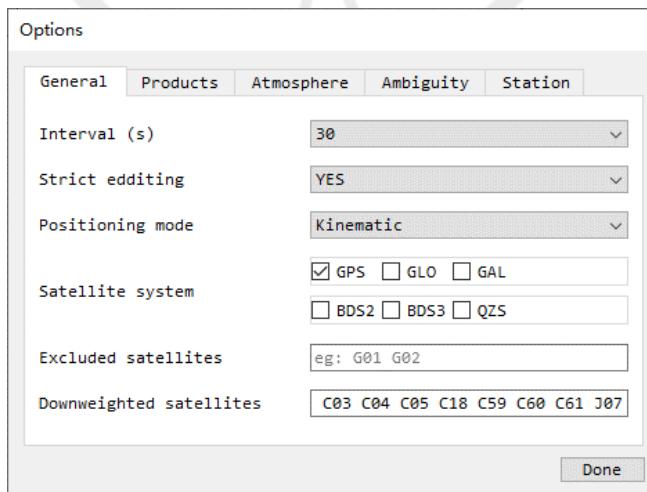


Figure 6-4 General Options

### 6.3.2 Products options

Product dir is the directory where the product is stored in Figure 6-5. By default, it is automatically specified as the next level of the product directory after the observation file directory is selected; you can also customize the path by mouse-clicking the folder icon on its right side.

Product options: There are satellite orbit product, satellite clock product, ERP product, quaternion product (optional) and phase deviation product, etc. If the products are missing, the software will automatically download and decompress the relevant product to the product directory under the directory where the observation file is located.

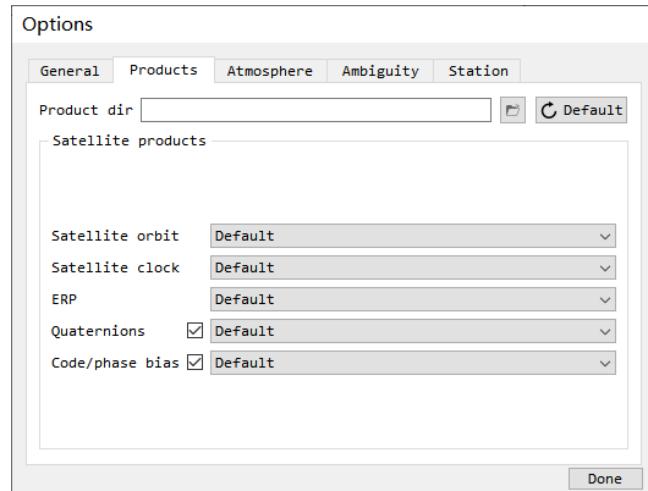


Figure 6-5 Product Options

If you want to choose another Analysis Center product, you can also customize it by changing Default to the file name, for example in Figure 6-6. Besides, the options of quaternions and bias can be set as “None” if there are no such products corresponding to orbit product and clock product.

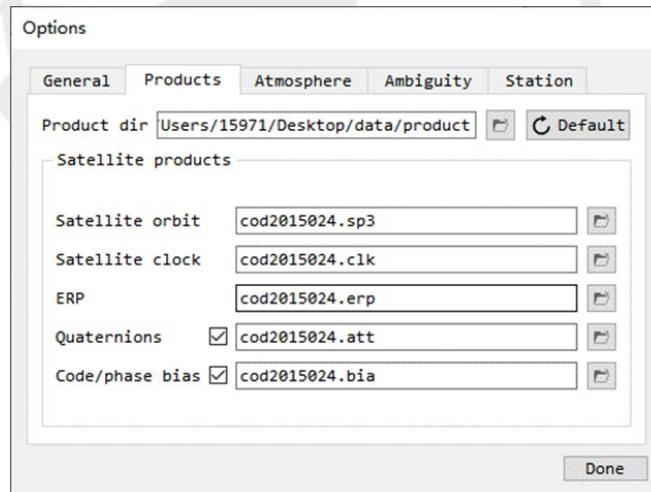


Figure 6-6 Using products of other AC

The broadcast ephemeris file will be automatically downloaded and extracted to the automatically created nav directory without user’s operation. If the broadcast ephemeris brdm-file is missing while online, the software will download it automatically; if it is not online, the user should download the required broadcast ephemeris brdm-file for the day in advance, create a new nav folder and put the brdm-file into it. Since the multi-system broadcast ephemeris “brdm” file did not exist in the early pre-2015 period, the software selects the “brdc” file of the GPS system for the calculation.

Software working directory: in Figure 6-7 the RINEX observation file directory selected in the main interface of the software must contain the observation files to be processed; then other directories will be created automatically while processing: the nav directory which holds the

broadcast ephemeris, the product directory which holds the satellite product files. After processing the observation file, the result files are generated in a multi-level directory such as “2020/001/abpo” under the working directory.

名称	修改日期	类型	大小
2020	2021/11/16 15:49	文件夹	
2021	2021/11/11 10:42	文件夹	
nav	2021/11/17 15:19	文件夹	
product	2021/11/16 15:50	文件夹	
abpo0010.20o	2021/8/12 18:23	200 文件	22,245 KB
abpo0010.21o	2021/10/5 19:03	210 文件	23,886 KB
abpo2200.20o	2021/11/14 22:47	200 文件	21,940 KB
ac122100.21o	2021/10/6 19:57	210 文件	4,390 KB
alic0010.21o	2021/10/3 20:57	210 文件	24,299 KB
ccj22100.21o	2021/10/6 19:57	210 文件	698 KB
jfng2420.20o	2021/10/5 19:00	200 文件	27,839 KB

Figure 6-7 Software Working Directory

### 6.3.3 Atmosphere options

- (1) 2nd-order ionosphere correction: whether to correct the second order ionosphere delay.
- (2) Troposphere mapping function: there are four options: GMF, NIE (NMF), VM1 (VMF1), VM3 (VMF3).
- (3) ZTD model: zenith troposphere estimation methods are mainly PWC , often estimated in 60 min, and STO.
- (4) HTG model: horizontal tropospheric gradient estimation methods, the 3 main ones are PWC, often estimated in 720 minutes, STO and NON.

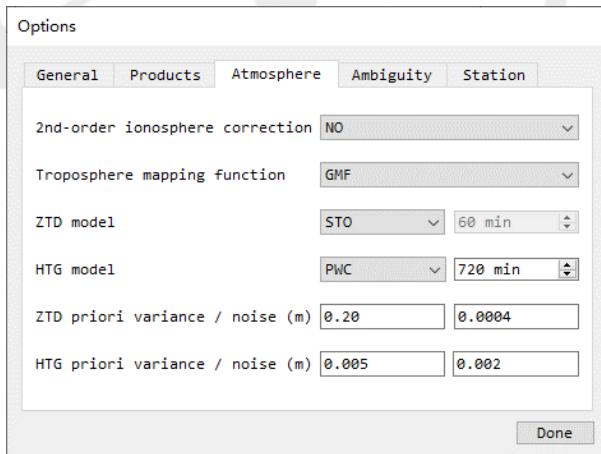


Figure 6-8 Atmospheric Delay Options

### 6.3.4 Ambiguity options

- (1) AR mode/Ambiguity co-var: The former is whether the ambiguity is fixed or not, i.e., the calculation is done by fixed solution or float solution; the latter is “YES”, i.e., the ambiguity is fixed by LAMBDA algorithm, and “NO”, i.e., the ambiguity is fixed by Rounding method is used to fix the fuzziness.
- (2) Ambiguity cut-off: the cutoff mean elevation angle used to determine if the fixed ambiguity is valid.
- (3) Ambiguity duration: the valid time duration of ambiguity fixation in seconds.
- (4) PCO on wide-lane: whether to perform PCO corrections on MW combinations.

- (5) Widelane round-off: bias, standard deviation, and threshold in cycle for judging wide-lane ambiguity resolution.
- (6) Narrowlane round-off: bias, standard deviation, and threshold for determining narrow-lane ambiguity fixation, in cycle.
- (7) Critical search: the four parameters are, the maximum number of ambiguities removed, the minimum number of ambiguities retained, the minimum value of ratio for ambiguity search and the threshold value in the LAMBDA algorithm in order.

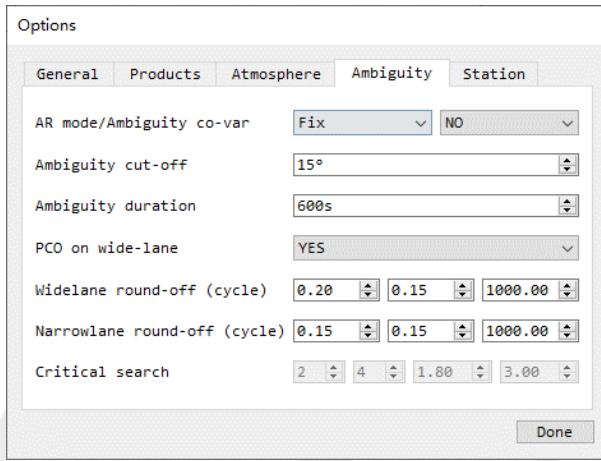


Figure 6-9 Ambiguity Options

### 6.3.5 Station options

- (1) Pseudo-range noise: pseudo-range observation noise in the unit of m.
- (2) Phase noise: phase observation noise, in the unit of cycle.
- (3) Tides: earth tide correction, tidal load and earth pole shift correction.
- (4) Observation cut-off: the cutoff height angle for data preprocessing as a tedit parameter.
- (5) A priori coordinate constraint: a priori three-dimensional sit constraint.

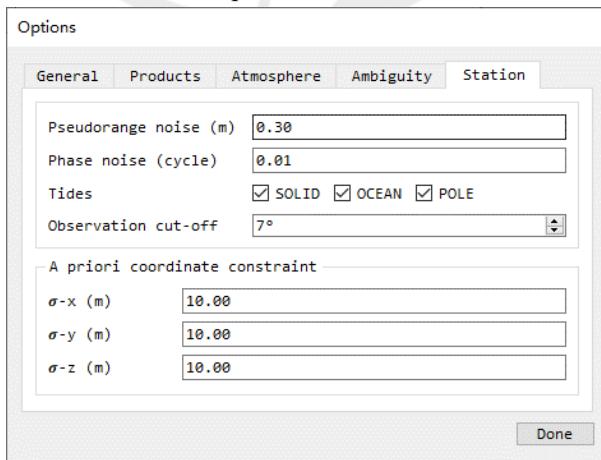


Figure 6-10 Station parameter options

### 6.3.6 Other functions

By clicking on the Load config file option under the File menu bar, the config file is redirected and the settings parameters in the software Options are updated simultaneously, and subsequent solving will follow the config file selected in this step as a template. The RINEX file directory, the

broadcast ephemeris file directory and the product catalog in the config file will be reset according to the directory set in the main interface.

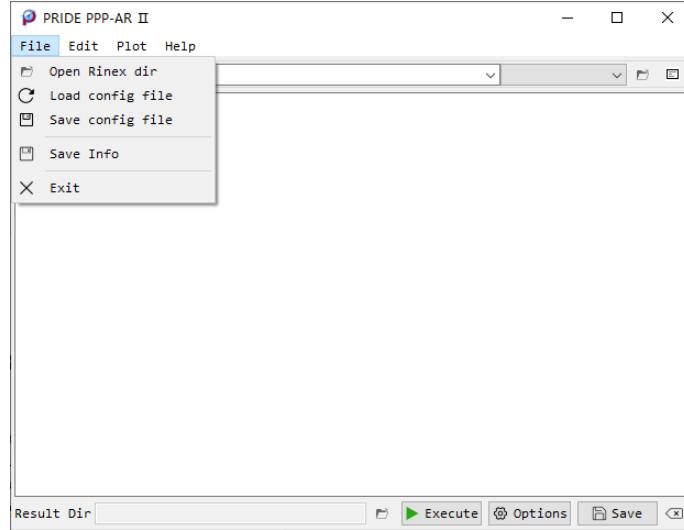


Figure 6-11 Menu bar File bar

## 6.4 Plotting

### 6.4.1 Main plotting window

- 1) Menu bar: At the top of the main interface is the menu bar, through the options in the File bar you can import the result file, or save the plot.
- 2) Toolbar: Below the menu bar is the toolbar, through these icons you can adjust the style of plotting, the time interval of data display, and you can open the cursor function, etc.
- 3) File import area: below the toolbar is the function area about file import, by clicking the button kin, res, ztd, and other result files you can plot ENU, res, elev, track, DOP, Nsats, Skyview, ztd and other plots.
- 4) Plotting area: below the functional area of file import is the plotting area, which is composed of several tabs such as ENU, res, elev, track, DOP, Nsats, Skyview, ztd, etc. By clicking the tabs you can switch the displayed plots.

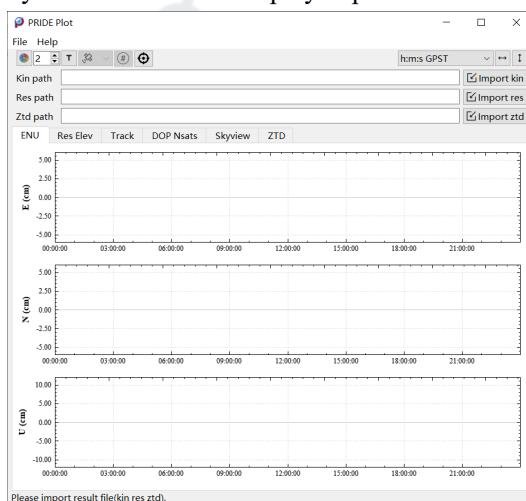


Figure 6-12 Plotting Interface

## 6.4.2 Plotting methods

### Plotting ENU, Track, DOP, Nsats

After importing the kin file, the software will automatically generate charts such as ENU-t, Track, DOP-t, Nsats-t. If you want to view the various types of maps, you only need to select the corresponding tab page. Kin file contains the station coordinates of positioning, the DOP value of each epoch, the number of satellites in each constellation.

The ENU-t plot shows the ENU directional deviation compared to the average coordinates of the dynamic positioning results in the kin file.

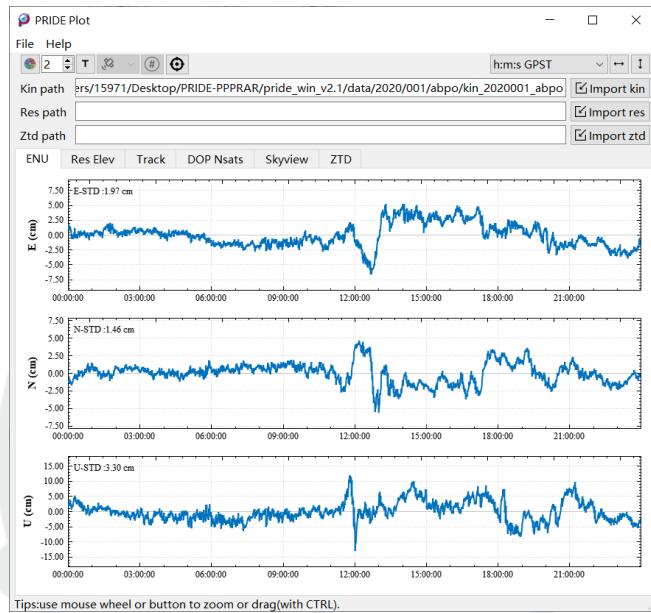


Figure 6-13 ENU-t chart

The planar trajectory map shows the planar trajectory of the dynamic positioning result, i.e. the trajectory map formed by converting the dynamic positioning coordinate points to the station-centered coordinate system and connecting them by ephemeral moments.

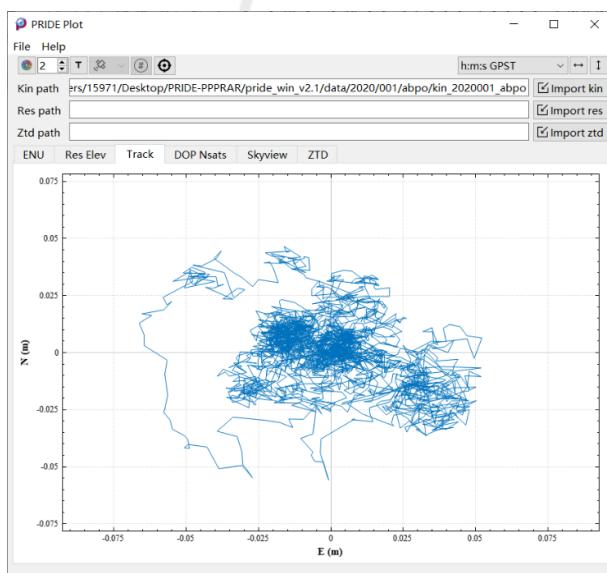


Figure 6-14 Position plane trajectory chart

At the top of Figure 6-15 is the DOP-t plot, which indicates the PDOP values for the observation period, and at the bottom of Figure 6-15 is the Nsats-t plot, which indicates the number of satellites involved in the solution during the observation period.

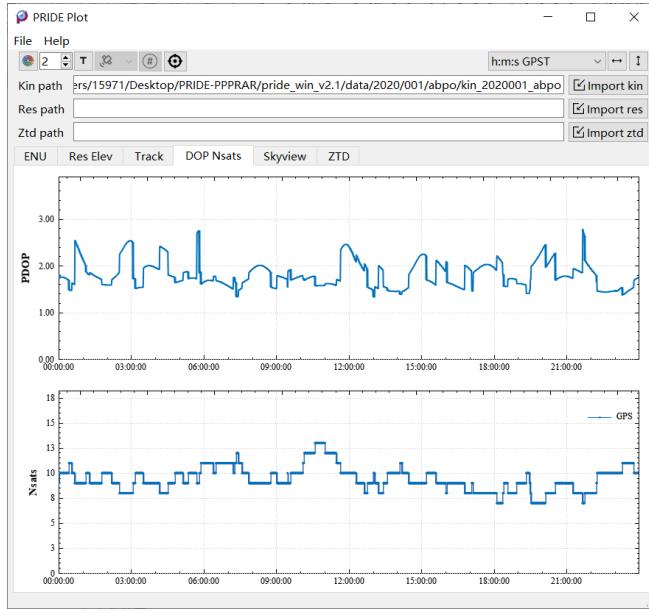


Figure 6-15 DOP and Nsats-t charts

### Plotting residuals, satellite elevation angles

After importing the res file, click on the combo box of the satellite icon in the toolbar and select the corresponding satellite system or PRN to view the overall residual chart of a satellite system or the residual chart of a single satellite, and the corresponding satellite elevation angle will also be displayed below.

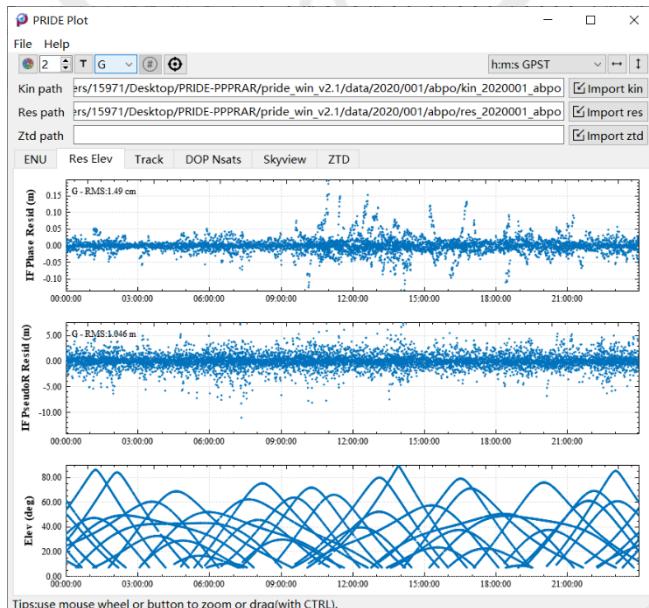


Figure 6-16 Res and elev-t charts

### Plot the satellite sky view

After importing the res file, select the tab page of Skyview, click the combo box of the satellite icon in the toolbar, select the corresponding satellite system or PRN to view the satellite sky view,

in addition, you can click the “#” icon in the toolbar to show or hide the satellite prn.

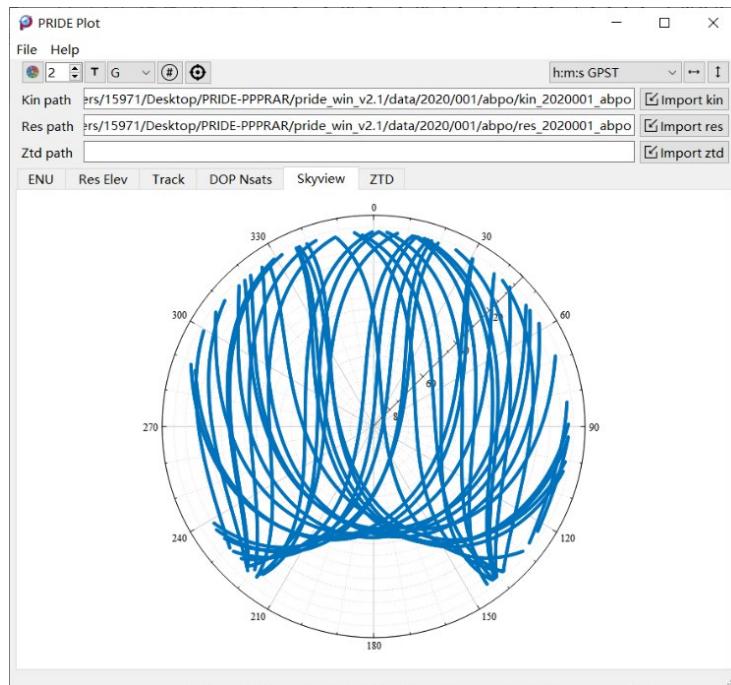


Figure 6-17 Satellite sky view

### Plotting the ztd chart

Import the ztd file and the software will automatically generate a ZTD plot, which contains a plot of ZDD, ZWD and the sum of the two ZTD over time in the ztd file.

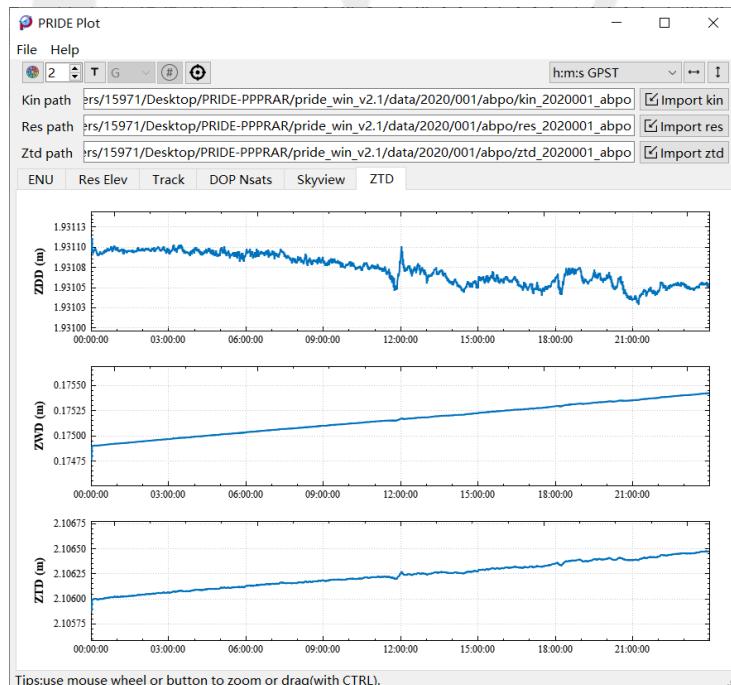


Figure 6-18 zdd, zwd and ztd-t charts

### Auxiliary functions

- (1) Cursor: Click the toolbar cursor switch button, then when the mouse moves into the plotting area, the cursor will follow the mouse and show both the horizontal and vertical axis values. If

the cursor button is clicked again, the cursor will be hidden. In particular, this feature is not available for the satellite sky view.

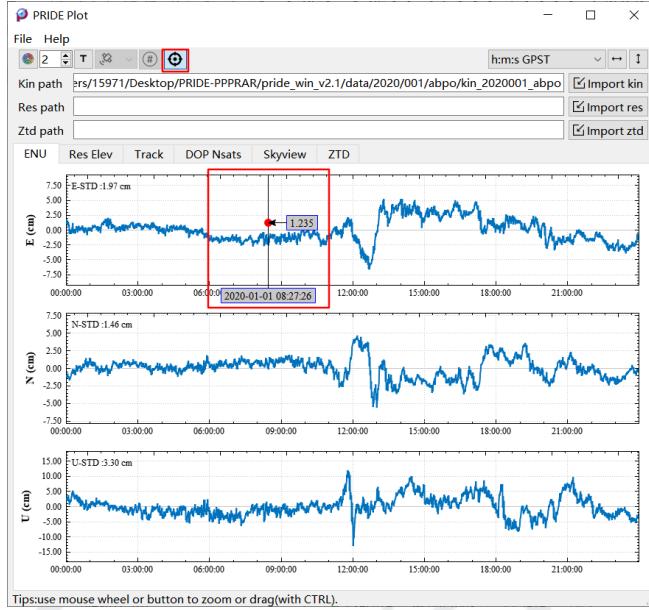


Figure 6-19 Cursor function demonstration

- (2) Frame or move data interval: Use the left mouse button to frame part of the data interval in the chart to achieve local zoom, and use the mouse wheel to zoom in locally with the mouse pointer position as the center; such as holding down the keyboard ctrl key at the same time, and hold down the left mouse button to move the chart where the mouse pointer is located left and right. In addition, the rightmost part of the toolbar has a button to restore the data display interval in the horizontal and vertical directions, click to reset the data display interval in the view respectively, while hitting the keyboard spacebar is equivalent to restore the horizontal and vertical directions at the same time.

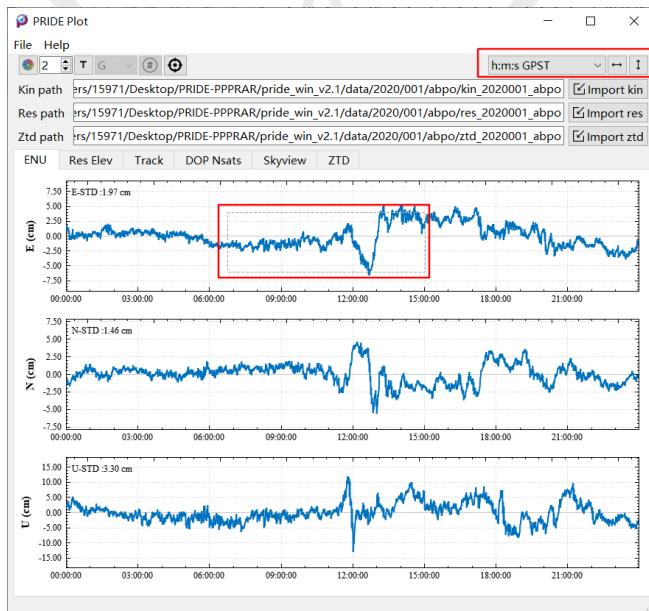


Figure 6-20 Local zoom function display

- (3) Change the style of the graph: the three leftmost controls of the toolbar serve to change the plotting line color, line width and scale text font, etc. In addition, you can also select the time format such as “h:m:s” according to the first combo box on the right in Figure 6-20.

# Appendix A. Required external files

This section briefly introduces the external files that need to be downloaded. For more information on the relevant files, please refer to the official website of IGS (<https://igs.org/>), the official website of IERS ([IERS](#)), etc.

## A.1 Precise products

### Satellite orbit products

The precise ephemeris product gives the orbit information of GNSS satellites at certain time intervals, including satellite coordinates, satellite clock errors and optionally motion velocity, coordinate standard deviation and satellite clock errors standard deviation. The current standard format is SP3 (Standard Product 3), including SP3-a, SP3-c and SP3-d. A brief description of SP3-d is given below, and the specific file format can be found at [sp3d.pdf \(igs.org\)](#).

#### 1. File header

- The first line starts with “#a”, “#c” or “#d”, indicating the SP3 file type; the third character is “P” or “V”, marking the position or speed; the penultimate data is the reference frame. It should be noted that PRIDE PPP-AR cannot recognize the "# a" version of sp3 files;
- The second line, beginning with “##”, records the GPS week for the corresponding day, the seconds of week, the sampling interval, the integer part and the fractional part of the MJD.

#### 2. Data blocks

- The line starting with “\*” marks the beginning of the epoch, followed by the corresponding epoch time;
- The first character of the data line is "P" or "V", followed by the PRN of the satellite;
- If the first letter is "P", the XYZ coordinates and clock deviation of the satellite will be recorded;
- If the first letter is "V", the change rate of satellite XYZ velocity and clock deviation is recorded;
- The end-of-file marker is "EOF".

```
#dP2021 1 1 0 0 0.00000000 1440 u+U IGS14 FIT WHU
## 2138 432000.00000000 60.00000000 59215 0.000000000000
+ 108 G01G02G03G04G05G06G07G08G09G10G12G13G14G15G16G17G18
+ G19G20G21G22G23G24G25G26G27G28G29G30G31G32R01R02R03
+ R04R05R07R08R09R12R13R14R15R16R17R18R19R20R21R22R24
+ E01E02E03E04E05E07E08E09E11E12E13E14E15E18E19E21E24
+ E25E26E27E30E31E33E36C01C02C03C04C05C06C07C08C09C10
+ C11C12C13C14C16C19C20C21C22C23C24C25C26C27C28C29C30
+ C32C33C34C35C36C37 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
++ 6 5 4 4 5 6 5 5 5 4 3 6 6 3 6 4
++ 5 5 6 5 4 5 4 4 4 6 5 6 6 5 5 5 5 3
++ 4 6 6 6 5 6 7 6 4 6 5 6 7 7 5 6 6
++ 6 5 6 6 4 5 5 6 5 6 5 6 6 6 6 4 6
++ 5 6 5 5 5 6 7 10 11 9 10 11 10 9 7 9 9
++ 7 6 7 8 9 5 7 6 7 5 7 6 5 6 6 6 7
++ 6 7 6 6 6 7 0 0 0 0 0 0 0 0 0 0 0 0
%c M cc GPS ccc cccc cccc cccc cccc cccc cccc cccc
%c cc cc ccc cccc cccc cccc cccc cccc cccc cccc
%f 1.2500000 1.025000000 0.00000000000 0.000000000000000
%f 0.0000000 0.000000000 0.00000000000 0.000000000000000
%i 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
%j 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
/* PCV:igs14_2148 OL/AL:FES2014b NONE YY ORB:CoN CLK:CoN
* 2021 1 1 0 0 0.00000000
PG01 13686.913718 -22099.331874 -4728.984961 787.523386
PG02 -19186.667008 9880.628187 -14824.322870 -560.896820
PG03 8561.424035 -13533.185254 -21253.783348 -44.532118
PG04 3793.780406 -21261.175099 -15424.276996 -169.081492
PG05 -24778.487941 3662.578471 8958.153908 -29.803304
PG06 -14414.317272 -5075.976878 -21665.436236 -4.584436
PG07 629.888463 -20311.343883 17168.828037 4.206769
PG08 9102.972867 -14406.457916 20306.648164 -4.949926
PG09 -6401.404378 -25206.795027 -5400.234870 -307.809463
PG10 20297.979374 11772.667043 12796.745618 -28.940789
```

Figure A-1 Example of a SP3-d file

## Clock difference products

The satellite clock difference product records the correction of the satellite time relative to the standard time. The latest file format is currently clock RINEX 3.04. A brief description of the corresponding format is given below, and the specific file format can be found at [https://files.igs.org/pub/data/format/rinex\\_clock304.txt](https://files.igs.org/pub/data/format/rinex_clock304.txt).

### 1. File header

- The comment “TIME SYSTEM ID” records the time system used;
- The comment “SYS / DCBS APPLIED” records the input bias-SINEX file;
- The comment “SYS / PCVS APPLIED” records the input ANTEX file;
- The comment “LEAP SECONDS” records the value of the leap seconds;
- The comment “SOLN STA NAME / NUM” records the station/receiver name, station/receiver identifier number and geocentric XYZ station coordinates.

### 2. Data blocks

- Column 1: Data type: "AS" represents satellite clock difference; "AR" represents the receiver clock difference (usually is the station);
- Column 2: The name of the satellite or station: "AS" means satellite PRN; "AR" represents the name of the station;
- Column 3-8: The epoch of the data occupies six columns (yyyy mm dd hh MM ss);
- Column 9: The number of clock difference data in this line (usually 1 or 2. If is 1, there will be only clock difference; if is 2, there will be add clock difference standard deviation);
- Column 10: Clock difference (unit: s);
- Column 11: Optional, when the value in the ninth column is 2, it represents the standard deviation of clock deviation (unit: s).

```

Clock information consistent with
WUM0MGXRAP_20210010000_01D_60S_ORB.SP3           COMMENT
WUM0MGXRAP_20210010000_01D_01D_ERP.ERP           COMMENT
Satellite clock values at intervals of 30 sec        COMMENT
Contact pride@whu.edu.cn                            COMMENT
Website pride.whu.edu.cn                           COMMENT
GPS                                                 TIME SYSTEM ID
18                                                 LEAP SECONDS
G PANDA          WUM0MGXRAP_20210010000_01D_01D_OSB.BIA   SYS / DCBS APPLIED
R PANDA          WUM0MGXRAP_20210010000_01D_01D_OSB.BIA   SYS / DCBS APPLIED
E PANDA          WUM0MGXRAP_20210010000_01D_01D_OSB.BIA   SYS / DCBS APPLIED
C PANDA          WUM0MGXRAP_20210010000_01D_01D_OSB.BIA   SYS / DCBS APPLIED
G PANDA          IGS14_2148.ATX                         SYS / PCVS APPLIED
R PANDA          IGS14_2148.ATX                         SYS / PCVS APPLIED
E PANDA          IGS14_2148.ATX                         SYS / PCVS APPLIED
C PANDA          IGS14_2148.ATX                         SYS / PCVS APPLIED
1 AS             # / TYPES OF DATA
WHU GNSS RESEARCH CENTER, WUHAN UNIVERSITY, P.R.CHINA ANALYSIS CENTER
1 # OF CLK REF
CEDU 50138M001 ANALYSIS CLK REF
159 IGS14      # OF SOLN STA / TRF
ABPO 33302M001 4097216530 4429119220 -2065771165SOLN STA NAME / NUM
.....
ZIMM 14001M004 4331296843 567556166 4633134123SOLN STA NAME / NUM
108 # OF SOLN SATS
G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G12 G13 G14 G15 G16 PRN LIST
G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 PRN LIST
G32 R01 R02 R03 R04 R05 R07 R08 R09 R12 R13 R14 R15 R16 R17 PRN LIST
R18 R19 R20 R21 R22 R24 E01 E02 E03 E04 E05 E07 E08 E09 E11 PRN LIST
E12 E13 E14 E15 E18 E19 E21 E24 E25 E26 E27 E30 E31 E33 E36 PRN LIST
C01 C02 C03 C04 C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 C16 PRN LIST
C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C32 C33 C34 PRN LIST
C35 C36 C37 PRN LIST
END OF HEADER
AS G01 2021 1 1 0 0 0.000000 1 0.787523386303E-03
AS G02 2021 1 1 0 0 0.000000 1 -0.560896819699E-03
AS G03 2021 1 1 0 0 0.000000 1 -0.445321176114E-04
AS G04 2021 1 1 0 0 0.000000 1 -0.169081492236E-03
AS G05 2021 1 1 0 0 0.000000 1 -0.298033041277E-04
AS G06 2021 1 1 0 0 0.000000 1 -0.458443554921E-05
AS G07 2021 1 1 0 0 0.000000 1 0.420676890748E-05
AS G08 2021 1 1 0 0 0.000000 1 -0.494992603914E-05

```

Figure A-2 Example of a clock RINEX 3.04 file

## Earth Rotation Parameter

When fixing the satellite orbit, ERP parameters need to be considered for data processing under the inertial reference frames. ERP files record the Earth rotation parameters, including polar position and UT1-UTC, etc. The current version is version 2. A brief description of the corresponding format is given below, and the specific file format can be found at [\[IGSMAIL-1943\] New IGS ERP Format \(version 2\)](#).

- MJD: modified Julian day
- Xpole and Ypole: pole coordinates
- UT1-UTC: Difference between UT1 (Universal Time) and UTC (Universal Time Coordinate)
- LOD: Length of day

```
version 2
DAY 1, YEAR 2021
-----
MJD      Xpole   Ypole   UT1-UTC   LOD   Xsig   Ysig   UTsig   LODsig   Nr Nf Nt   Xrt   Yrt   Xrtsig   Yrtsg
(10**-.6") (0.1 usec) (10**-.6") (0.1 usec) (10**-.6"/d) (10**-.6"/d)
59215.50    68274  304714 -1750491 -5274     8     9      7      5  159 159  77   -766   1633     10     13
```

Figure A-3 Example of an ERP file

## Code/Phase bias

The current version of the bias file is Bias-SINEX V1.00. The absolute bias OSB (Observable-specific Signal Bias) of the original code/phase observations is recorded in the PRIDE PPP-AR default product. A brief description of the corresponding format is given below, and the specific file format can be found at [sinex\\_bias\\_100.dvi \(igs.org\)](#).

### 1. File header

- The penultimate parameter in the first row is the bias model, with “A” denoting absolute bias and “R” denoting relative bias;
- The comment “OBSERVATION\_SAMPLING” records the sampling interval;
- The comment “PARAMETER\_SPACING” records the effective time span of the bias;
- The comment “TIME\_SYSTEM” records the time system used;
- The comment “APC\_MODEL” records the antenna correction model of the bias.

```
%=BIA 1.00 WHU 2021:232:39318 WHU 2021:001:00000 2021:001:86400 A 00001063
*-----
* Bias Solution INdependent EXchange Format(Bias-SINEX)
*-----
+FILE/REFERENCE
+INFO_TYPE      INFO
DESCRIPTION      PRIDE Lab, GNSS Research Center, Wuhan University
INPUT           IGS14_2148.ATX
OUTPUT          WHU 1-day rapid bias products in Bias-SINEX format
CONTACT         pride@whu.edu.cn
SOFTWARE        PANDA
HARDWARE        Centos: Linux, x86_64
-FILE/REFERENCE
*-----
+FILE/COMMENT
*PRODUCT_REFERENCE
GPS phase biases and phase clocks are estimated with the same stations
Published by PRIDE Lab, GNSS Research Center, Wuhan University
URL: ftp://igs.gnsswhu.cn/pub/whu/phasebias
URL: pride.whu.edu.cn
Overview of the satellite biases included in the file
GPS   C1C, C1W
GPS   C2C, C2W, C2L, C2S, C2X
GPS   C50, CSX
GLONASS C1C, C1P
GLONASS C2C, C2P
GALILEO C1C, C1X
GALILEO C50, CSX
GALILEO C6C
GALILEO C70, C7X
GALILEO C80, C8X
BDS-2   C2I
BDS-2   C7I
BDS-2   C6I
BDS-3   C1X, C1P
BDS-3   C2I
BDS-3   C5X, CSP
```

Figure A-4 Example of a code/bias file header

## 2. Data blocks

- The column sequence of data blocks is bias type, space vehicle number (SVN) of the satellite, satellite PRN, observation data type, start and end time, unit, bias value and its standard deviation;

Generally speaking, there are three types of bias, and the three bias values can be converted to each other according to the formula. It should be noted that PRIDE PPP-AR can only handle OSB type deviation files.

- Differential Signal Bias (DSB)
- Ionosphere-free Signal Bias (ISB)
- Observable-specific Signal Bias (OSB)

For observation types, it consists of three characters. The first character represents the type of observation value, usually C (code pseudo-range) or L (carrier phase); The second character is the frequency number, which has different label for different frequencies. The corresponding relationship between frequency and label can be seen in Table 5-4; The third character is the observation attribute, mainly distinguished by channel (branch) or code type.

- The file end flag is "%=ENDBIA"

```
+BIAS/SOLUTION
*BIAS SVN PRN STATION_ OBS1 OBS2 BIAS_START_ BIAS_END_ UNIT_ ESTIMATED_VALUE_ STD_DEV_ ESTIMATED_SLOPE_ STD_DEV_
OSB G063 G01 C1C 2021:001:00000 2021:001:06400 ns 0.956390000000000E+01 .172000E-01
OSB G063 G01 C1W 2021:001:00000 2021:001:06400 ns 0.107335000000000E+02 .509000E-03
OSB G063 G01 C2L 2021:001:00000 2021:001:06400 ns 0.162136000000000E+02 .416000E-01
OSB G063 G01 C2S 2021:001:00000 2021:001:06400 ns 0.162185000000000E+02 .496000E-01
OSB G063 G01 C2W 2021:001:00000 2021:001:06400 ns 0.162185000000000E+02 .496000E-01
OSB G063 G01 C2X 2021:001:00000 2021:001:06400 ns 0.164653600000000E+02 .610000E-01
OSB G063 G01 C50 2021:001:00000 2021:001:06400 ns 0.707190000000000E-01 .525000E-01
OSB G063 G01 C5X 2021:001:00000 2021:001:06400 ns 0.672590000000000E-01 .763000E-01
OSB G063 G01 L1C 2021:001:00000 2021:001:06400 ns -.124695839306045E+01 .116424E-01
OSB G063 G01 L1W 2021:001:00000 2021:001:06400 ns -.124695839306045E+01 .116424E-01
OSB G063 G01 L2W 2021:001:00000 2021:001:06400 ns -.193179422306557E+01 .188925E-01
OSB G063 G01 L2S 2021:001:00000 2021:001:06400 ns -.193179422306557E+01 .188925E-01
OSB G063 G01 L2L 2021:001:00000 2021:001:06400 ns -.193179422306557E+01 .188925E-01
OSB G061 G02 C1C 2021:001:00000 2021:001:06400 ns -.111071000000000E+02 .732000E-01
```

Figure A-5 Example of a code/phase bias file data blocks

## Quaternions

The quaternions file records the quaternions associated with the satellite attitude, which can be converted into a rotation matrix for the transformed of the earth-fixed system to the satellite-fixed system. The current file version is ORBXEX 0.09 (ORBit EXchange format) and the corresponding brief format is described below.

### 1. File header

- The comment “TIME\_SYSTEM” records time system, consistent with the satellite orbit/clock difference file
- The comment “EPOCH\_INTERVAL” records the sampling interval;
- The comment “COORD\_SYSTEM” records the ECEF (Earth Center Earth Fixed) frame involved in the transformation.

```
%=ORBEX 0.09
%
+FILE/DESCRIPTION
DESCRIPTION Satellite attitude quaternions of WHU GNSS rapid solution
CREATED_BY PRIDE Lab, GNSS Research Center, Wuhan University
CREATION_DATE 2021 09 01 15 03 00
INPUT_DATA u-u
CONTACT pride@whu.edu.cn
TIME_SYSTEM GPS
START_TIME 2021 1 1 0 0 0.000000000000
END_TIME 2021 1 2 0 0 0.000000000000
EPOCH_INTERVAL 30.000
COORD_SYSTEM IGS14
FRAME_TYPE ECEF
LIST_OF_REC_TYPES ATT
-FILE/DESCRIPTION
+SATELLITE/ID_AND_DESCRIPTION
G01
G02
G03
G04
G05
G06
G07
G08
```

Figure A-6 Example of a quaternions file header

## 2. Data blocks

The data blocks are marked by “+EPHEMERIS/DATA” and “-EPHEMERIS/DATA”.

- The current epoch line is marked with "# #", followed by the corresponding epoch time and the number of satellites in that epoch;
- The data row is marked with "ATT", followed by satellite PRN, number of data, and corresponding quaternion.

```
+EPHEMERIS/DATA
*ATT RECORDS: TRANSFORMATION FROM TERRESTRIAL FRAME COORDINATES (T) TO SAT. BODY FRAME ONES (B) SUCH AS
*          (0,B) = q.(0,T).trans(q)
*REC ID_      N   q0_(scalar)   q1_x   q2_y   q3_z
## 2021 01 01 00 00 0.000000000000 108
ATT G01      4   0.0073517832149779 -0.3321223384064447  0.5479071307935610  0.7677489691563009
ATT G02      4   0.3402538341753952  0.3002354837408475 -0.3560351632772442  0.8168995930602414
ATT G03      4   0.0484591928309526  0.1831033504492600 -0.2591092501550277 -0.9470941168482292
ATT G04      4   0.1069203119576232  0.1339736365491190 -0.4375600468391984 -0.8827005817437573
ATT G05      4   0.5662958751712760  0.0292807960652229 -0.8170189033867401  0.1045549054540916
ATT G06      4   0.0949382755672016 -0.2737637514495153 -0.1283321265132913 -0.9484571669449235
ATT G07      4   0.0575120861592225  0.1516730144530112 -0.8942494247512676 -0.4171398122504945
ATT G08      4   0.1188266213933063 -0.1947180209761077  0.9192863497307452  0.3207455900774349
ATT G09      4   0.2321295003625461  0.0348372110365338 -0.6301839128939313 -0.7401151935464672
ATT G10     4   0.2750776156997116  0.3941410640233388  0.7642288529814175 -0.4300457967033500
ATT G12     4   0.2035175787414587  0.2000545881893258 -0.2767905821578833  0.9175760080322030
ATT G13     4   0.2856794158925113 -0.0015783940180094 -0.9548189452364981  0.0818874949250409
ATT G14     4   0.3883506231434809  0.0018203162087713 -0.8747153061776299 -0.2899200115403300
ATT G15     4   0.1768128795176963 -0.0632962859235457 -0.9278902991090358  0.3221030559375204
ATT G16     4   0.0682758023991445 -0.8082866220576663  0.0972907666636814  0.5766677189953965
ATT G17     4   0.3271520070861443 -0.1198626323065541 -0.5312153727546062 -0.7722789271922652
```

Figure A- 7 Example of a quaternions data blocks

## IONEX maps

IONEX-Format (Ionosphere map Exchange format) is a global ionospheric product calculated daily by the IGS using observations from GNSS stations. It mainly provides a generic interface to IGS ionospheric products that supports the exchange of 2- or 3-dimensional TEC maps given in a geographic grid. A brief description of the corresponding format is given below, and the specific file format can be found at [ionex1.pdf\(jgs.org\)](http://ionex1.pdf(jgs.org)).

### 1. File header

- The lines with the label “DESCRIPTION” give a brief description of the technique, model, etc.;
- “INTERVAL” indicates the interval between the TEC maps, in seconds (integer);
- “# OF MAPS IN FILE” indicates the total number of TEC/RMS/HGT maps;
- “ELEVATION CUTOFF” indicates the minimum elevation angle in degrees;
- “BASE RADIUS” indicates the mean earth radius or bottom of height grid (in km);
- “HGT1 / HGT2 / DHGT” defines an equidistant grid in height;
- “LAT1 / LAT2 / DLAT” defines an equidistant grid in latitude;
- “LON1 / LON2 / DLON” defines an equidistant grid in longitude.

### 2. Data blocks

The data block of a single epoch is enclosed by “START OF TEC MPA” and “END OF TEC MAP”, “START OF RMS MAP” and “END OF RMS MAP”.

- “EPOCH OF CURRENT MAP” indicates the epoch of current MAP (UT);
- “LAT/LON1/LON2/DLON/H” record initializing a new TEC/RMS/HGT data block for latitude “LAT” (and height ‘H(GT)'), from “LON1” to “LON2”.

START OF TEC MAP											
EPOCH OF CURRENT MAP											
LAT/LON1/LON2/DLON/H											
1											
2021	1	1	0	0	0						
87.5-180.0	180.0	5.0	450.0								
13	13	14	14	15	15	15	15	16	16	16	15
14	14	13	13	12	11	11	10	9	8	8	5
4	4	3	3	3	2	2	2	2	2	2	2
2	3	3	3	3	4	4	4	5	5	6	8
8	9	9	10	10	11	12	12	13			
85.0-180.0	180.0	5.0	450.0								
15	16	17	19	20	21	21	22	23	23	23	21
20	19	18	16	15	13	12	10	8	7	5	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	2	2	3	4	6
7	8	9	10	11	12	13	14	15			
82.5-180.0	180.0	5.0	450.0								
16	17	19	21	23	24	25	27	28	28	29	26
25	23	21	19	16	14	11	9	7	4	2	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	2	2	3	4
5	6	7	8	10	11	13	14	16			
80.0-180.0	180.0	5.0	450.0								
16	18	20	22	24	26	28	29	30	31	32	29
27	25	22	19	16	13	10	7	4	2	0	0
0	0	0	0	0	0	0	0	0	0	0	1
1	2	2	2	2	2	2	2	2	2	3	4
5	5	6	8	9	10	12	14	16			

Figure A-8 Example of an IONEX maps file

## Grid-wise VMF1/VMF3

VMF1 and VMF3 are tropospheric mapping models developed by the Vienna University of Technology, Austria. VMF1/VMF3 value for arbitrary sites can be determined through interpolation from the grid-wise VMF1/VMF3 data. A brief description of the corresponding format is given below, and the specific file format can be found at [VMF Data Server - Products \(tuwien.ac.at\)](http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/).

### 1. File header

- The line where “! Epoch:” is located records the epoch corresponding to the file;
- “! Range/resolution” indicates the latitude and longitude ranges and their respective increments;

### 2. Data blocks

- latitude (unit: °)
- longitude (unit: °)
- hydrostatic “a” coefficient
- wet “a” coefficient
- hydrostatic zenith delay (unit: m)
- wet zenith delay (unit: m)

```
! Version: 1.0
! Source: J. Boehm, TU Vienna (created: 2021-03-22)
! Data_types: VMF1 (lat lon ah aw zhd zwd)
! Epoch: 2021 01 01 00 00 0.0
! Scale_factor: 1.e+00
! Range/resolution: -90 90 0 360 2 2.5
! Comment: http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/
90.0 0.0 0.00118018 0.00051471 2.3070 0.0296
90.0 2.5 0.00118018 0.00051471 2.3070 0.0296
90.0 5.0 0.00118018 0.00051471 2.3070 0.0296
90.0 7.5 0.00118018 0.00051471 2.3070 0.0296
90.0 10.0 0.00118018 0.00051471 2.3070 0.0296
90.0 12.5 0.00118018 0.00051471 2.3070 0.0296
90.0 15.0 0.00118018 0.00051471 2.3070 0.0296
90.0 17.5 0.00118018 0.00051471 2.3070 0.0296
90.0 20.0 0.00118018 0.00051471 2.3070 0.0296
90.0 22.5 0.00118018 0.00051471 2.3070 0.0296
90.0 25.0 0.00118018 0.00051471 2.3070 0.0296
```

Figure A-9. Example of a grid-wise VMF1 file

```

! Version:          1.0
! Source:           D. Landskron, TU Vienna (created: 2021-01-02)
! Data_types:       VMF3 (lat lon ah aw zhd zwd)
! Epoch:            2021 01 01 00 00 0.0
! Scale_factor:     1.e+00
! Range/resolution: -89.5 89.5 0.5 359.5 1 1
! Comment:          vmf.geo.tuwien.ac.at/trop_products/GRID/1x1/VMF3/VMF3_OP/2021/
89.5   0.5  0.00117105  0.00066185  2.3072  0.0338
89.5   1.5  0.00117107  0.00066421  2.3073  0.0338
89.5   2.5  0.00117108  0.00066495  2.3073  0.0337
89.5   3.5  0.00117110  0.00066328  2.3074  0.0337
89.5   4.5  0.00117113  0.00065998  2.3074  0.0336
89.5   5.5  0.00117115  0.00065458  2.3075  0.0336
89.5   6.5  0.00117116  0.00064727  2.3075  0.0335
89.5   7.5  0.00117118  0.00063827  2.3075  0.0334
89.5   8.5  0.00117120  0.00062723  2.3076  0.0333
89.5   9.5  0.00117123  0.00061520  2.3076  0.0331
89.5  10.5  0.00117125  0.00060236  2.3077  0.0330
89.5  11.5  0.00117127  0.00058876  2.3077  0.0329
89.5  12.5  0.00117131  0.00057491  2.3078  0.0327
89.5  13.5  0.00117133  0.00056083  2.3078  0.0326
89.5  14.5  0.00117135  0.00054727  2.3079  0.0324
89.5  15.5  0.00117138  0.00053527  2.3079  0.0323

```

Figure A-10 Example of a grid-wise VMF3 file

## SINEX

The SINEX (Solution Independent Exchange format) file records the station positions and velocity. The SINEX file with “.snx” suffix records the station position/velocity, and the SINEX file with “.ssc” suffix records the station coordinates. What we need is the SOLUTION/ESTIMATE Block, enclosed by the “+SOLUTION/ESTIMATE Block” and the “-SOLUTION/ESTIMATE Block”. The brief format of this section is presented below, and the specific file format can be found at [Microsoft Word - sinex\\_v202.doc \(iers.org\)](#).

- Index: Index of estimated parameters. Values from 1 to the number of parameters.
- \_TYPE\_: Identification of the type of parameter.
- CODE: Site code for which the parameter is estimated.
- PT: Point Code for which the parameter is estimated.
- SOLN: Solution ID at a Site/Point code for which the parameter is estimated.
- \_REF\_EPOCH\_: Epoch at which the estimated parameter is valid.
- UNIT: Units used for the estimates add sigmas.
- S: Constraint applied to the parameter.
- \_\_ESTIMATED\_VALUE\_\_: Estimated value of the parameter.
- \_\_STD\_DEV\_\_: Estimated standard deviation for the parameter.

```

+SOLUTION/ESTIMATE
*INDEX _TYPE_ CODE PT SOLN _REF_EPOCH_ UNIT S __ESTIMATED_VALUE__ __STD_DEV__
  1 STAX AB01 A    1 21:335:43200 m    2 -3.89656321430101e+06 2.19449e-03
  2 STAY AB01 A    1 21:335:43200 m    2 -3.95471543079333e+05 9.29684e-04
  3 STAZ AB01 A    1 21:335:43200 m    2  5.01714162850610e+06 2.54759e-03
  4 STAX AB07 A    3 21:335:43200 m    2 -3.42575038202844e+06 1.81464e-03
  5 STAY AB07 A    3 21:335:43200 m    2 -1.21468607197146e+06 1.03099e-03
  6 STAZ AB07 A    3 21:335:43200 m    2  5.22366245316521e+06 2.47390e-03
  7 STAX AB09 A    1 21:335:43200 m    2 -2.58361493551525e+06 1.33789e-03
  8 STAY AB09 A    1 21:335:43200 m    2 -5.46237009535480e+05 8.93759e-04
  9 STAZ AB09 A    1 21:335:43200 m    2  5.78650166876350e+06 2.61165e-03
 10 STAX AB51 A    1 21:335:43200 m    2 -2.38374983293552e+06 1.28158e-03

```

Figure A- 11 Example of a SINEX file

## A.2 Table files

### leap.sec

The time difference between UTC and UT1 needs to be kept within 0.9s as specified, otherwise the adjustment will take the form of leap seconds. The leap seconds file required by the software can be downloaded at <ftp://igs.gnsswhu.cn/pub/whu/phasebias/table/leap.sec>. It records the MJD and its leap second value on the day before the leap second occurred. Note that the first line of the leap seconds file ends with a “\*” sign to distinguish it from other files with the same naming format. In case of no internet access computing, the user needs to download the file beforehand and place it in the table directory specified in the configuration file.

```
+leap sec *
45151 21
45516 22
46247 23
47161 24
47892 25
48257 26
48804 27
49169 28
49534 29
50083 30
50630 31
51179 32
53736 33
54832 34
56109 35
57204 36
57754 37
59761 38
-leap sec
```

Figure A-12 Example of a leap.sec file

### sat\_parameters

The “sat\_parameters” file is used to record the satellite parameters. A brief description of the corresponding file format is as follows.

- PRN: PRN of the satellite;
- SVN: SVN of the satellite;
- LAUNCHED: Launch time of the satellite in the format of YYYYDDD:SSSSS;
- DECOMMISSIONED: Decommission time of the satellite in the format of YYYYDDD:SSSSS;
- COSPAR-ID: Committee on Space Research-ID;
- MASS: Mass of the satellite in the unit of kg;
- MAX\_YAW: Maximum speed of satellite rotation at the beginning of design
- FID: The frequency ID of the satellite;
- BLOCK-TYPE: Block type of the satellite;

#	LAUNCHED #PRN SVN	DECOMMISSIONED YYYYDDD:SSSSS YYYYDDD:SSSSS COSPAR-ID	MASS [KG]	MAX_YAW [DEG]	FID	BLOCK-TYPE
#-----	+prn_indexed					
G01	G032	1992327:00000 2008290:86399 1992-079A	930.00	0.000	0	BLOCK IIA
G01	G037	2008297:00000 2009006:86399 1993-032A	930.00	0.000	0	BLOCK IIA
G01	G049	2009083:00000 2011126:86399 2009-014A	1080.00	0.000	0	BLOCK IIR-M
G01	G035	2011153:00000 2011193:86399 1993-054A	930.00	0.000	0	BLOCK IIA
G01	G063	2011197:00000 0000000:00000 2011-036A	1633.00	0.000	0	BLOCK IIF
G02	G013	1989161:00000 2004133:86399 1989-044A	843.00	0.000	0	BLOCK II
G02	G061	2004311:00000 0000000:00000 2004-045A	1080.00	0.000	0	BLOCK IIR-B
G03	G011	1985282:00000 1994107:86399 1985-093A	455.00	0.000	0	BLOCK I
G03	G033	1996088:00000 2014230:86399 1996-019A	930.00	0.000	0	BLOCK IIA
G03	G035	2014248:00000 2014293:86399 1993-054A	930.00	0.000	0	BLOCK IIA
G03	G069	2014302:00000 0000000:00000 2014-068A	1633.00	0.000	0	BLOCK IIF
G04	G001	1978053:00000 1985198:86399 1978-020A	455.00	0.000	0	BLOCK I
G04	G034	1993299:00000 2015313:86399 1993-068A	930.00	0.000	0	BLOCK IIA
G04	G049	2016033:00000 2016257:86399 2009-014A	1080.00	0.000	0	BLOCK IIR-M
G04	G032	2016259:00000 2016340:86399 1992-079A	930.00	0.000	0	BLOCK IIA
G04	G034	2016344:00000 2017003:86399 1993-068A	930.00	0.000	0	BLOCK IIA
G04	G049	2017006:00000 2017132:86399 2009-014A	1080.00	0.000	0	BLOCK IIR-M
G04	G038	2017139:00000 2017195:86399 1997-067A	930.00	0.000	0	BLOCK IIA

Figure A- 13 Example of the sat\_parameters file

## ANTEX

The ANTEX (The Antenna Exchange Format) file is used to record the PCO/PCV at the satellite and station ends, which is stored in the “igsXX.atx” file, consistent with the current igsXX reference frame. The current version of the ANTEX file is Version 1.4. The brief description of the corresponding file format is as follows, and the specific format of the file can be viewed at <https://files.igs.org/pub/data/format/antex14.txt>.

### 1. File header

- “ANTEX VERSION /SYST” denotes file version and satellite systems included in the file
- “PCV TYPE / REFANT” denotes the phase center variation type, ‘A’: absolute values, ‘R’: relative values;

### 2. Data blocks

The data block contains satellite antennas and receiver antennas, all organized in a hierarchical sorting way, single data block enclosed by “START OF ANTENNA” and “END OF ANTENNA”. Satellite antenna part: first sorted according to the satellite system, then sorted according to satellite code “sNN”, and finally sorted according to “VALID FROM”.

- “TYPE / SERIAL NO” denotes the antenna type, satellite PRN, satellite SVN and cosplay-id;
- “DAZI” denotes increment of the azimuth, “0.0” denotes non-azimuth-dependent phase center variations;
- “ZEN1 / ZEN2 / DZEN” denotes the zenith distance “ZEN1” to “ZEN2” with increment “DZEN”;
- “VALID FROM” and “VALID FROM” represents the start of validity period and end of validity period in GPS time, respectively;
- “START OF FREQUENCY” and “END OF FREQUENCY” indicate the start and end of a new frequency section, respectively;
- “NORTH / EAST / UP” denotes the mean antenna phase center relative to the center of mass of the satellite in X-, Y- and Z-direction (unit: mm);
- The flag “NOAZI” denotes the non-azimuth-dependent PCV values, the PCV values from “ZEN1” to “ZEN2” were subsequently recorded.

```

BLOCK IIA          G01           G032      START OF ANTENNA
                  0             0   1992-079A TYPE / SERIAL NO
                               29-JAN-17 METH / BY / # / DATE
      0.0
      0.0 17.0  1.0
      2
      1992 11 22  0  0  0.0000000
      2008 10 16 23  59 59.9999999
IGS14_2163
G01
      279.00  0.00 2319.50
      NOAZI -0.80 -0.90 -0.90 -0.80 -0.40  0.20
G01
G02
      279.00  0.00 2319.50
      NOAZI -0.80 -0.90 -0.90 -0.80 -0.40  0.20
G02
END OF ANTENNA

```

Figure A-14 Example of the satellite section of an ANTEX file

Receiver antennas part: first sorted according to antenna type, then sorted according to receiver radome code, and finally sorted according to the “SERIAL NO”.

- “TYPE / SERIAL NO” denotes the antenna type and serial number;
- “NORTH / EAST / UP” denotes the mean antenna phase center relative to the antenna reference point (ARP). North, east and up component (in millimeters);
- IF “DAZI” > 0.0, the PCV value corresponding to the azimuth angle in increments of “DAZI” is recorded after the line where “NOAZI” is located.

```

TWIVSP6037L    NONE
ROBOT          Geo++ GmbH      5   12-NOV-20 START OF ANTENNA
                           TYPE / SERIAL NO
      5.0
      0.0 90.0  5.0
      21
IGS14_2163
      Freq. [MHz] | Freq. Codes
      -----+-----
      1602.000 | R01 R04
      1575.420 | G01 E01 J01 S01 C01
      1561.098 | C02
      1278.750 | E06 J06
      1268.520 | C06
      1246.000 | R02 R06
      1227.600 | G02 J02
      1207.140 | E07 C07
      1202.025 | R03
      1191.795 | E08 C08
      1176.450 | G05 E05 J05 C05 S05 I05
G01
      0.35  -0.70  48.82
      NOAZI  0.00  -0.10  -0.35  -0.64  -0.85  -0.88  -0.73  -0.50  -0.32  -0.34  -0.63  -1.08  -1.48  -1.57  -1.14  -0.19  1.00  1.93  2.02
      0.0  0.00  -0.02  -0.25  -0.61  -0.99  -1.27  -1.35  -1.23  -1.00  -0.76  -0.62  -0.61  -0.61  -0.47  -0.01  0.77  1.66  2.28  2.17
      5.0  0.00  -0.01  -0.23  -0.57  -0.94  -1.20  -1.28  -1.17  -0.96  -0.76  -0.68  -0.72  -0.76  -0.63  -0.15  0.66  1.57  2.15  1.91
      10.0 0.00  0.00  -0.21  -0.54  -0.89  -1.13  -1.20  -1.10  -0.91  -0.77  -0.76  -0.86  -0.94  -0.81  -0.29  0.59  1.55  2.10  1.72
      15.0 0.00  0.00  -0.19  -0.50  -0.83  -1.05  -1.10  -1.01  -0.86  -0.78  -0.84  -0.84  -0.84  -0.02  1.15  -1.01  -0.44  0.52  1.57  2.13  1.64
      20.0 0.00  0.01  -0.17  -0.47  -0.77  -0.97  -1.00  -0.91  -0.80  -0.78  -0.92  -1.19  -1.37  -1.24  -0.62  0.45  1.61  2.22  1.66
      25.0 0.00  0.02  -0.15  -0.43  -0.71  -0.88  -0.89  -0.80  -0.71  -0.76  -0.99  -1.35  -1.61  -1.50  -0.83  0.34  1.63  2.35  1.78
      30.0 0.00  0.02  -0.14  -0.40  -0.65  -0.79  -0.78  -0.68  -0.61  -0.72  -1.04  -1.50  -1.85  -1.79  -1.09  0.18  1.60  2.46  1.96
      35.0 0.00  0.03  -0.12  -0.37  -0.60  -0.70  -0.66  -0.55  -0.50  -0.65  -1.06  -1.62  -2.07  -2.08  -1.39  -0.06  1.50  2.52  2.16
      40.0 0.00  0.03  -0.11  -0.35  -0.55  -0.62  -0.55  -0.41  -0.36  -0.55  -1.04  -1.71  -2.27  -2.36  -1.72  -0.36  1.30  2.49  2.34
      45.0 0.00  0.03  -0.11  -0.32  -0.50  -0.54  -0.44  -0.28  -0.22  -0.44  -0.98  -1.74  -2.42  -2.63  -2.07  -0.73  0.99  2.35  2.43
      50.0 0.00  0.03  -0.10  -0.31  -0.46  -0.48  -0.34  -0.15  -0.08  -0.30  -0.89  -1.73  -2.51  -2.85  -2.41  -1.15  0.59  2.08  2.41

```

Figure A-15 Example of the receiver section of an ANTEX file

## Appendix B. Typical examples

### B.1 Daily solutions

We test a series of IGS static stations in 2020. Then we compare the static PPP-AR results with IGS SINEX solutions. The figures listed below (Figure B-1) record the difference between our solutions and IGS SINEX solutions in east/north/up directions, respectively. The X axis, which denotes day of year, ranges from 1 to 366. The Y axis denotes different stations. The color map, which ranges from blue to red, represents the difference value in the unit of centimeter.

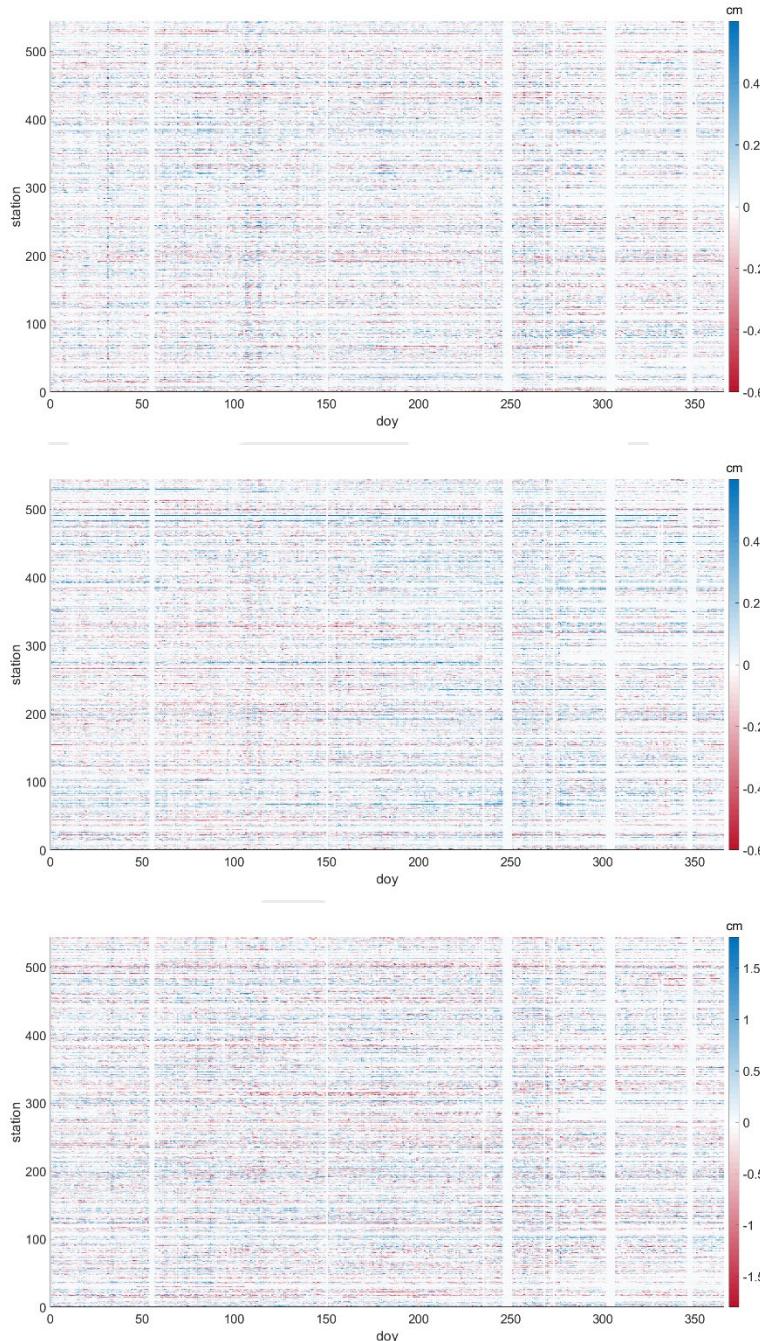


Figure B-1 Difference between PRIDE PPP-AR II solution and IGS SINEX solution of various stations.

## B.2 Super-high-rate (50 Hz) data

PRIDE PPP-AR II can still process super-high-rate data, up to 50 Hz. Then we test HLFY station (1300 kilometers away from epicenter), to presenting the 2011 earthquake of the Pacific coast of Tōhoku occurred in Japan at 05:46:24 (UTC) on March 11, 2011 with a magnitude of MW 9.0. As shown in Figure B-2, the evident horizontal vibration is reach about 10 centimeters.

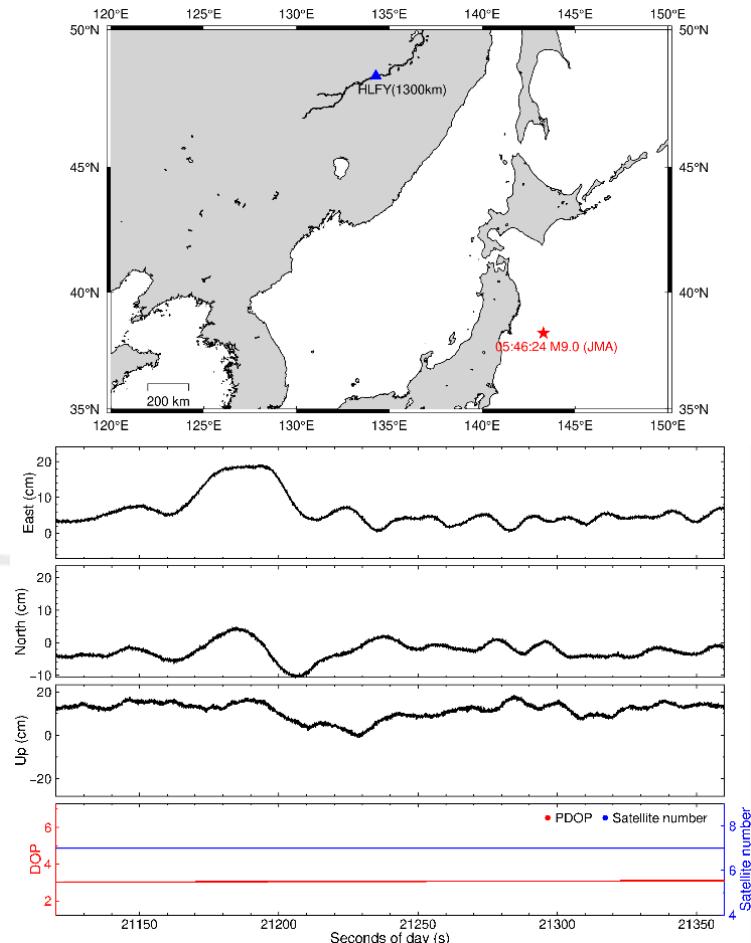


Figure B-2 Time series of super-high-rate kinematic solutions (cm) in east, north, and up components at station HLFY on March 11, 2011

## B.3 High-dynamic mobile platforms

In an aerial photogrammetry experiment, high-dynamic PPP has been realized. The observation period is on November 27, 2017 and lasting about 5 hours. The sampling rate is 0.5 seconds. The trajectory of the aircraft is shown in Figure B-3. And we use relative positioning solutions of WayPoint software (a commercial positioning software) as the reference solutions, whose maximum baseline length is up to 170 kilometers. As shown in Figure B-4, In the airborne experiment with less shielding, the positioning accuracy is basically the same with that of commercial software. Besides, fixed ambiguity can also significantly improve the positioning accuracy in high-dynamic data solutions.

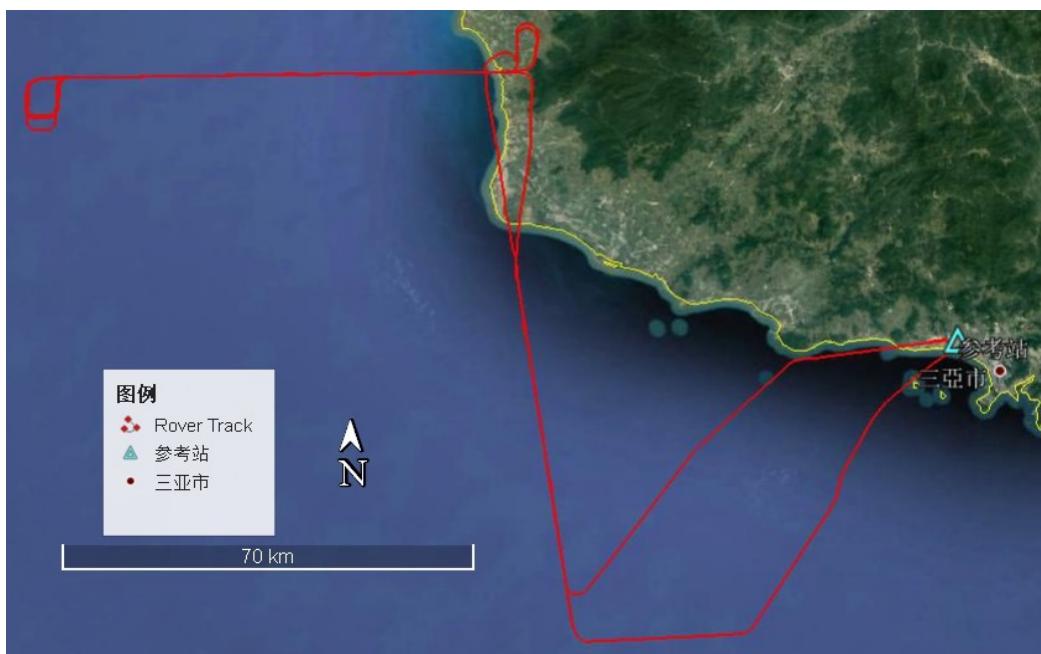


Figure B-3 Trajectory of the aircraft in high-dynamic aerial photogrammetry experiment

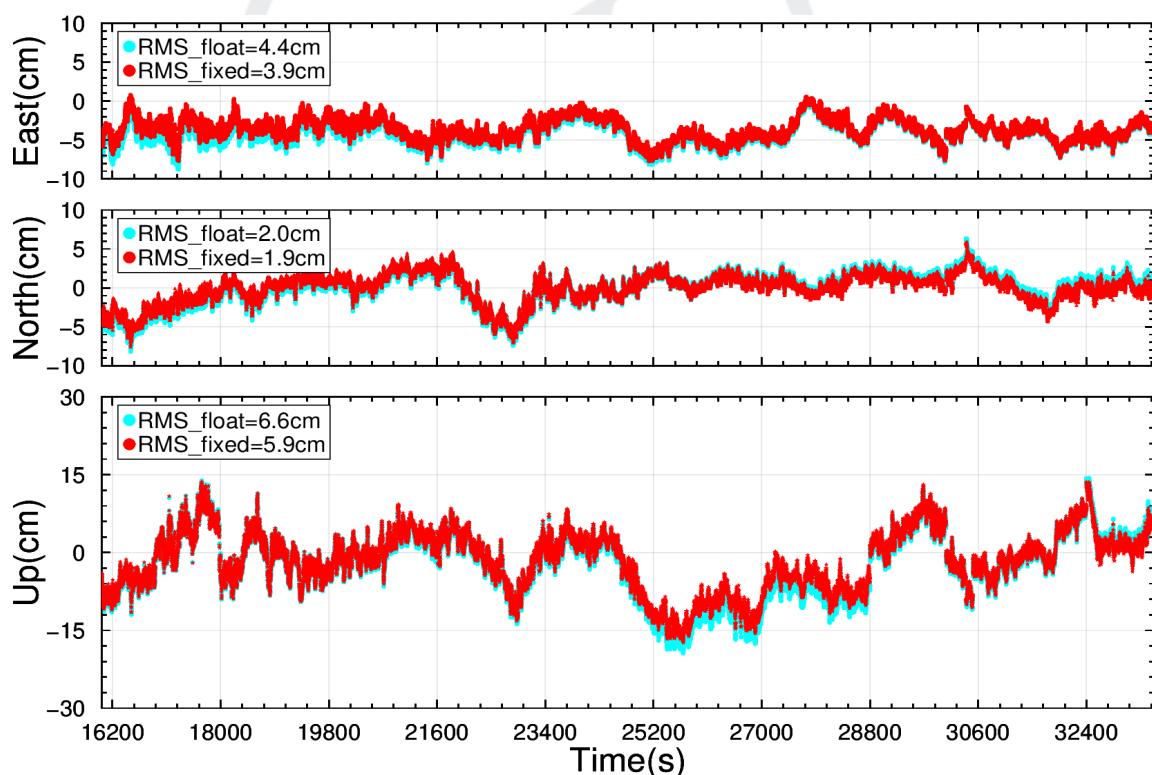


Figure B-4 Location differences between PRIDE PPP-AR and WayPoint software

## Appendix C. GPS data processing when SA is on

GPS data when SA is on have low-precision broadcast ephemeris, so the usage of broadcast ephemeris in these periods should be cautious. To process these GPS data for users easily, we have set some configurations in “***tedit***” module to avoid obtaining satellite clock corrections from broadcast ephemeris. Besides, users should change the “**Strict editing**” mode from “**YES**” to “**NO**” in configuration file. And change the products name in the configuration file.

As an example, we select precise satellite clock/orbit/ERP repro2 products of JPL to process GPS data when SA is on. We test an IGS station (ALBH) in 1995. The figure listed below (Figure C-1) records the position time series in east/north/up directions, respectively. The X axis, which denotes day of year, ranges from 1 to 365. The Y axis denotes changes of positions.

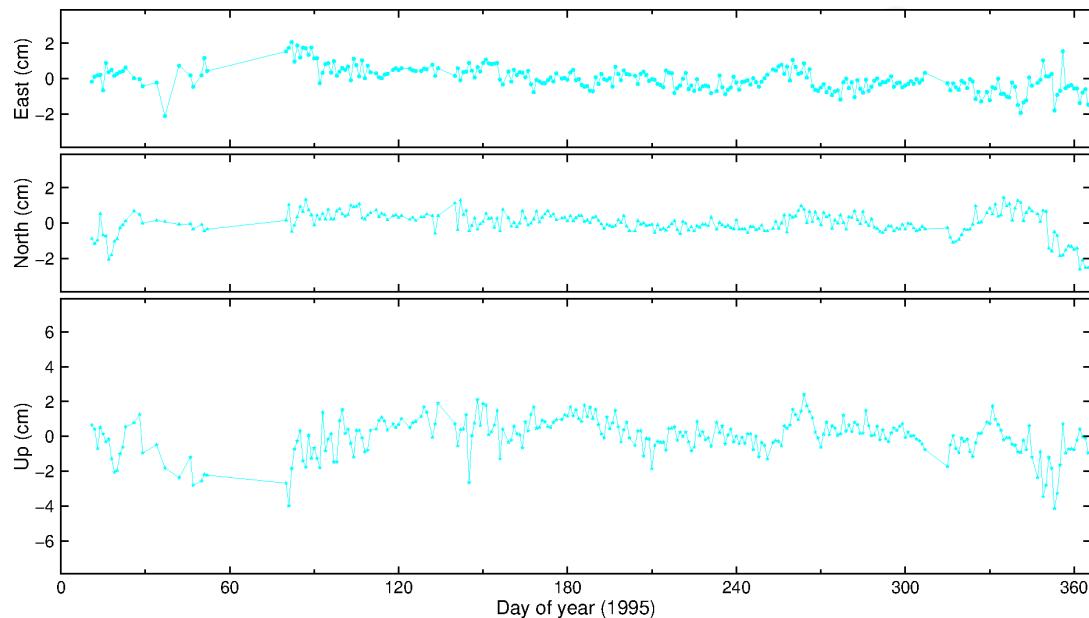


Figure C-1 Position time series at station ALBH in 1995

