

PRIDE PPP-AR III

MANUAL

Multi-GNSS Precise Point Positioning with Ambiguity Resolution

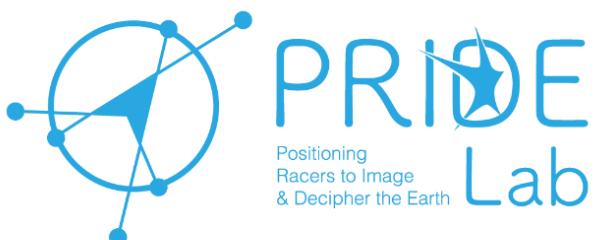
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**Dedicated to those
who are devoted to high-precision GNSS**



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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](#)
- [ZENG J, GENG J, LI G, et al. Improving cycle slip detection in ambiguity-fixed precise point positioning for kinematic LEO orbit determination\[J/OL\]. GPS Solutions, 2024, 28\(3\): 135. doi:10.1007/s10291-024-01639-1.](#)
- [Geng, J., Zhang, H., Li, G. et al. Multipath mitigation for GPS/Galileo/BDS-3 precise point positioning with overlap-frequency signals. Satell Navig 5, 22 \(2024\). <https://doi.org/10.1186/s43020-024-00144-7>](#)

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.
 - 15) Use oceanload correction module supported by Chinese Academy of Surveying and Mapping to enable oceanload correction without oceanload coefficient.
 - 16) determine whether cross-day ambiguities need to be truncated according to the bias-SINEX file DOCB data block;
 - 17) Support multipath modeling and compensation for static measurement stations.

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.

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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. 2024-8-15 (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
- Add oceanload correction module supported by Chinese Academy of Surveying and Mapping to enable oceanload correction without oceanload coefficient.
- Support random walk constraint between epochs in position domain for P-mode.
- Add function to determine whether cross-day ambiguities need to be truncated according to the bias-SINEX file DOCB data block.

14. 2025-01-06 (v3.1.0)

- Release of PRIDE PPP-AR v3.1.0
- Add mhmm module and corresponding command-line options, supporting multipath modeling and compensation for multiple constellations.

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; ρ_r^s is the station-satellite geometric distance; c is the speed of light in vacuum; δt_r and δt^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 ; λ_1 and λ_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 τ 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 ω 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

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

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.

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 multipath 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.

At present, the main algorithms for compensating multipath delay are sidereal filtering (SF) and multipath hemispherical map (MHM). The former utilizes the repeatability of satellite orbits to filter observations in the time domain, which requires a longer observation time and requires the establishment of separate models for each satellite, resulting in more complex calculations. The MHM also utilizes the repeatability of satellite orbits, but considers that the multipath delay of satellite signals from the same direction and frequency should be the same. A model is established with altitude and azimuth as independent variables, and satellites of the same frequency can use the same MHM model, which is simpler to calculate and more suitable for application.

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 错误!未找到引用源。 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 λ_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 错误!未找到引用源。, the clock is re-estimated in the

ionosphere-free combination (equation(3-12)), i.e.

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

where, $\delta t_{r,F}$ and δt_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:

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

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. If multipath correction is performed, mhm will generate the corresponding "mhm-file" to provide multipath correction values in the least-squares section. 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.

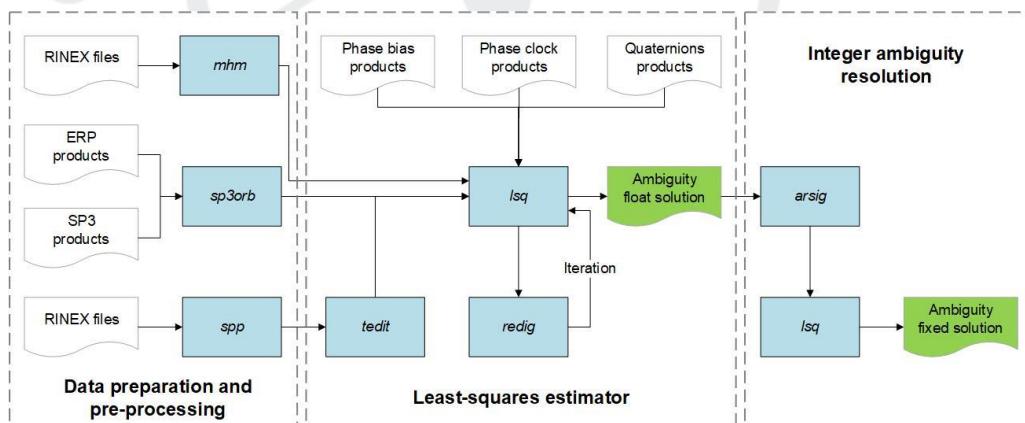


Figure 4-1 Program structure of PRIDE PPP-AR

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} -ti ${interval} -o
kin_${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, sampleing 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.

● **otl** is used to calculate the tide correction component of the station. The calculation code used in this module is the method from the website <https://www.zcphygeodesy.com/> provided by researcher ChuanYin Zhang, which is modularized into a separate executable program here. The usage is as follows. (Note: The results generated by this module are in binary files.)

```
otl -b ${lat} -l ${lon} -h ${hgt} -s ${ts} -e ${te} -i ${ti} -o ${outfile}
```

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

- [-b]** station latitude (unit: °)
- [-l]** station longitude (unit: °)
- [-h]** station ellipsoid height (unit: m)
- [-ts]** start time(format:year/month/day hour:minute:second)
- [-te]** end time(format:year/month/day hour:minute:second)
- [-ti]** interval (Unit: s)
- \${outfile}** output file name

- ***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} -rnxn ${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).

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

- ***mhm*** is used to construct the MHM model. Firstly, determine whether the “res-file” in the mhm folder was generated through F/S mode and whether it belongs to the same station. Secondly, divide the residuals of each satellite in each “res-file” into a $1^\circ \times 1^\circ$ grid according to their corresponding elevation and azimuth angles, and construct a 90×360 grid. Finally, perform quality control on the residuals in each $1^\circ \times 1^\circ$ grid, remove coarse errors, and output the mean value after removal as the multipath correction value for that grid to the “mhm-file”.

mhm \${resdir}

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

\$ {resdir} is residual folder for modeling

- ***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 *lsq* module to realize ambiguities fixed PPP solutions.

arsig \${config}

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

\${config} 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

YES

NO(Default)

Should requests for updating/downloading files be skipped to save processing time in offline mode.

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

Do not skip requests, automatic downloading of broadcast ephemeris and precise products, etc., is possible.

3. Product Settings

USECACHE=YES

YES(Default)

NO

Whether to use precision products and some table files under the local path

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

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. Determine whether to call the **PrepareMhmModel()** function to generate a “mhm-file” based on the settings;
6. Call the **ProcessSingleSession()** function based on input parameters to start the computation.

- The **PrepareMhmModel()** function is used to generate a “mhm-file” for the station, and its flow is as follows:

1. Obtain the satellite constellation and determine the modeling period based on the configuration file;
2. Check if the “res-file” for the modeling period exists; if it does not exist, use the Rinex OBS file and configuration file of the modeling period to calculate the “res-file” in S mode;
3. Call the mhm module to calculate the “mhm-file”.

- 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/>

Dailly: <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

VMF3: 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_{site} {year} {doy}

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/

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 otl

otl is used to calculate the tide correction component of the station. Tide correction is necessary to be considered for high-precision PPP positioning solution, and the tide correction has a great impact on the coastal station, and its component can be up to 5cm in U direction, so it needs to be eliminated in the solution.

There are two methods for tide correction calculation in the software. One is the conventional Scherneck method (the model is **FES2004**), but this method requires that the tide correction coefficients for the corresponding station coordinates are available in the oceanload file under the table directory. If users want to continue to use the conventional Scherneck's method to calculate the tide correction, they need to refer to section 5.4.3 to get the tide correction coefficients of the

stations (they need to submit the coordinates on the web site, and then get the tide correction coefficients by email), and then add the obtained coefficients into the oceanload file under the table directory, which is a cumbersome operation; In another way we borrowed the tide component calculation method from the geophysical geodesy large-scale scientific computing platform (www.zcphygeodesy.com) developed by researcher ChuanYin Zhang of the China Academy of Surveying and Mapping Sciences.

4.4.3 mhm

mhm is used to calculate the multipath correction values of stations. Multipath delay is one of the important error sources of high-precision PPP, which is difficult to eliminate or weaken through differential methods or observation value combinations, and restricts the precision of multi-system GNSS precision positioning.

The software currently uses the multipath hemispherical map to compensate multipath delay, which is mainly divided into two parts: first, check whether the header information of the “res-file” used for modeling meets the requirements, then obtain the signal frequency of each constellation and determine whether it belongs to overlap-frequency signal, and then divide the satellite residuals into a $360^\circ \times 90^\circ$ grid according to azimuth and elevation angles. Next, calculate the average and standard deviation of each $1^\circ \times 1^\circ$ grid, and perform quality control to eliminate errors. Finally, calculate the RMS and mean STD of the entire model as the model indicator output.

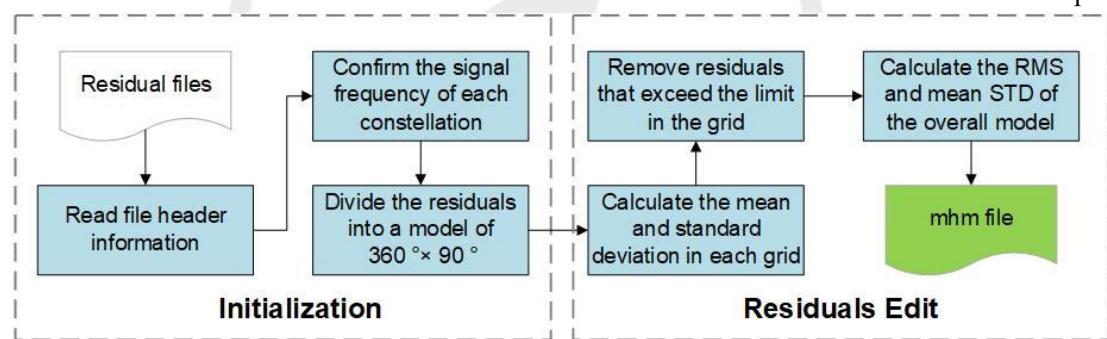


Figure 4-2 **mhm** algorithm flow.

4.4.4 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

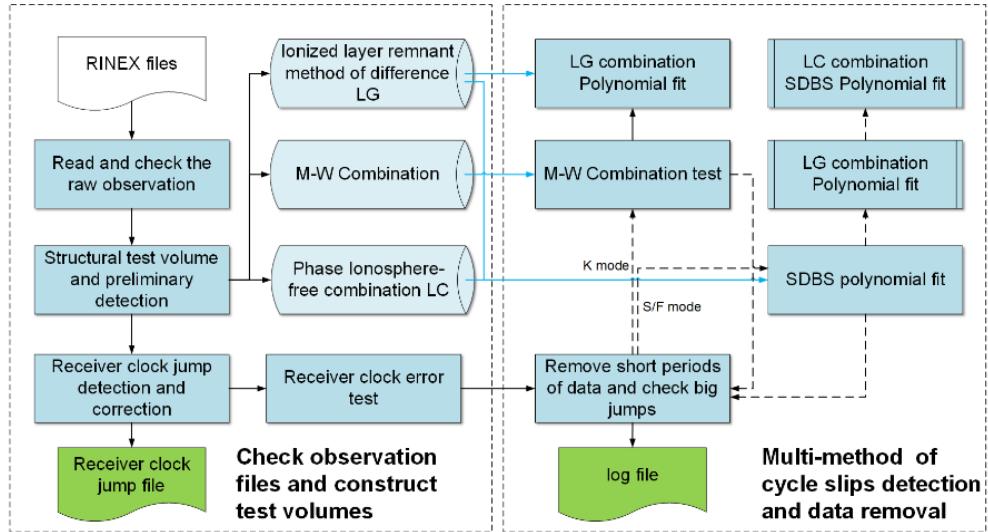


Figure 4-3 *tedit* algorithm flow. (The light blue columns indicate the constructed test volume; the blue line indicates the input of each test volume; the black dashed line indicates the running process controlled by the *pdp3* script and the process is performed only once; SDBS indicates the single 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:

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

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, ρ and ΔT^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:

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

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.

4.4.5 *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

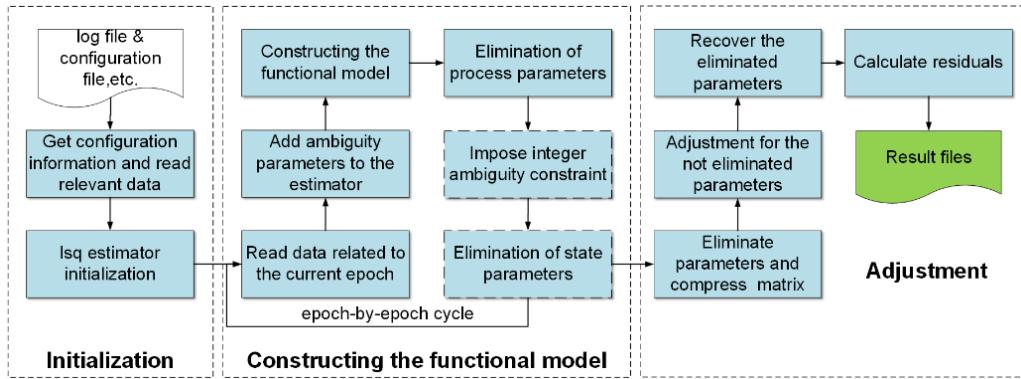


Figure 4-4 *lsq* algorithm flow. (The dashed box part is executed only when the ambiguity parameters is eliminated)

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.

4.4.6 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-.

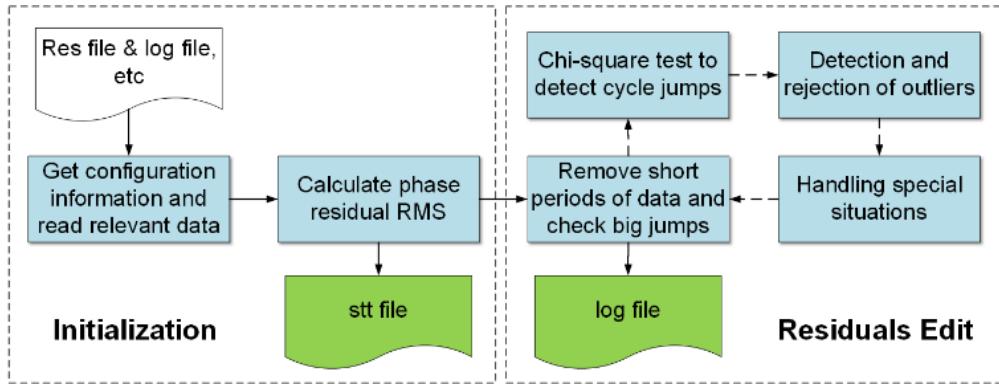


Figure 4-5 *redig* algorithm flow. The black dashed line indicates that the process is executed only once

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.

4.4.7 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-.

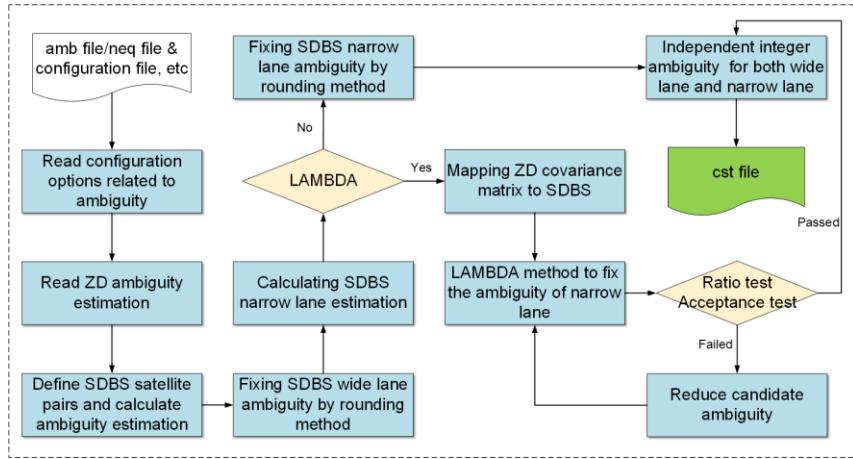


Figure 4-6. *arsig* algorithm flow. ZD indicates the zero difference

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 Aps(Command User Interface Application Programs, CUI Aps). 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

get_ctrl	Get configuration parameters
lsq	Least squares adjustment
otl	Calculation of tidal corrections
pboPOS	Convert “pos_” files to PBO position series
redig	Residual editing
sp3orb	Satellite orbit format and coordinate system conversion
spp	Standard single point positioning
tedit	Pre-processing of observation data
xyz2enu	Convert ECEF position in “kin_file” to ENU
\scripts	Scripts that facilitate data process
lat2obx.py	Convert LEO attitude products to ORBEX format
leoatx.py	LEO antenna information
merge2brdm.py	Merge GPS and GLONASS broadcast ephemerides to brdm file
pdp3.sh	Automatic processing Shell script (Linux)
plotkin2ps0.py	Python script for plotting LEO result
plotkin.py	Python script for plotting Kinematic results
plotkin.sh	GMT script for plotting Kinematic results
plotmhm.py	Python script for plotting MHM model
plotmhm.sh	GMT script for plotting MHM model
plotres.py	Python script for plotting Residuals
plotres.sh	GMT script for plotting Residuals
plottrack.py	Python script for plotting track
plotztd.py	Python script for plotting zenith troposphere delays
prepare_leodata.py	Prepare the data for low orbit satellites
\src	Source programs
arsig/	Ambiguity resolution
header/	Header files
lib/	Library functions
lsq/	Least squares adjustment
mhm/	Multipath delay compensation
otl/	Tidal load correction
orbit/	Satellite orbit format and coordinate system conversion
redig	Residuals edit
spp/	Standard point positioning

tedit/	Pre-processing of observation data
utils/	Universal tools
Makefile	Compile Command
\table	Dependent table files
FES2004S1.dat	Tidal load spherical harmonic coefficient model
Love_load_cm.dat	Load Love numbers
config_template	Configuration file template
file_name	File names definition
gpt3_1.grd	External grid file of meteorological parameters file ($1^\circ \times 1^\circ$)
leap.sec	Leap seconds
oceanload	Ocean tide loading file
orography_ell	Global terrain file for VMF1 ($2.5^\circ \times 2.5^\circ$)
orography_ell_1x1	Global terrain file for VMF3 ($1^\circ \times 1^\circ$)
sat_parameters	Satellite parameters
ANTEX files	Provide antenna offset data in need
install.sh	Installation script
ChangeLog.txt	Change log of the software
README.md	Software related information
LICENSE.txt	GPL3 protocol
\doc	Document flag
logo	The logo printed on screen when installing successfully
Manual	Manual of the software
\example	Examples
test.sh	Test script
\data	Data of examples
\results_ref	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.

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.

```

Bamf
Static      10.000000 10.000000 10.000000
YES
2024 6 26 0 0 0.00
2024 6 26 23 59 30.00
    30.00
    7.00
    0.30
    0.01
WUM0MGXRAP_20241780000_01D_05M_ORB.SP3
WUM0MGXRAP_20241780000_01D_30S_CLK.CLK
WUM0MGXRAP_20241780000_01D_01D_ERP.ERP
WUM0MGXRAP_20241780000_01D_30S_ATT.OBX
WUM0MGXRAP_20241780000_01D_01D_OSB.BIA
SEPT POLARXS
SEPCHOKE_B3E6 SPKE
    0.0000 0.0000 0.0000
G L1 1 -0.59 0.94 127.35
G L2 2 -0.35 0.22 141.43
R G1 1 0.69 -0.06 126.32
R G2 2 -0.41 0.18 141.11
E E1 1 -0.59 0.94 127.35
E E5a 5 -0.35 0.11 141.36
C B1I 2 -0.43 0.15 128.98
C B3I 6 -0.51 0.19 139.98
J L1 1 -0.59 0.94 127.35
J L2 2 -0.35 0.22 141.43
IGS20_2317
WNO
STO
PWC:720
NO
SOLID POLE OCEAN(Zhang)
YES GPS 42 GAL 27 BDS2 2 BDS3 33 QZSS 0 AMB FIXING
    600.00
    15.00
    0.20 0.15 1000.00
    0.15 0.15 1000.00
    3 4 1.80 3.00
DEFAULT
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)
        SITE ANTENNA PCO E/N/H (millimeter)
        TABLE ANTEX
        RECEIVER CLOCK
        TROP ZENITH
        TROP GRADIENT
        IONO 2ND
        TIDES
        AMB DURATION (sec)
        AMB CUTOFF (deg)
        AMB WIDELANE
        AMB NARROWLANE
        AMB SEARCH
        AMB AT DAT-BOUNDARY
        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

```

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.

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. And then next lines record the health diagnosis data. The comment “AMB” denotes adding a new ambiguity parameter. The content includes satellite number and ending time. The start time is the time which has been given at the line with “TIM”. The comment “DEL” denotes the data of the satellite deleted as bad data.

Rinex	Health	Diagnose	ABMF	COMMENT
30.00	30.00			INT AMB/DEL
35	151	0		AMB MAX/TOT/NEW
84016	15059	0		EPO AVA/REM/NEW
				END OF HEADER
TIM	2020	1 1 0 0	0.0000000	
G01			2020 1 1 5 7	30.0000000 AMB
G03				DEL_LOWELLEVATION
G07			2020 1 1 5 16	0.0000000 AMB
G08			2020 1 1 3 59	30.0000000 AMB
G09			2020 1 1 2 54	30.0000000 AMB
G11			2020 1 1 5 13	30.0000000 AMB
G16			2020 1 1 2 9	30.0000000 AMB

Figure 5-7 the RINEX health diagnosis (‘log_’) file

pos file

Static position results are recorded in the 'pos' file, with only one set of coordinates. The parameters in the ‘pos’ file are: station name, reference time (mjd / sod), coordinates (m), variance of X/Y/Z, covariance of XY/XZ/YZ, unit weighted mean errors (m), the number of observations used. This file only appears in the results of static solution. Besides, the **pbo** (Table 5-2) can be used convert “pos_” file to PBO format.

*Name	Mjd	X	Y	Z	Sx	Sy	Sz
abmf	58849.4997	2919785.7904	-5383744.9574	1774604.8600	0.45205365580695E-08	0.12554067299805E-07	0.19373651212222E-08
Rxy	Rxz	Ryz	Sig0	Nobs			
-0.62544711497610E-08	0.19899133644847E-08	-0.37287323791219E-08	0.27449728760266E+01	84244			

Figure 5-8 The static station coordinate (‘pos_’) file

rck file

The results of receiver clock are recorded in ‘rck’ file. In the file body, there are records of epoch time and receiver clock.

Year	Mon	Day	Hour	Min	Sec	RCK(GPS)	RCK(GLONASS)	RCK(Galileo)	RCK(BDS-2)	RCK(BDS-3)	RCK(QZSS)
2020	1	1	0	0	0.000000	-13728.219285	-13730.034491	-13731.471963	0.000000	-13746.530497	0.000000
Epoch time						RCK					
Year/Mon/Day/Hour/Min						GPS/GLONASS/Galileo/BDS-2/BDS-3/QZSS					
/Sec											
2020	1	1	0	4	0.000000	-13728.265477	-13730.091647	-13731.518927	0.000000	-13746.577134	0.000000
2020	1	1	0	4	30.000000	-13727.215732	-13729.004363	-13730.468355	0.000000	-13745.528060	0.000000
2020	1	1	0	5	0.000000	-13728.426294	-13730.250553	-13731.677951	0.000000	-13746.738652	0.000000
2020	1	1	0	5	30.000000	-13728.220995	-13730.046238	-13731.475552	0.000000	-13746.534211	0.000000
2020	1	1	0	6	0.000000	-13728.279183	-13730.106420	-13731.534766	0.000000	-13746.594715	0.000000
2020	1	1	0	6	30.000000	-13728.178309	-13730.005375	-13731.434285	0.000000	-13746.492892	0.000000
2020	1	1	0	7	0.000000	-13727.633369	-13729.456718	-13730.898063	0.000000	-13745.949818	0.000000
2020	1	1	0	7	30.000000	-13728.394478	-13730.212014	-13731.649080	0.000000	-13746.709727	0.000000
2020	1	1	0	8	0.000000	-13727.999439	-13729.816943	-13731.253353	0.000000	-13746.311681	0.000000
2020	1	1	0	8	30.000000	-13728.020207	-13729.838083	-13731.277005	0.000000	-13746.333749	0.000000

Figure 5-9 The receiver clock offset correction ('rck_') file

res file

The values of residuals for observation are recorded in 'res' file, as an output of **Isq**. The parameters in 'res' file are: PRN, phase residual (m), pseudo-range residual (m), pseudo-range/phase weights in the observation equation, data status identification (0 denotes satellite existed, 1 denotes satellite newly added), satellite elevation (°), azimuth (°), observation types.

Epoch time											
TIM	2020	1	1	0	0	0.000000	58849	0.00			
G01	-0.008	2.328	0.11584584D+06	0.46610807D+01	1	27.257	-178.149	L1C L2W C1W C2W			
G07	-0.003	0.771	0.61295961D+05	0.24662554D+01	1	19.459	-35.065	L1C L2W C1W C2W			
G08	0.008	-0.908	0.13807699D+06	0.55555556D+01	1	65.831	-27.950	L1C L2W C1W C2W			
G09	-0.020	-1.812	0.13807699D+06	0.55555556D+01	1	36.001	-91.299	L1C L2W C1W C2W			
G11	-0.000	0.384	0.13807699D+06	0.55555556D+01	1	48.517	-157.424	L1C L2W C1W C2W			
G16	0.004	-0.495	0.92782148D+05	0.37331085D+01	1	24.196	51.077	L1C L2W C1W C2W			
G23	0.003	0.627	0.13807699D+06	0.55555556D+01	1	40.829	-124.678	L1C L2W C1W C2W			
G26	0.005	-4.838	0.26461507D+05	0.10646841D+01	1	12.644	74.579	L1C L2W C1W C2W			
G27	0.000	0.525	0.13807699D+06	0.55555556D+01	1	40.864	21.277	L1C L2W C1W C2W			

↓ ↓ ↓

PRN Weights, data status identification, satellite elevation, azimuth and observation types

phase residual (m)
pseudorange residual (m)

Figure 5-10 the residuals for observation ('res_') file

stt file

The statistic value of phase residuals are recorded in 'stt' file and you can check this file to obtain the quality of PPP result. The parameters in the 'stt' file are: RMS of phase residuals (mm), time series of residuals (mm).

```
+RMS OF RESIDUALS--PHASE(MM)
NAME SUMM G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R1
1 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 E01 E02 E03 E04 E05 E07 E08 E09 E11 E12 E13 E14 E15 E21 E22 E25 E26 E27 E30 E31 E33 C01 C02 C03 C04 C05 C06 C07 C0
8 C09 C10 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C32 C33 C34 C35 C36 C37
ABMF 16 19 10 25 15 14 16 18 14 6 7 13 17 13 15 14 9 11 12 15 19 14 14 16 13 14 12 14 20 16 21 11 19 14 16 15 16 11 2
5 15 16 16 15 13 21 18 19 13 14 6 7 20 13 10 26 12 12 19 12 26 0 31 11 26 18 12 15 16 12 8 14 0 0 0 0 0 0 0 0
0 15 16 16 15 13 21 18 19 13 14 6 7 20 13 10 26 12 12 19 12 26 0 31 11 26 18 12 15 16 12 8 14 0 0 0 0 0 0 0 0
NAME SUMM G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R1
1 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 E01 E02 E03 E04 E05 E07 E08 E09 E11 E12 E13 E14 E15 E21 E22 E25 E26 E27 E30 E31 E33 C01 C02 C03 C04 C05 C06 C07 C08 C
8 C09 C10 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C32 C33 C34 C35 C36 C37
-RMS OF RESIDUALS--PHASE(MM)
+TIME SERIES OF RESIDUALS--PHASE(MM)
ABMF G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R11 R
12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 E01 E02 E03 E04 E05 E07 E08 E09 E11 E12 E13 E14 E15 E21 E24 E25 E26 E27 E30 E31 E33 C01 C02 C03 C04 C05 C06 C07 C08 C
09 C10 C12 C13 C14 C16 C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C32 C33 C34 C35 C36 C37

```

Figure 5-11 the phase residual of single satellite ('stt_') file

ztd file

The value of zenith tropospheric delay (ZTD) are record in 'ztd' file. The parameters in the 'ztd' file are: epoch time, initial value of dry tropospheric delay (m), initial value of wet tropospheric delay (m), wet tropospheric delay correction (m).

*	Year	Mon	Day	Hour	Min	Sec	ZDD	ZWDini	ZWDcor
2020	1	1	0	0	0.000000		2.311437	0.194235	0.040568
2020	1	1	0	0	30.000000		2.311463	0.193990	0.040568
2020	1	1	0	1	0.000000		2.311463	0.193990	0.040568
2020	1	1	0	1	30.000000		2.311463	0.193990	0.040568
2020	1	1	0	2	0.000000		2.311463	0.193989	0.040568
2020	1	1	0	2	30.000000		2.311463	0.193989	0.040568
2020	1	1	0	3	0.000000		2.311463	0.193989	0.040568
2020	1	1	0	3	30.000000		2.311463	0.193988	0.040568
2020	1	1	0	4	0.000000		2.311463	0.193988	0.040568
2020	1	1	0	4	30.000000		2.311463	0.193988	0.040568
2020	1	1	0	5	0.000000		2.311463	0.193987	0.040568
2020	1	1	0	5	30.000000		2.311463	0.193987	0.040568
2020	1	1	0	6	0.000000		2.311463	0.193987	0.040568
2020	1	1	0	6	30.000000		2.311463	0.193986	0.040568
2020	1	1	0	7	0.000000		2.311463	0.193986	0.040568
2020	1	1	0	7	30.000000		2.311463	0.193986	0.040568

epoch time

initial value of dry / wet tropospheric delay,
wet tropospheric delay correction

Figure 5-12 the zenith tropospheric delay ('ztd_') file

kin file

The results of position are recorded in 'kin' file when using the K model (kinematic), P model (piece-wise const) or L model (Low earth orbit). The coordinates in this file are recorded epoch by epoch. The parameters in the 'kin' file are: reference time, position coordinates X/Y/Z (m), position coordinates B/L/H (°/°/m), number of satellites, PDOP. Besides, You can run *xyz2enu* to get the corresponding topocentric coordinate.

As shown in Table 5-2, there are some useful scripts under the “scripts/” directory that facilitate users to process results. Note that if your Python 3 path is not “/usr/bin/python3”, you can use the **which** command to find the path of python3 in your computer.

```
which python3
/usr/local/bin/python3
```

Then, modify these python programs’ header to the corresponding path.

```
#!/usr/bin/env python3
#!/usr/local/bin/python3
```

Copy the modified python scripts to the path where software environment variables are located (~/.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

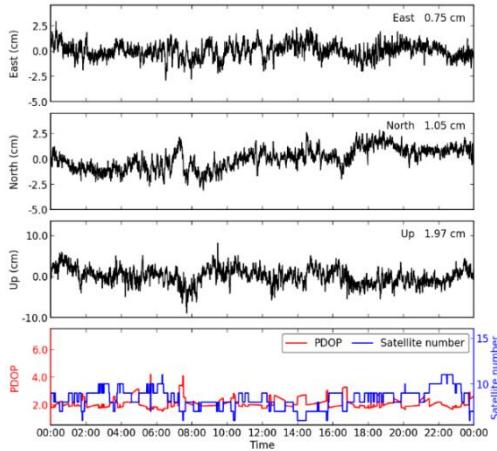
Plots of position time series

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 5-15 Example of *plotkin.py*

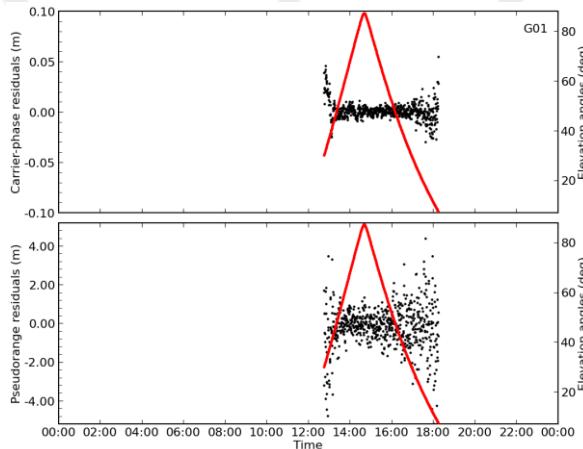
Plots of residuals

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 <i>plotres.py</i> , and the picture will be saved as “PRN.png”
png_filename	denotes the PNG format picture will be saved in <i>plotres.sh</i> , and the <i>plotres.sh</i> will plot all satellites contained in the ‘res’ file

Figure 5-16 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

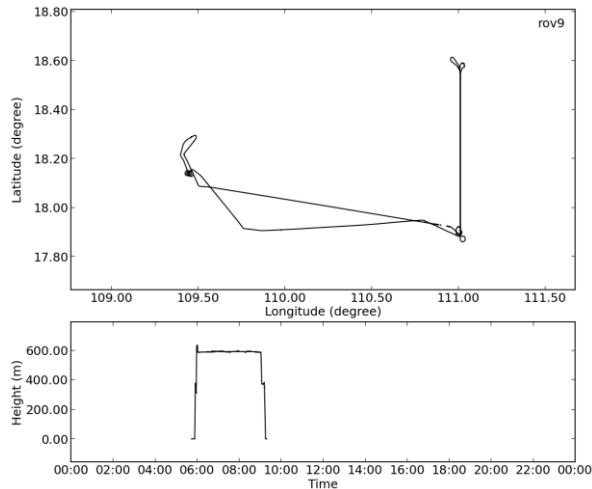


Figure 5-17. Example of plottrack.py

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

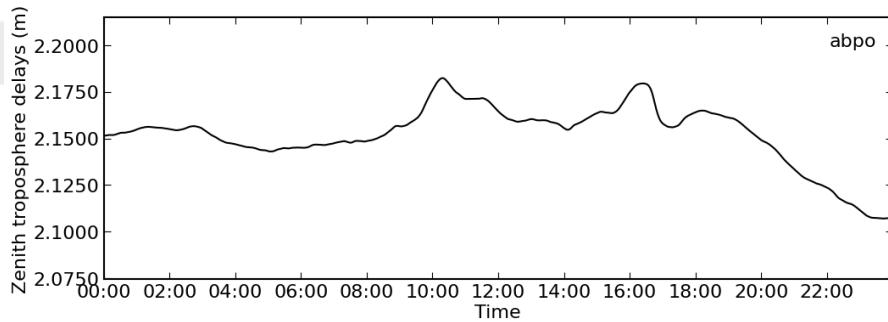


Figure 5-18 Example of plotztd.py

Plots of LEO satellites positio time series

plotkin2psos.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

```
plotkin2psos.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

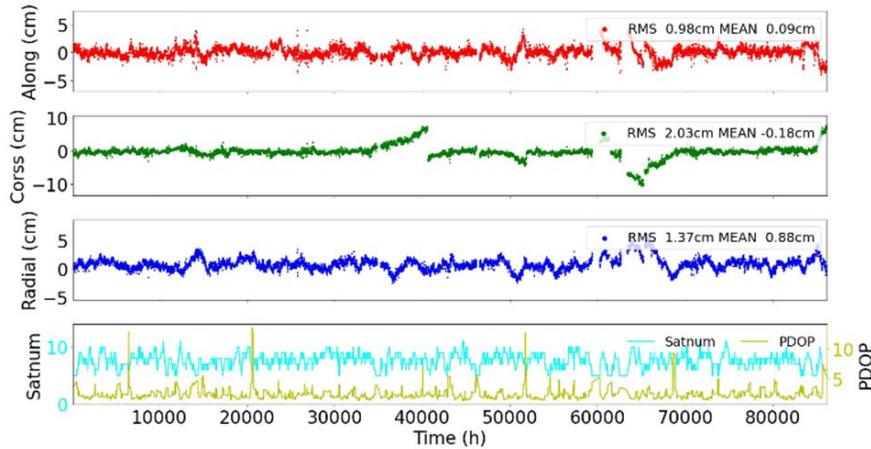


Figure 5-19 Example of plotkin2psosh

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).

Plots of MHM model map

plotmhm.py is used to plot the MHM model map.

```
plotmhm.py mhm_file [png_file]
```

where

mhm_file is the name of mhm-file
png_file is the PNG format picture name to be saved

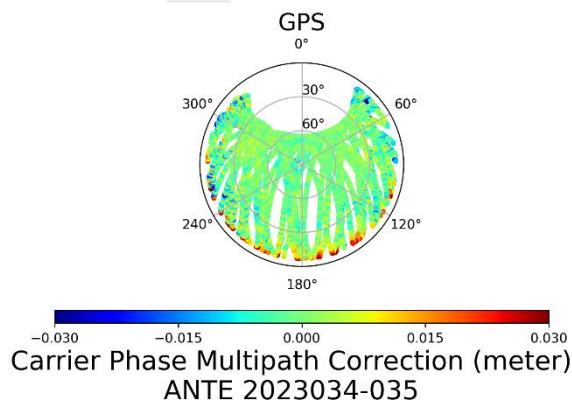


Figure 5-209 Example of plotmhm.py

5.3.3 Table Files

Ocean Tide Loading File

As shown in Section 错误!未找到引用源。, there are two strategies for the software's current tide correction, one is the conventional Scherneck method (modelled as **FES2004**), and the oceanload in the table file are the files needed for the first method. The second is to cite researcher ChuanYin Zhang's computational method, and the Love_load_cm.dat and FES2004S1.dat in the table file are the files needed for the second method.

The first method needs to get the tide coefficient information, some stations may be missing. If you need to get the tide coefficient information, you can submit the station coordinates to the website (<http://holt.oso.chalmers.se/loading/>) according to the need. Then the acquired data will be copied to the local tide coefficient file oceanload. site coordinates in *sit.xyz* can be used to acquire tide coefficient information. The parameters and format of these files are described on the website, and the submission method is described in section 5.4.3.

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 5-21):

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 5-21 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 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 5-22. 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 "GREGC2J":
-----+-----+-----+-----+-----+-----+-----+-----+
  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 5-22 `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
G	L1	L2	L5			
R	L1	L2				
E	E1		E5a	E6	E5b	E5
C	B1C	B1I	B2a	B3	B2b	B2
J	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[length]> [constraint] 或 --mode <char[length]> [constraint]:** 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; for P mode, one can also set the positional random walk constraint between epochs, the unit is m/sqrt(s), the default constraint value is 0.01m/sqrt(s); **and the positional random walk constraint is only applicable to P mode.** 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 "staname 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.
 - **-mp [num], --multipath [num]**: perform multipath compensation. When this option is not entered, no multipath compensation is performed. [num] represents the number of days for additional modeling outside of a sidereal day. When [num] is a positive number, it represents modeling using data before that day. When num is a negative number, it represents modeling using data after that day. If this parameter is not set, a sidereal day is used by default for modeling.
 - **-h <char[length] [num]>, --htg <char[length] [num]>**: disable horizontal tropospheric gradient (HTG) estimation. Options include (1) S: STO model. (2) P: PWC model. (3) N: NO model used. [length] sets PWS model's estimate time, options have 60, 720, default is 720min. [num] sets process noise parameters, default P model is 0.002m/sqrt(h), S model is 0.0004m/sqrt(s).
 - **-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.
- **-toff <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.
- **-twnd <num>, --time-window <num>**: processing time window in seconds, for not standard or super high rate RINEX observation file. The range is 0.0001~1.
- **-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 [num], --rck [num]**: receiver clock offset estimation using the random walk model. The default mode for receiver clock estimation is white noise estimation. But when you specify the option “-r”, it changes to the random walk model. 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

- **Multipath** = Default

Multipath compensation, corresponding to command line option is **-mp** or **--multipath**. "Default" means NO. If changed to YES, multipath compensation will be enabled, and the improvement effect depends on the station environment.

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 **--wape-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 = Default

Whether to truncate the ambiguity at midnight is used to solve the discontinuity at the day boundary, the default setting is Default, that is, the ambiguity will be truncated at midnight or not by simple calculation based on the DOCB data block in the bias-SINEX file, when the DOCB data block does not exist in the bias-SINEX file, the ambiguity will be forced to be truncated at midnight; when set to YES, the ambiguity will be forced to be truncated at midnight; when set to CON, the ambiguity will be forced continuous at midnight.

- 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
```

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 5-23), 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](#).

Figure 5-23 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 5-24).

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 5-24 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/abmf0010.200`
- 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 **pbopos** to convert “pos_” file to PBO format.
`pbopos abmf pos_2020001_abmf`
- 5) Plot residuals to analyze the solution.

```
plotres.py res_2020001_abmf G01
```

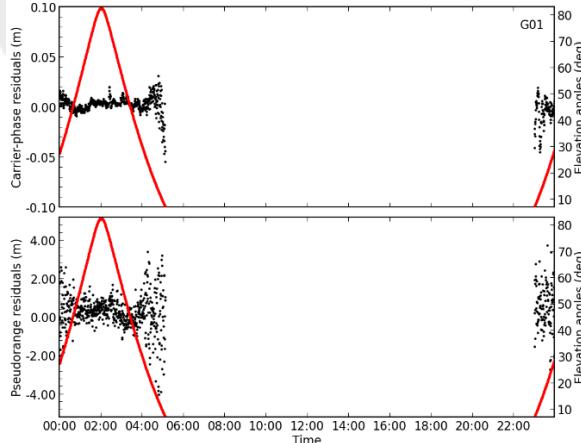


Figure 5-25 Residuals of abmf, 001 day in 2020

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/ccj22100.210`
- 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_20211210_ccj2 enu_20211210_ccj2
```

- 5) Plot displacement of station.

```
plotkin.py kin_20211210_ccj2 enuts_ccj2
```

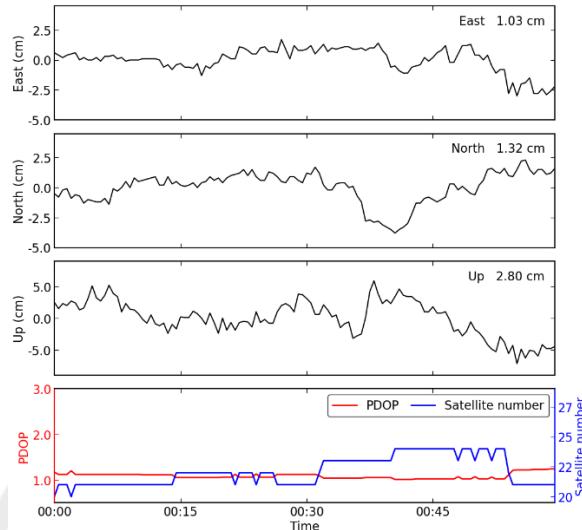


Figure 5-26 Position time series of ccj2, 210 day in 2021

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/ac122100.210
```
- 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_20211210_ac12 enuts_ac12
```

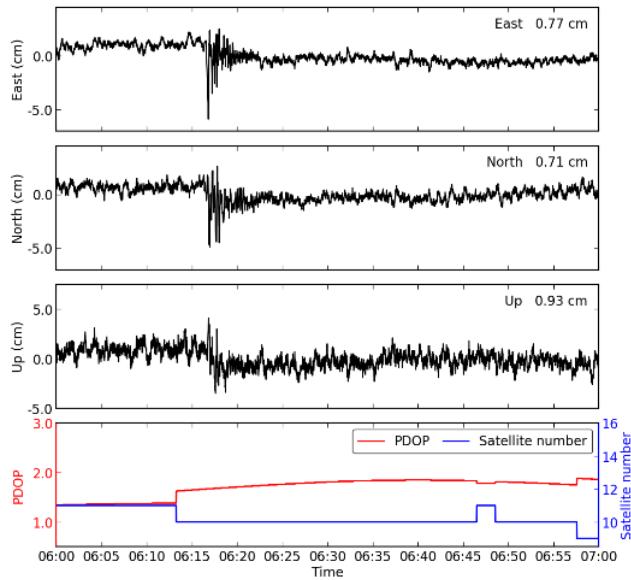


Figure 5-27 Position time series of ac12, 210 day in 2021

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 **--wapec-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/.
- 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>Code/phase 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/ccj22100.210`
- 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`

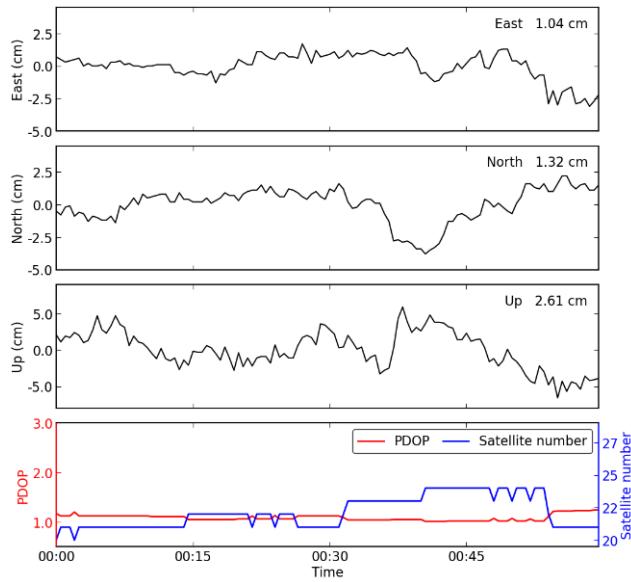


Figure 5-28 Position time series of ccj2, 210 day in 2021

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

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

Satellite parameter file: 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/BAK000IDN_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
```

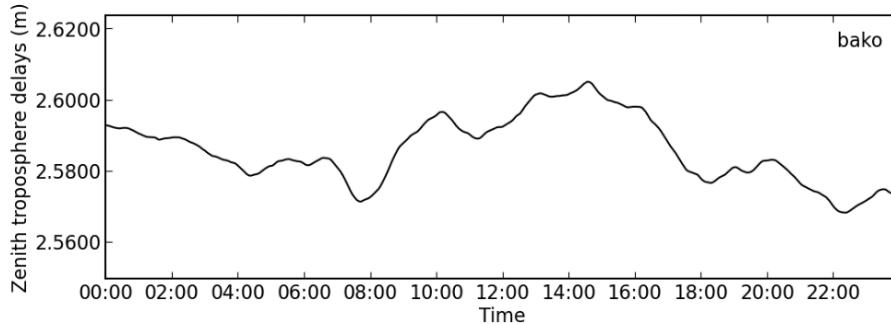


Figure 5-29 ZTD time series of bako, 220 day in 2021

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/2023/grac0010.23o`
- 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`

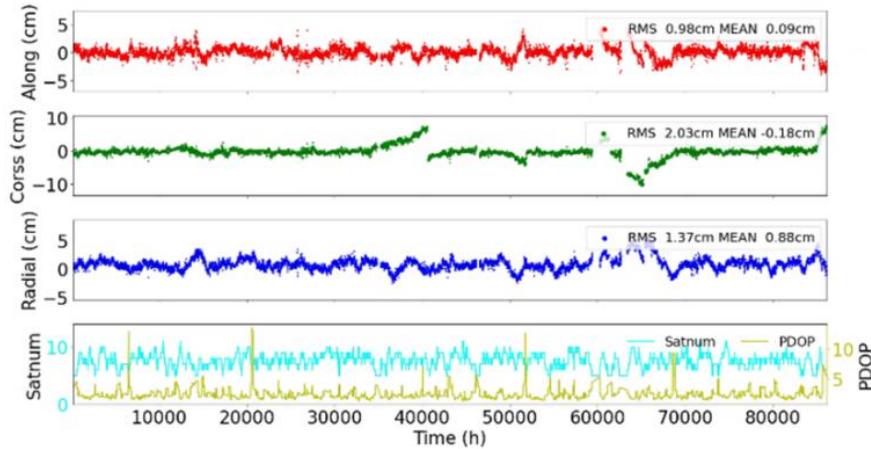


Figure 5-30 Time series diagram of grace satellite's resolution accuracy on the 1 day of 2023

Example 7: Adding random walk constraint in position domain

To add random walk constraint in position domain, the P mode of the software must be required (other modes are not supported). It is used as follows:

```
pdp3 -m <p[length] [constraint]>
```

Where -m is the mode setting, length is the time length, and constraint is the value of the constraint in m/sqrt(s), the default is 0.01m/sqrt(s). For the specific usage of each parameter of the pdp3 command, refer to 5.4.1.

A common setting for observation data with a 30s sampling rate is `-m p30 0.0001`, which has the specific meaning that the solution is performed in P-mode, with a solution length of 30s and an additional between-epoch random walk constraint of magnitude 0.0001 m/sqrt(s).

- 1) Back to the 'Practice' directory and create 'Practice7' directory.
- 2) Data preparation. Users are requested to prepare observation data of 2024 doy 001, sampling 30s for abpo station and place it in the Pratice7 folder. There are several methods to get data, here is a ftp link "ftps://igs.gnsswhu.cn/pub/gps/data/daily/2024/001/24o/abpo0010.24o.gz";
- 3) Open the terminal, switch to the "Practice/Practice7" directory, and enter the following command to start data processing;

```
pdp3 -m P30 0.0001 abpo0010.24o
```

- 4) Enter the command to draw a timing diagram for constraint positioning between calendar elements;

```
plotkin.sh 2024/001/kin_2024001_abpo abpo_P30
```

- 5) Compare the positioning timing diagrams for the default K mode.

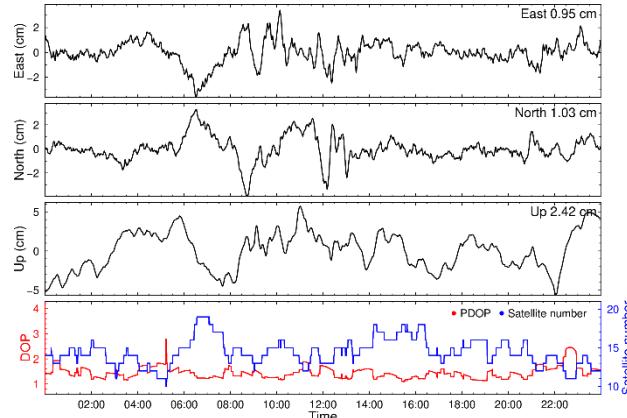


Figure 5-31 random walk constraint (0.0001 m/sqrt(s)) position sequence for abpo of 2024 001

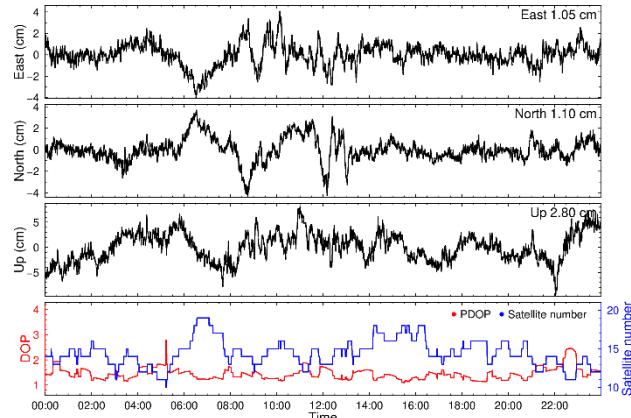


Figure 5-32 kinematic position sequence for abpo of 2024 001

Example 8: Cross-day solution and docb product testing

The software currently supports cross-day solution, using the -s and -e parameters to set the start and end time, and prepare the observation file of multiple days. When starting cross-day solution, it is inevitable to encounter the problem of whether the cross-day ambiguity is truncated or not, the OSB product of WUM0MGXRAP provides the docb indicator to assist in determining whether the cross-day ambiguity is truncated or not, this example will introduce the cross-day solution. The steps are as follows:

- 1) Back to the 'Practice' directory and create 'Practice8' directory.
- 2) Data preparation. Users are requested to prepare their own observation data from doy 027-028 in 2024 of bamf, and place them in the Practice8 folder;
- 3) Open the terminal, switch to the "Practice/Practice8" directory, and enter the following command to start data processing (refer to Section 5.4.1 for the detailed explanation of the command);

pdp3 -s 2024/178 20:00:00 -e 2024/179 04:00:00 -sys GEC bamf1780.240

- 4) Enter the command to draw a timing sequence for positioning;

plotkin.sh 2024/178-179/kin_2024178_bamf bamf_docb

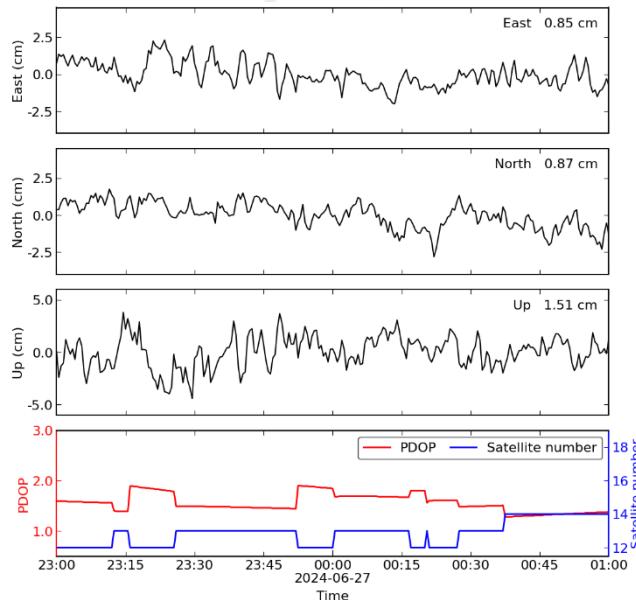


Figure 5-33 Time sequence plot of cross-day position on doy 178-179 in 2024 of bamf (half-hourly)

results before and after the day boundary)



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.

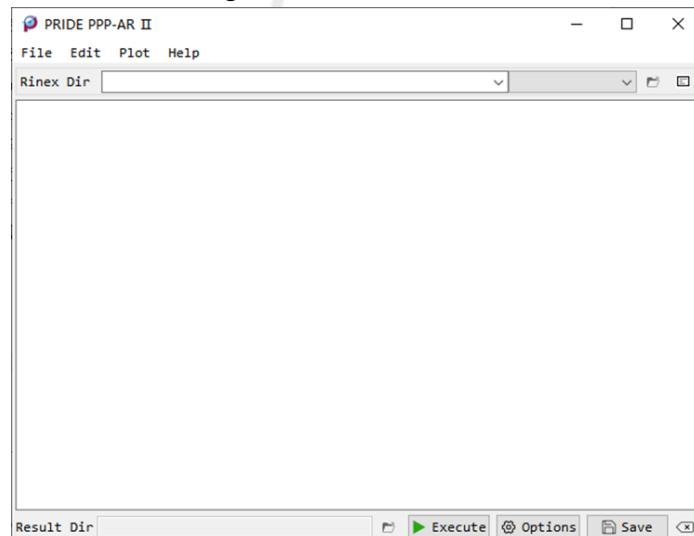


Figure 6-1. Main interface of the software PRIDE PPP-AR

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.

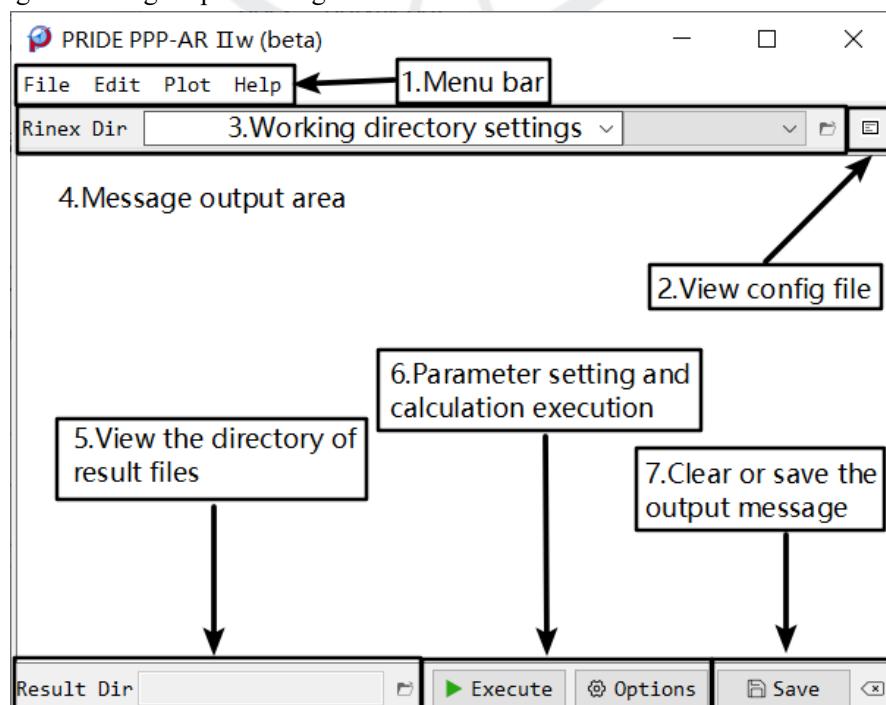
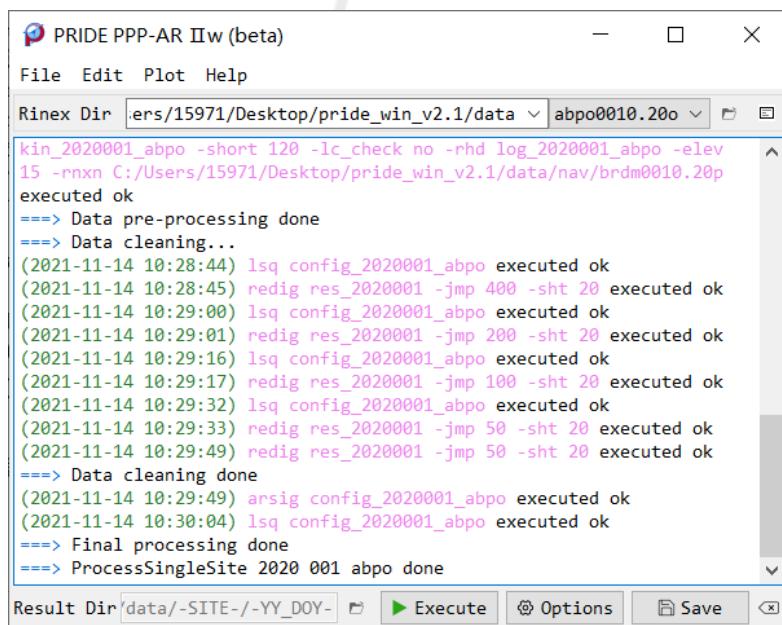


Figure 6-2 Main components of the main software interface

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 "abpo0010.20o" dropdown is also visible. The main 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 -rnxn 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 "Result Dir", "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).

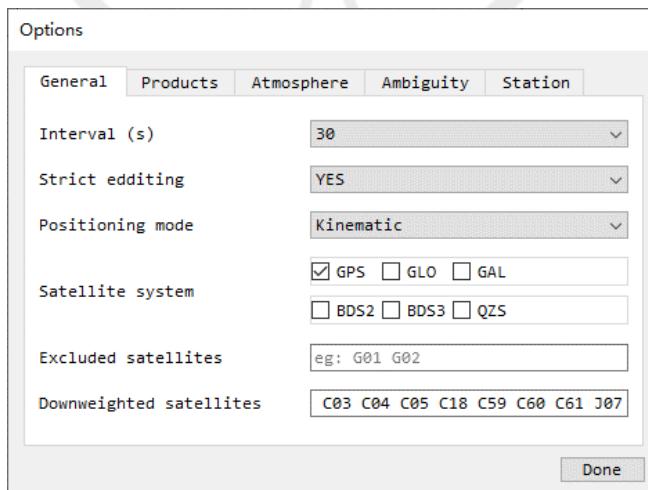


Figure 6-4 General Options

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.

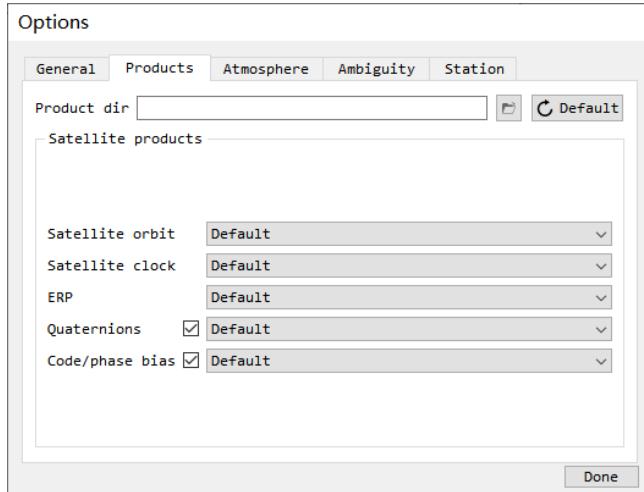


Figure 6-5 Product Options

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.

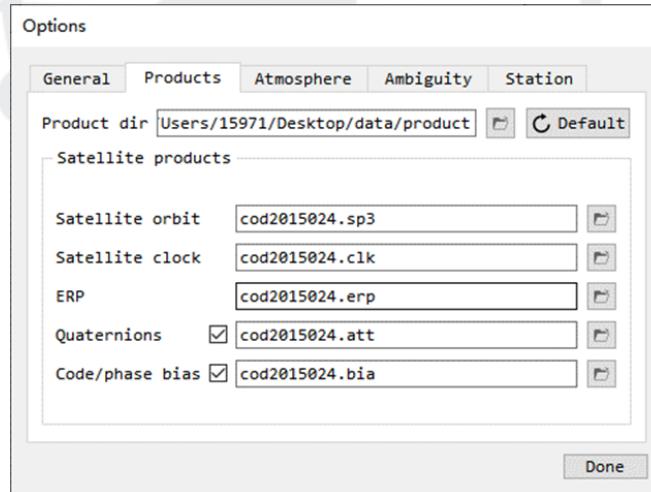


Figure 6-6 Using products of other AC

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.

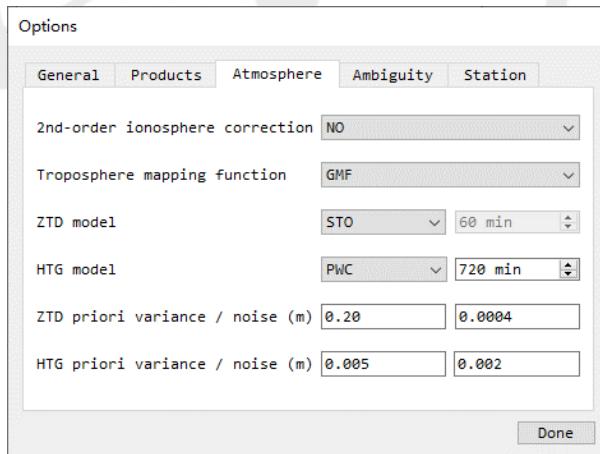


Figure 6-8 Atmospheric Delay Options

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.

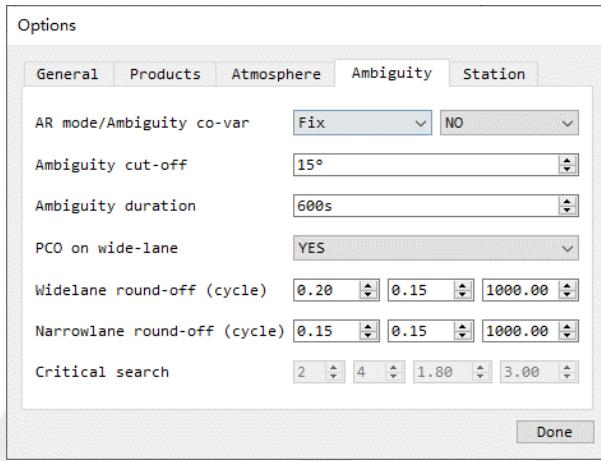


Figure 6-9 Ambiguity Options

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.

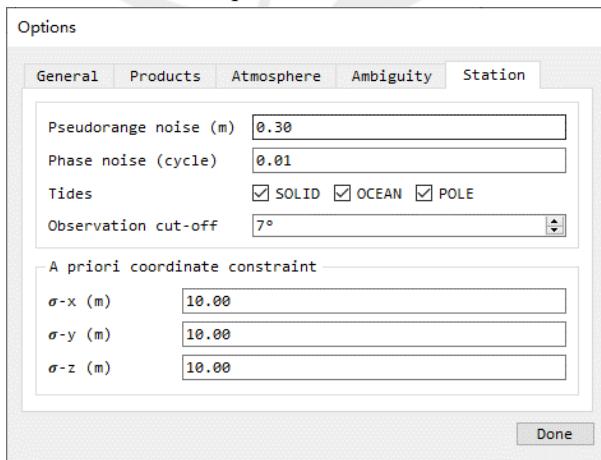


Figure 6-10 Station parameter options

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.

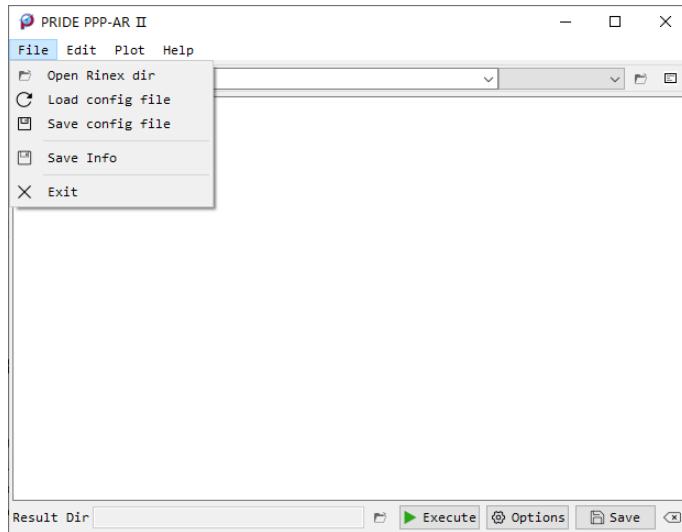


Figure 6-11 Menu bar File bar

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.

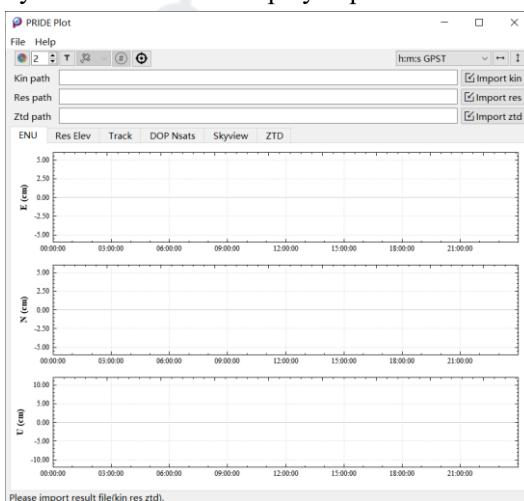


Figure 6-12 Plotting Interface

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.

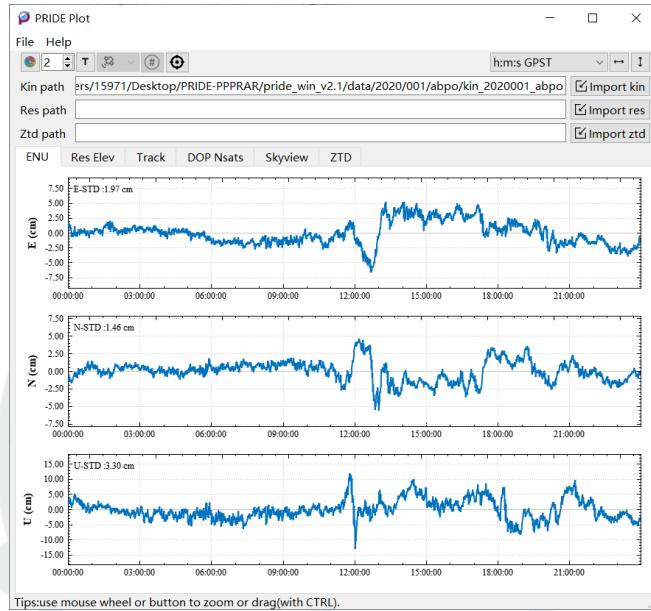


Figure 6-13 ENU-t chart

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.

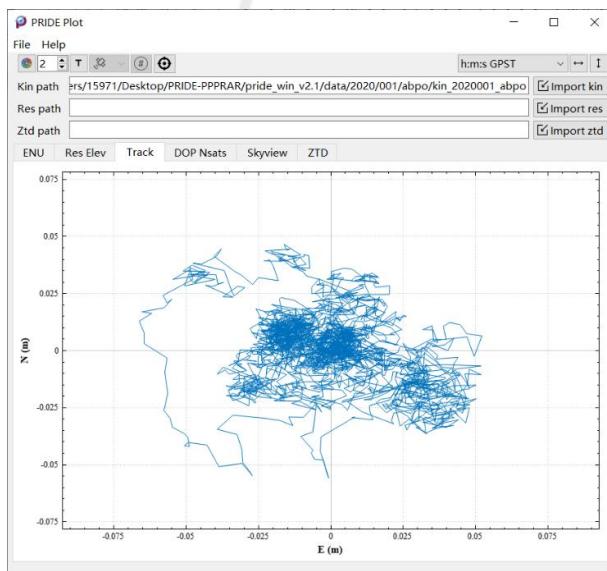


Figure 6-14 Position plane trajectory chart

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.

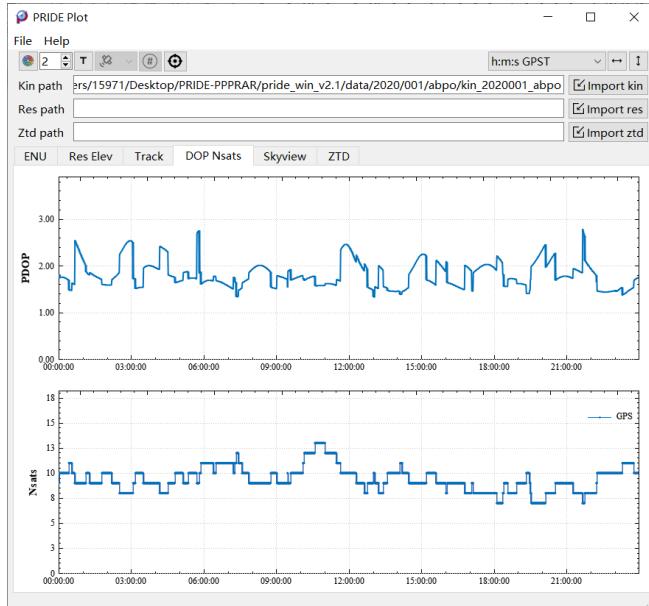


Figure 6-15 DOP and Nsats-t charts

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.

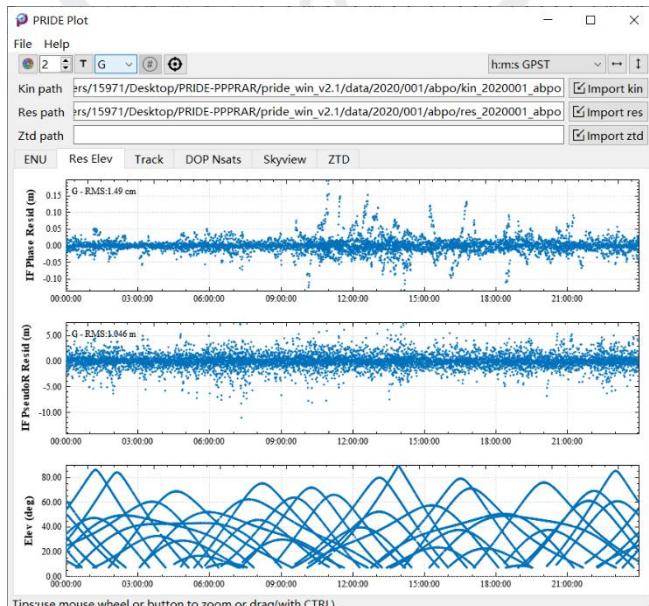


Figure 6-16 Res and elev-t charts

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.

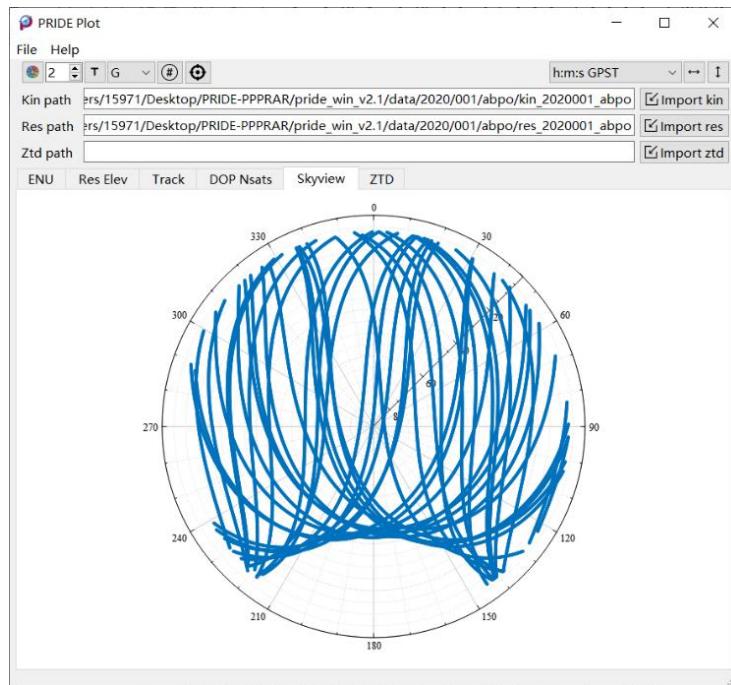


Figure 6-17 Satellite sky view

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.

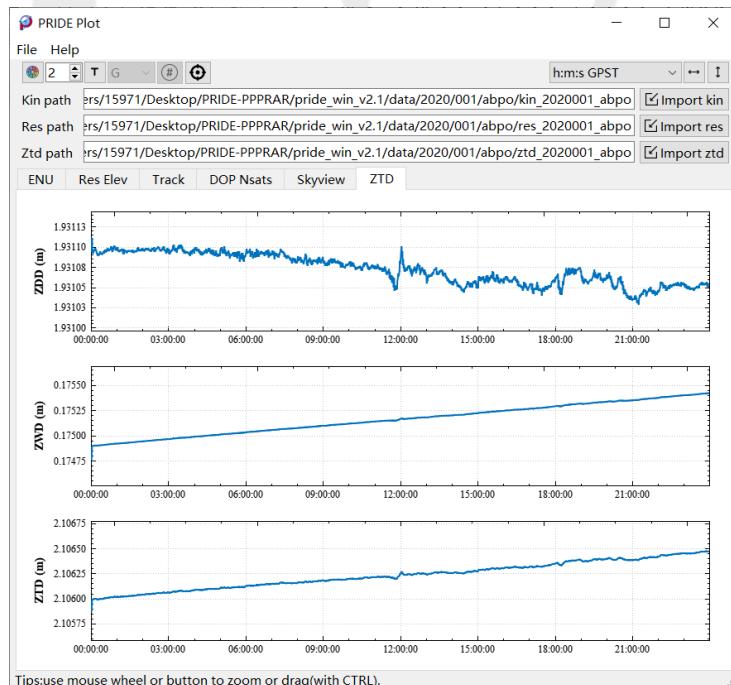


Figure 6-18 zdd, zwd and ztd-t charts

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.

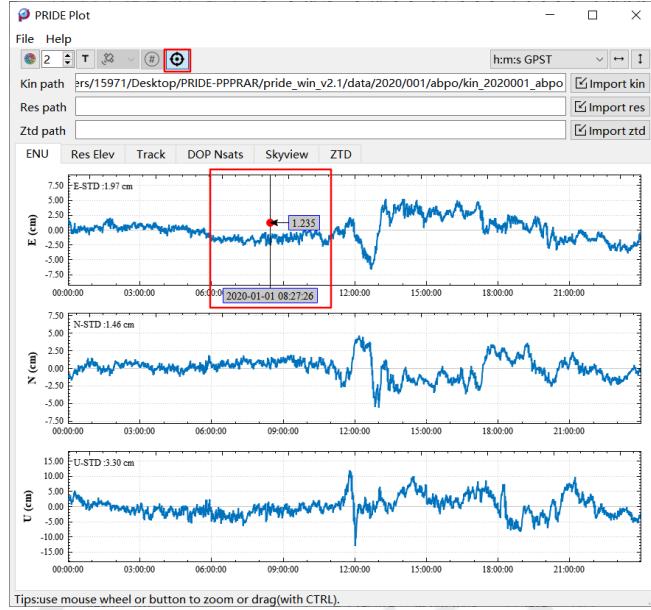


Figure 6-19 Cursor function demonstration

- (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.

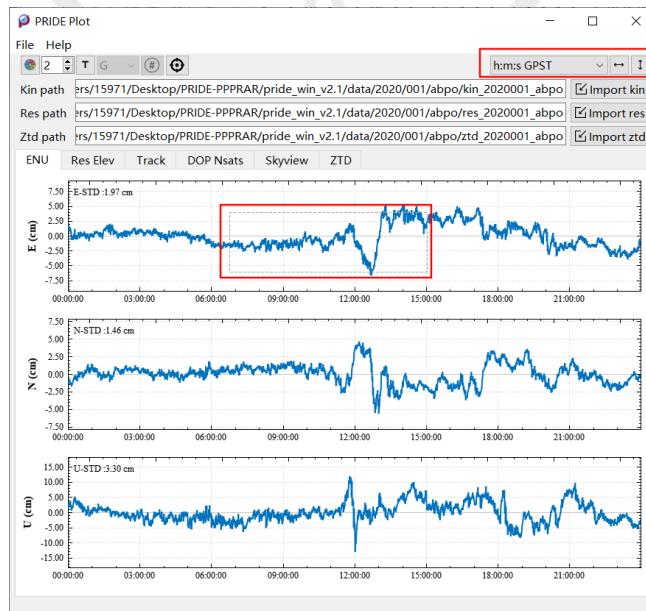


Figure 6-20 Local zoom function display

- (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 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 4 6
++ 5 6 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.

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") (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, C5P
```

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 .500000E-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 .618000E-03
OSB G063 G01 C2X 2021:001:00000 2021:001:06400 ns 0.164655000000000E+02 .618000E-03
OSB G063 G01 C5Q 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 L2Z 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.

```
*ATT RECORDS: TRANSFORMATION FROM TERRESTRIAL FRAME COORDINATES (T) TO SAT.
*(0,B) = q.(0,T).trans(q)
*REC ID_      N q0_scalar_ _q1_x_ _q2_y_ _q3_z_
## 2024 06 26 00 00 0.000000000000 110
ATT G02        4 -0.2765636 -0.1003112 0.9492132 -0.1115550
ATT G03        4 0.1846167 0.5439692 -0.5465095 0.6093780
ATT G04        4 0.0088224 0.4420089 -0.0474806 0.8957097
ATT G05        4 0.0189251 -0.4035999 0.0088024 0.9146975
ATT G06        4 -0.2177449 0.0587376 -0.6431927 0.7317378
ATT G07        4 -0.0829491 0.1961168 -0.4721345 0.8554219
ATT G08        4 -0.1842088 0.6866250 0.3863796 0.5876428
ATT G09        4 -0.0346432 0.2205293 -0.2245400 0.9485507
ATT G10        4 0.0862312 0.1085061 0.9265881 0.3496070
ATT G11        4 -0.2635273 -0.1352910 -0.4233488 0.8561691
ATT G12        4 0.5501343 -0.0591299 0.7905605 0.2624309
ATT G13        4 0.5332482 0.1093869 0.7017999 -0.4595189
ATT G14        4 -0.0357125 -0.2062997 0.8830935 -0.4198940
ATT G15        4 0.6185201 0.0120480 0.7825779 -0.0697098
ATT G16        4 0.0098452 0.3610054 0.0966427 0.9274904
ATT G17        4 0.1067423 -0.1069445 0.9295085 -0.3364268
ATT G18        4 0.2306192 -0.0072881 0.5145227 0.8258499
```

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	5.0	450.0	16	16	15
87.5-180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	15	15	15
13	13	14	14	15	15	15	15	15	16	16	16
14	14	13	13	12	11	11	10	9	8	8	7
4	4	3	3	3	2	2	2	2	2	2	2
2	3	3	3	3	4	4	4	5	5	5	6
8	9	9	10	10	11	12	12	13	6	6	7
85.0-180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	23	23	23
15	16	17	19	20	21	21	22	23	23	23	22
20	19	18	16	15	13	12	10	8	7	5	4
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	2	2	3	4	4
7	8	9	10	11	12	13	14	15	5	5	6
82.5-180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	29	29	28
16	17	19	21	23	24	25	27	28	28	29	27
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	1	2	2	3
5	6	7	8	10	11	13	14	16	3	3	4
80.0-180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	32	32	31
16	18	20	22	24	26	28	29	30	31	32	30
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	3
5	5	6	8	9	10	12	14	16	4	4	4

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.

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.

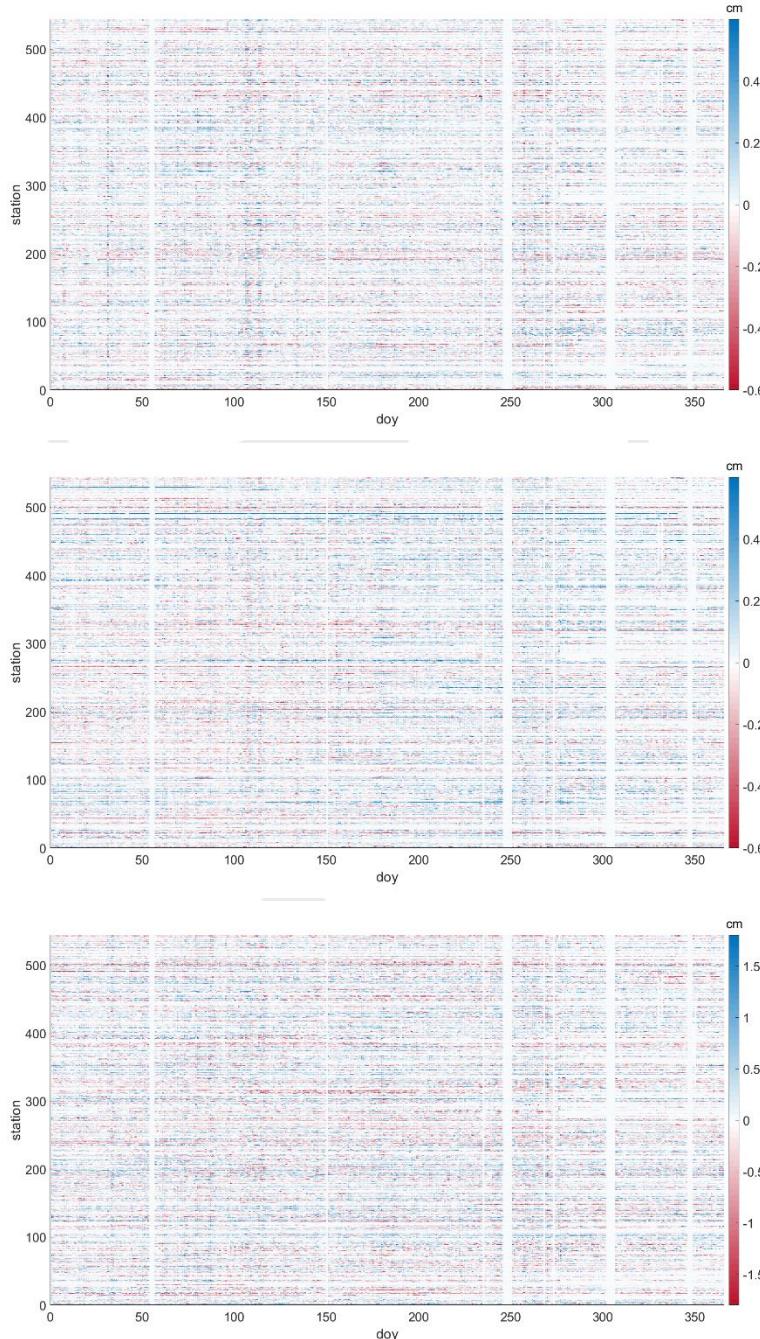


Figure B-1 Difference between PRIDE PPP-AR III solution and IGS SINEX solution of various stations.

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

PRIDE PPP-AR III 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.

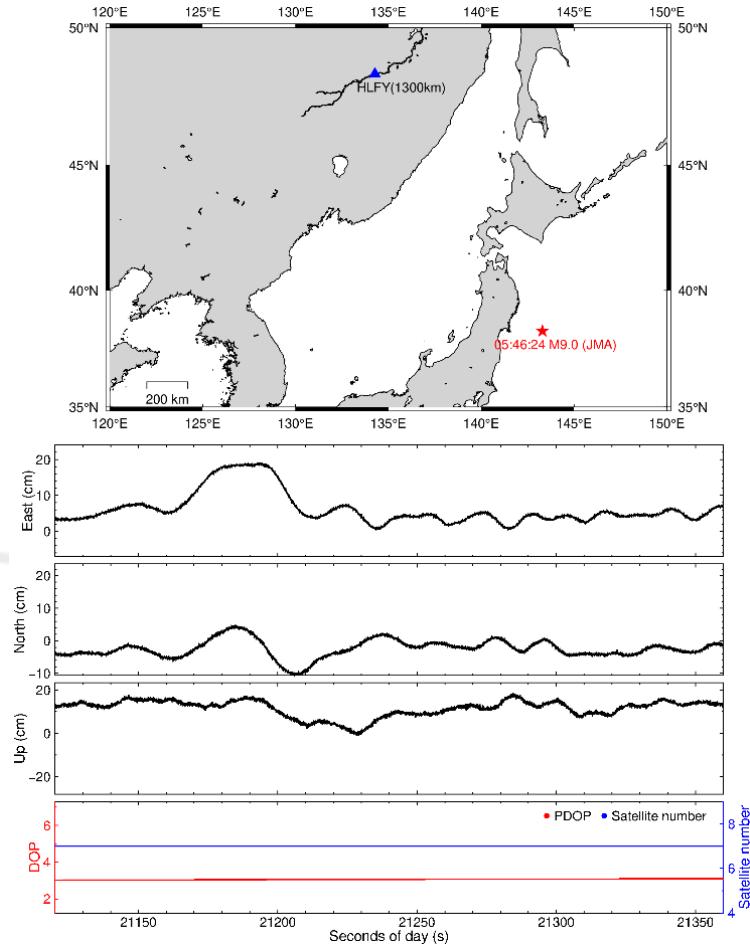


Figure B-2 Time series of super-high-rate kinematic solutions (cm) in east, north, and up components at station HLFY on March 11, 2011

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.

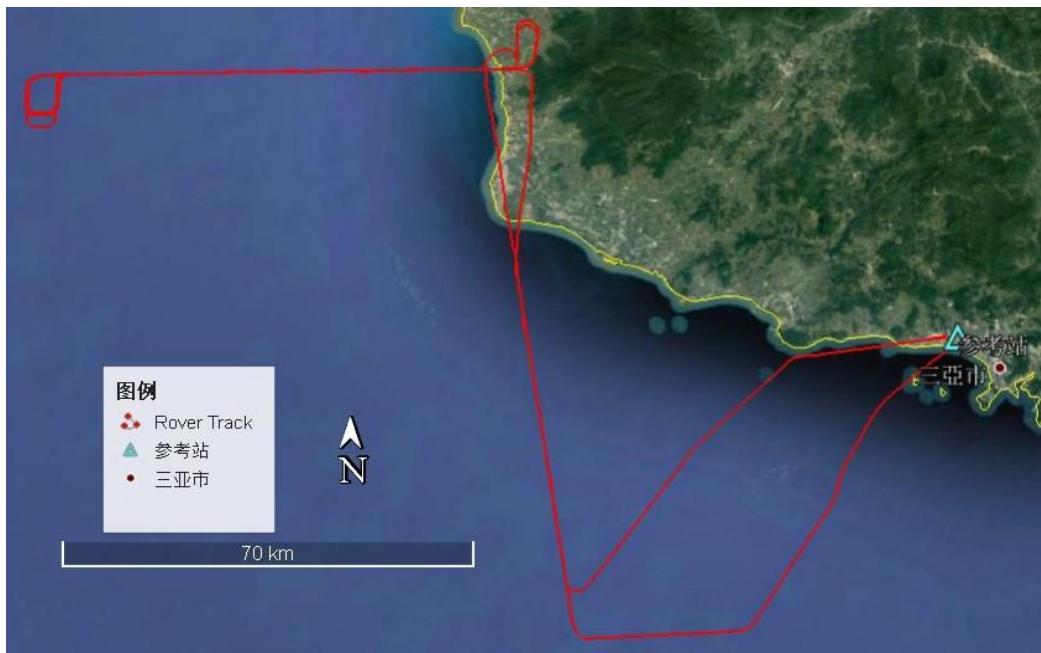


Figure B-3 Trajectory of the aircraft in high-dynamic aerial photogrammetry experiment

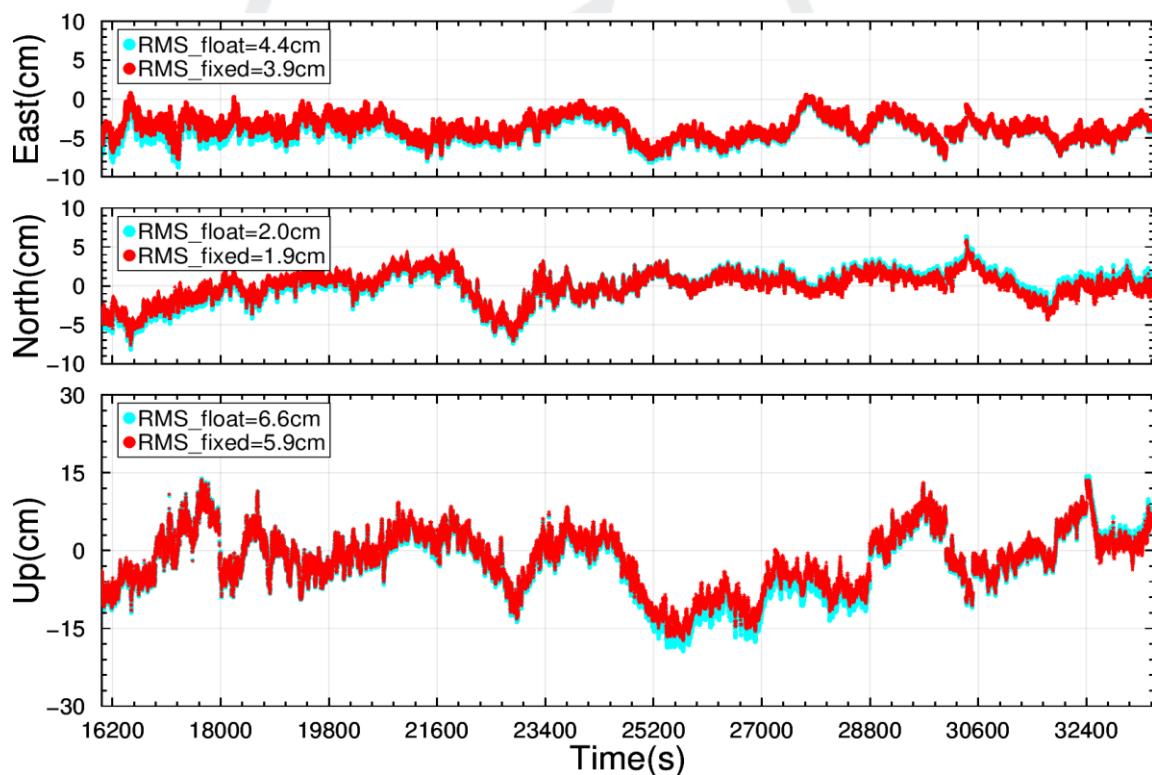


Figure B-4 Location differences between PRIDE PPP-AR and WayPoint software

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.

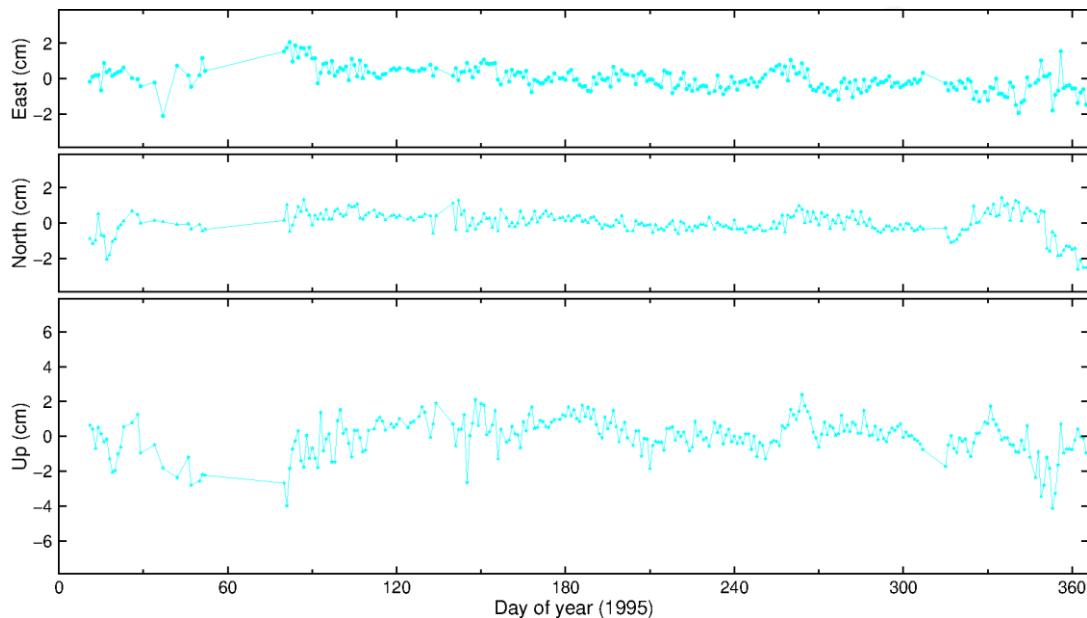


Figure C-1 Position time series at station ALBH in 1995

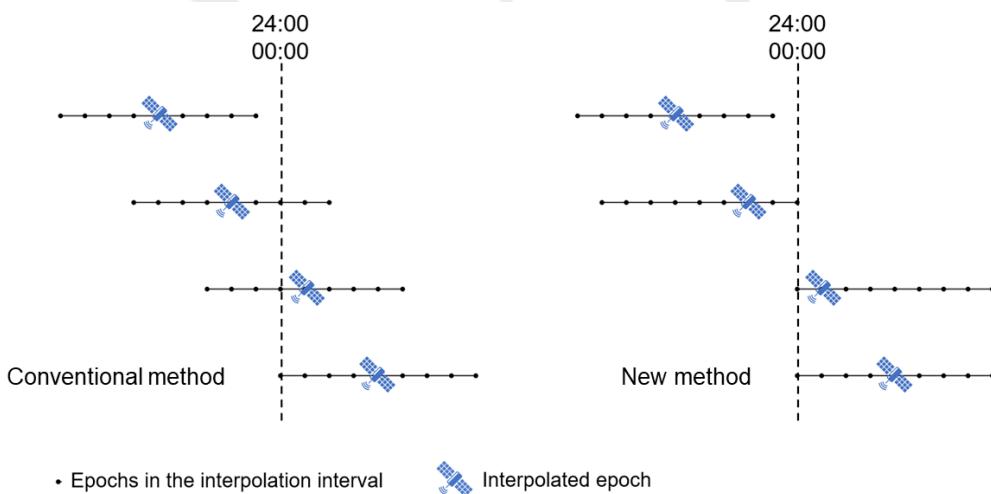


Appendix D. Instruction on DOCB in WUM Rapid products

This guide is intended for PPP users who want to apply WUM0MGXRAP products (including orbits, clocks, and biases) to PPP software other than PRIDE PPP-AR. Users must be able to modify their software accordingly.

Compared to conventional IGS products, the aligned product offers additional orbit and clock estimates for each GPS, Galileo, and BDS satellite at the second midnight epoch (24:00:00) in the SP3 file and CLK file, respectively. The continuity index at day boundaries, termed as DOCB (Discontinuity of Orbits, Clocks, and Biases), is added to the SINEX-Bias file. To ensure optimal continuous data processing, users' PPP software must:

1) Read the estimates for the 24:00:00 epoch from the previous day's product and the 00:00:00 epoch from the next day's product. Prevent orbit and clock interpolations across day boundaries (i.e., 24:00:00 or 00:00:00). This mechanism is illustrated in the following diagram. Taking orbit interpolation as an example, conventional methods (left) tend to place the interpolation point in the middle of the interpolation interval. However, in our proposed method (right), when the interpolation point falls on the previous day, the epoch 24:00:00 of the previous day's products should be used; when the interpolation point falls on the following day, the epoch 00:00:00 of the following day's products should be used instead. Because the interpolation methods for orbit and clock differ, the compatibility of their interpolation results will be compromised by the discontinuities in orbits and clocks. However, this problem can be avoided by interpolating them within a day.



2) Read the code and phase DOCB values from the SINEX-Bias file, then compute the DOCB values according to specified signal choices for each satellite. If the DOCB value exceed a predefined threshold (e.g., 0.10 cycle), the rapid products for this satellite cannot support continuous processing at the day boundary, and a reset of its corresponding ambiguities is necessary. The code and phase DOCB values in the SINEX-Bias file is defined as follows:

+DAY BOUNDARY DISCONTINUITY										
*TERM	SVN	PRN	STATION	OBS1	OBS2	DISCON_START	DISCON_END			
						UNIT	ESTIMATED_VALUE	STD_DEV		
DOCB	G061	G02		C1C		2024:099:86400	2024:100:00000	ns	0.07754	0.00000
DOCB	G061	G02		C1W		2024:099:86400	2024:100:00000	ns	0.07294	0.00000
DOCB	G061	G02		C2W		2024:099:86400	2024:100:00000	ns	0.12011	0.00000
DOCB	G061	G02		L1C		2024:099:86400	2024:100:00000	ns	-0.04260	0.00000
DOCB	G061	G02		L1W		2024:099:86400	2024:100:00000	ns	-0.04260	0.00000
DOCB	G061	G02		L2W		2024:099:86400	2024:100:00000	ns	-0.08099	0.00000
DOCB	G069	G03		C1C		2024:099:86400	2024:100:00000	ns	0.06434	0.00000
DOCB	G069	G03		C1W		2024:099:86400	2024:100:00000	ns	0.06084	0.00000
DOCB	G069	G03		C2X		2024:099:86400	2024:100:00000	ns	0.11051	0.00000
DOCB	G069	G03		C2S		2024:099:86400	2024:100:00000	ns	0.12501	0.00000
DOCB	G069	G03		C2L		2024:099:86400	2024:100:00000	ns	0.10821	0.00000
DOCB	G069	G03		C2W		2024:099:86400	2024:100:00000	ns	0.10021	0.00000
DOCB	G069	G03		C5X		2024:099:86400	2024:100:00000	ns	0.10153	0.00000
DOCB	G069	G03		C50		2024:099:86400	2024:100:00000	ns	0.11978	0.00000
DOCB	G069	G03		L1C		2024:099:86400	2024:100:00000	ns	-0.08316	0.00000
DOCB	G069	G03		L1W		2024:099:86400	2024:100:00000	ns	-0.08316	0.00000
DOCB	G069	G03		L2X		2024:099:86400	2024:100:00000	ns	-0.13920	0.00000
DOCB	G069	G03		L2S		2024:099:86400	2024:100:00000	ns	-0.13920	0.00000
DOCB	G069	G03		L2L		2024:099:86400	2024:100:00000	ns	-0.13920	0.00000
DOCB	G069	G03		L2W		2024:099:86400	2024:100:00000	ns	-0.13920	0.00000
DOCB	G069	G03		L5X		2024:099:86400	2024:100:00000	ns	-0.16318	0.00000
DOCB	G069	G03		L5Q		2024:099:86400	2024:100:00000	ns	-0.16318	0.00000

The columns are similar to those of “OSB.” From left to right, they represent the abbreviation “DOCB”, the SVN and PRN number of the satellite, the observation type label, the time of the day boundary (the two time labels are exactly the same and is intended to emphasize the “day boundary” concept), the unit of DOCB, the DOCB value, and the standard deviation of DOCB.

For example, when a user selects the observations “L1W”, “L2W”, “C1W” and “C2W” for the satellite G02 and forms a dual-frequency ionosphere-free combination, the DOCB values of the corresponding observations, d_{L1W} , d_{L2W} , d_{C1W} , and d_{C2W} should be read and formed as the wide-/narrow-lane combinations,

$$d_{WL} = (f_1 \cdot d_{L1W} - f_2 \cdot d_{L2W}) - \frac{f_1 - f_2}{f_1 + f_2} \cdot (f_1 \cdot d_{C1W} + f_2 \cdot d_{C2W})$$

$$d_{NL} = \frac{f_1^2 \cdot d_{L1W} + f_2^2 \cdot d_{L2W}}{f_1 - f_2}$$

where f_1 and f_2 are the frequencies of the selected dual-frequency observables, d_{L1W} , d_{L2W} , d_{C1W} , and d_{C2W} are in units of seconds, and d_{WL} , d_{NL} are in units of cycles.

Then, it is determined whether d_{WL} and d_{NL} exceed a predefined threshold (e.g., 0.10 cycle). If it does, the ambiguity parameter of the satellite is regarded as having a “cycle slip” at that day boundary, and it should be reset to avoid degraded PPP results.