PRIDE-PPPAR VER1.0

MANUAL

***GPS** Precise Point Positioning with Ambiguity Resolution*

Provided by

PRIDELab

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2. Overview

2.1 PRIDE-PPPAR

PRIDE-PPPAR is an open source software for GPS Precise Point Positioning with Ambiguity Resolution, which is created by PRIDELab, GNSS Research Center, Wuhan University. PRIDE-PPPAR consists of several APs (application programs), which is shown in section 3.1.

The program is hosted on Github(xxx.github.com) for efficient clone/download.

2.2 Follow us

You can contact us for **bug reports** and **comments** by sending an email or leave message at our website.

Contact: pride@whu.edu.cn

Website: pride.whu.edu.cn

For Chinese users, we will provide **QQ Group** service. Group Number: 1234567. Leave your organization and name when applying for admission.

3. User Requirements

3.1 System Requirements

PRIDE-PPPAR is composed of several CUI APs. The executable binary CUI APs included in the package require Linux environment. On the other OS or environment, you have to compile and build CUI APs by yourself. All of the library functions and APIs were written in Fortran90, and built with gfortran on Linux. A series of tests are conducted in different Linux systems with several gfortran versions, the tests results are listed as below.

Gfortran compiler need to be installed before installing PRIDE-PPPAR.

Linux version (x64 default)	gfortran version	Pass-test result	Notes
Ubuntu14.04.4	4.8.4	pass	1. Pre-install gfortran before installation; 2. Test result is consistent with reference
Ubuntu14.04.4 x86	4.8.4	pass	1. ./install.sh, print ”lsq command not found”; solution: install “lsq” and reboot. 2. Test result is consistent with reference

Ubuntu16.04.11	5.4.0	pass	Test result is consistent with reference
Ubuntu16.04.11 x86	5.4.0	pass	1. /install.sh, print ”lsq command not found”; solution: install “lsq” and reboot. 2. Test result is consistent with reference
Ubuntu18.04	7.3.0	pass	1. Pre-install make before ./install.sh 2. Restart the terminal 3. Test result is consistent with reference
Arch Linux	8.2.1	pass	1. Test result is consistent with reference 2. There might be bugs in program ”tedit”
CentOS 6.5	4.4.7	pass	Test result is consistent with reference
CentOS 7	4.8.5	pass	Test result is consistent with reference
Debian 9.6	6.3.0	pass	Test result is consistent with reference
Debian 8.11	4.9.2	pass	1. Pre-install gfortran before installation; 2. Test result is consistent with reference

3.2 License

IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

4. Instructions

4.1 Installation and Validation

Structures of PRIDE-PPPAR

PRIDE-PPPAR		Instructions
\bin		
	\tedit	Pre-processing RINEX files
	\sp3orb	Transform sp3 into self-defined binary file
	\lsq	Least squares adjustment
	\redig	Residual editing
	\arsig	Ambiguity resolution
	\get_ctrl	Get configuration parameters
	\mergeerp	Merge erp(3 files) into one
	\mergesp3	Merge sp3(3 files) into one
\scripts		Some scripts for efficient data processing
	\rtk2xyz.sh	Get initial coordinates of stations
	\download_obsdata.sh	Download RINEX files
	\rnx2rtkp	Open source program form RTKLIB(http://www.rtklib.com/)
	\teqc \crxrnx	Refer to UNAVCO(https://www.unavco.org/)
	\pridelab_pppar.pl	Automatic processing script
\src		Source programs
	\header	Header files
	\arsig	Ambiguity resolution
	\de405	JPL planetary emphasis
	\get_ctrl	Get configuration parameters
	\lambda	LAMBDA
	\lib	Library functions
	\lsq	Least squares adjustment
	\orbit	Orbit
	\mergeerp	Merge erp(3 files) into one
	\mergesp3	Merge sp3(3 files) into one
	\redig	Residual editing
	\tedit	Pre-processing RINEX files
\table		
	\abs_igs.atx	Antenna phase center offsets and variations
	\jpleph_de405	Planetary ephemeris file

	\leap.sec	Leap second between TAI and UTC(Need to be updated)
	\oceanload	Ocean tide loading file
	\ file_name	File names definition of PRIDE-PPPAR
	\sit.xyz	Initial coordinates of all stations
\install.sh		Installation script
\test.sh		Validation script

Installation

Step 1: Make sure you have installed some essential programs in advance.
i.e. ***bash, make, gfortran***
Step 2: Run script $**./install.sh** to install the program automatically.
(This script executes Makefile to build CUI Aps and add the CUI Aps to system PATH)

Validation

Step 1: $ **./test.sh**
Step 2:$ **Compare results with reference results.**

The script $**./test.sh** in **/example** folder is used to validate the correctness and effectiveness of the installation. Run test.sh, two examples of PPP and PPP-AR are conducted. The data processing procedure is conducted and some information is printed to the screen. After that, two folders (FR and AR) are created. Then compare the solution files between results and reference results to make sure the software installation is correct and valid.

4.2 Quick Start ~~PPP~~

In the folder of script, you can find the Perl script named ***pride_pppar.pl***. Run this script in your work directory as below and then check the results file in relevant directory.

& pride_pppar.pl ses.ppp 20170101 20170101 FR

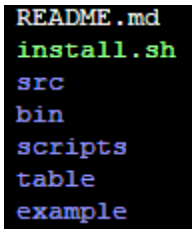
ses.ppp denotes session configuration file and the parameters and format of these files are described in ***Appendix A.2***. ***20170101*** and ***20170101*** denote start time and ending time of data processing, respectively. According the time format (YYYYMMDD), you can set the time as required and multi-day data processing is accomplished. The last parameter ***FR*** denotes the processing model. The processing model has two options, ***FR and AR.***

FR – PPP Float Resolution
AR – PPP Ambiguity Resolution

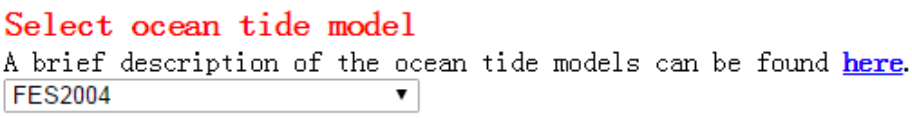
PPP

After Installation and validation, let's start PPP data processing! Here we start with an example.

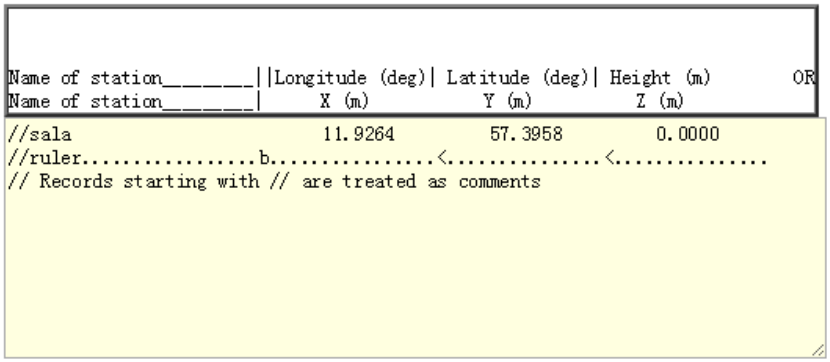
1. The PRIDE-PPPAR software directory is as below:



2. Create working folder **/project**, and its subfolder **/data**.
3. Copy RINEX Observation Files and Navigation Files to **/project/data/year/doy**, i.e. /project/data/2016/001.
4. Copy /scripts/pridelab_pppar.pl and ses.ppp to **/project** directory.
5. Change into **/project/data** directory, run $ ./rtk2xyz.sh **2016/001/** to get sit.xyz, which records the appropriate XYZ coordinates of the stations. Then copy the coordinates to the file **/table/sit.xyz** as the format requied.
6. **[Optional choice for stations near offshore areas]**Get Ocean tide loading parameters using the coordinates in sit.xyz, according to the website (http://holt.oso.chalmers.se/loading/). Choose the model **FES2004**, and leave the rest of the options as their defaults.

   Then submit a task by add station coordinates as below at the website. When you get the oceanload coefficients through your email, copy them to **/table/oceanload** as the original format.

7. Change the configuration through file ses.ppp, make sure the session configure is correct for local project. (i.e. Rinex directory, sp3 directory)
8. Change into **/project**, Run the script to start data processing.[?? S model and K model]
   $ ./pridelab_pppar.pl ses.ppp 20160101 20160101 FR
9. After processing, the solution files will be in the **/project/2016/001** directory. The **/problem** directory records problem data.

PPP with Ambiguity Resolution

1. Conduct procedure 1~7 listed above.
2. Change into **/project** directory, run the script to start data processing.
   $ ./pridelab_pppar.pl ses.ppp 20160101 20160101 AR
3. After processing, the solution files will be in the **/project/2016/001** directory. The **/problem** directory records problem data.

5. Modules of PRIDE PPP-AR

5.1 Data Preparation

Merge ERP Files with mergeerp

mergeerp is used to merge three-day ERP (Earth Rotation Parameter) files into one file.

& mergeerp cod19001.erp cod19002.erp cod19003.erp mer_cod19001.erp

Input: three ERP files (yesterday, today, tomorrow)

cod19001.erp cod19002.erp cod19003.erp

Output: three-day ERP product result of today

mer_cod19001.erp

Merge Precise Emphasis Files with mergesp3

mergesp3 is used to merge three-day SP3 (IGS Standard Product–3) orbit files into one file.

& mergesp3 igs19000.sp3 igs19001.sp3 igs19002.sp3 mer_igs19001.sp3

Input: three SP3 files (yesterday, today, tomorrow)

igs19000.sp3 igs19001.sp3 igs19002.sp3

Output: three-day SP3 orbit product result

mer_igs19001.sp3

Prepare Binary Orbit File with sp3orb

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 files.

& sp3orb igs20341.sp3 -cfg ses.ppp [–erp igserp]

Input:

igs20341.sp3 SP3 orbit file

–cfg ses.ppp session configuration file

[–erp igserp] ERP file

Output:

orb_2018365 Binary format orbit product

The parameters and format of these files are described in ***Appendix A***.

5.2 Data Pre-processing

Pre-processing with tedit

tedit which is based on the pre-processing algorithms by Blewitt (1990) is used to identify bad measurements and cycle slips in a RINEX observation file and generate RINEX health diagnosis files (***rhd***).

& tedit o_file -int 30 -rnxn n_file -rhd rhd_file -xyz $x $y $z -short 1200 -lc_check yes/no/only -pc_check 300 -elev 7 -len 86400 -time 2017 01 01 00 00 00

Input: files and configuration parameters

o_file	RINEX observation file
-int 30	sampling interval for data editing, Default is 30 seconds
-rnxn n_file	broadcast ephemeris file. If ***-check_lc*** is active or ***-elev*** is on, this file is required.
-rhd rhd_file	output ***rhd*** file.
-time 2017 01 01 00 00 00	start time for data editing
-len 86400	length of data to be edited. Default is all data in rinex file'
-short 1200	data piece shorter than this value will be removed.
-elev 7	cutoff elevation in degree. Default is to use all data.
-lc_check yes/no/only	yes = check LC and edit WL and IONO and try to connect WL and ION no = edit WL and IONO and try to connect WL and ION observation. only= check LC only
-pc_check 300	check PC
-xyz $x $y $z	initial station coordinate

Output: rhd files named rhd_year day of year_station name

rhd_2017001_algo

5.3 Data Post-processing

Parameters Estimation with lsq

lsq is least squares adjustment. The module lsq is used to reduce raw measurements and estimate unknown parameters.

& lsq ses.ppp

Input: configuration file

ses.ppp	session configuration file

Output: solution files

-pos/kin	***static position / kinematic trajectory***
-res	***residual information***
-ztd	***zenith troposphere delay***
-rck	***receiver clock information***
-htg	***horizontal troposphere gradients***
-rhd	***RINEX health diagnosis***
-stt	***phase residual statistics information***

-amb ***ambiguity information***

Residual Edit with redig

Residual editing. ***redig*** is applied to posterior residuals. Once new bad measurements or new cycle slips are identified, run ***lsq*** again. Then, final results can be collected.

& redig ses.ppp -jmp jump -sht nsht [-hug huge-residual]

Input:

ses.ppp session configuration file

-jmp jump if difference residuals between adjacent epochs are larger than ***jump***, add a new ambiguity.

-sht nsht validity time of ambiguity shorter than ***nsht*** will be removed

[-hug huge-residual] residuals larger than this value will be removed.

Ambiguity Resolution with arsig

Ambiguity resolution. **arsig** employs FCBs to retrieve the integer properties of single difference ambiguities between satellites at a single receiver.

& arsig ses.ppp

Input:

ses.ppp session configuration file

Output: solution files with ambiguity resolution

6. Appendix A File Specifications

A.1 Table Files

Initial Station Coordinates File (*sit.xyz*)

The coordinate information of all stations is recorded in file ***sit.xyz***, which provides initial station coordinates for data processing. An example is shown below:

```
AHBB -2458176.8421  4763392.1814  3445108.5871
BJFS -2148744.7810  4426639.3900  4044655.1820
BJGB -2210613.3090  4309151.6761  4136713.9164
BJSH -2154109.9359  4373148.6804  4099356.4488
BJYQ -2130929.3627  4375280.6944  4109781.9487
```

Fig.1 Coordinate file(sit.xyz)

The name of station is recorded in the first column and the following is the coordinate information at WGS84. The width of the data columns should be separated at least one space.

Ocean Tide Loading File (*oceanload*)

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

Leap Seconds File (*leap.sec*)

The conversion between TAI and UTC is performed by reading the file ***leap.sec***, which provides leap seconds since 30 Jun 1982, at which time TAI-UTC was 21 seconds. The format of ***leap.sec*** is given below:

```
+leap sec
 45150   21                  ! 30 JUN 1982 LEAP SEC INCREMENT
 45515   22                  ! 30 JUN 1983 LEAP SEC INCREMENT
 46246   23                  ! 30 JUN 1985 LEAP SEC INCREMENT
 47160   24                  ! 31 DEC 1987 LEAP SEC INCREMENT
 47891   25                  ! 31 DEC 1989 LEAP SEC INCREMENT
 48256   26                  ! 31 DEC 1990 LEAP SEC INCREMENT
 48803   27                  ! 30 JUN 1992 LEAP SEC INCREMENT
 49168   28                  ! 30 JUN 1993 LEAP SEC INCREMENT
 49533   29                  ! 30 JUN 1994 LEAP SEC INCREMENT
 50082   30                  ! 31 DEC 1995 LEAP SEC INCREMENT
 50629   31                  ! 30 JUN 1997 LEAP SEC INCREMENT
 51178   32                  ! 31 DEC 1998 LEAP SEC INCREMENT
 53735   33                  ! 31 DEC 2005 LEAP SEC INCREMENT
 54831   34                  ! 31 DEC 2008 LEAP SEC INCREMENT
 56108   35                  ! 30 JUN 2012 LEAP SEC INCREMENT
 57203   36                  ! 30 JUN 2015 LEAP SEC INCREMENT
 57749   37                  ! LIMIT OF TABLE (28 Dec 2016)
-leap sec
```

Fig.2 leap second file(leap.sec)

The first column is the MJDAY (Modified Julian Day) of leap second day. The second column is number of leap second. The comments are calendar dates. The date of RINEX O file processed should be larger than the MJD of the last row (which is the date limit of data processing), otherwise the program will stop and an error message will be printed. The update message of leap seconds should be continually concerned and updated at some site, e.g. (https://hpiers.obspm.fr/iers/bul/bulc/Leap_Second.dat).

Antenna Phase-center Offsets and Variations File (*abs_igs.atx*)

In order to get the information of antenna phase center offsets (PCO) and variations (PCV), the latest **igs08.atx** file provided by IGS is commonly used. Antenna phase center offsets and variations file is named as ***abs_igs.atx*** in the table directory. You can refer to Antenna Exchange Format Version 1.4 (ANTEX) for detailed parameters and format.

JPL Planetary Ephemeris File (*jpleph_de405*)

The planetary ephemeris file is essential for getting the position and velocity of sun and lunar. It is a self-defined binary file for efficient access. Date of jpleph_de405 is valid until 1 Jan. 2020. More valid files will be updated at our site soon (www.pride.whu.edu.cn).

File Name Definition File (*file_name*)

File names of PRIDE-PPPAR are defined in this 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_2019001_algo*" denotes the residual of

station algo in 1st, 2019. The format of ***file_name*** is as below:

```
amb         amb_-YYYY--DDD-
cck         cck_-YYYY--DDD-
con         con_-YYYY--DDD-
fip         fip_-YYYY--DDD-
htg         htg_-YYYY--DDD-
ion         ion_-YYYY--DDD-_-SNAM-
kin         kin_-YYYY--DDD-_-SNAM-
neq         neq_-YYYY--DDD-
orb         orb_-YYYY--DDD-
pos         pos_-YYYY--DDD-
rck         rck_-YYYY--DDD-
res         res_-YYYY--DDD-
sdr         res_-YYYY--DDD-
rhd         rhd_-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-
trp         trp_-YYYY--DDD-_-SNAM-
vmf         vmf_-YYYY--DDD-
ztd         ztd_-YYYY--DDD-
```

Fig.3 Format of file_name

A.2 Configuration File

configuration file (*ses.ppp*)

The session configuration file (***ses.ppp***) is used to record the processing strategies for ***PRIDE-PPPAR***. The session configuration file contains processing options, solution options and file options. It is a text file utilizing " **Keyword = Value "** format records for various options. For enumeration values, the selectable value is an enumeration label (NO, YES ...). The texts after **!** in a line are treated as comments. An example is as below:

```
#
## Session configure
Session time     = 2010 2 20 00 0 0 86360
Broadcast directory = /media/cxy/STUDY/earth/test/maule/ANTUCO/ANTUCO/2010/051
Rinex directory     = /media/cxy/STUDY/earth/test/maule/ANTUCO/ANTUCO/2010/051
Sp3 directory = /media/cxy/STUDY/precise products
Table directory = /home/cxy/table
Interval = 30
#
## strategies
Observation      = LCPC
Weight           = ELEV
Correction       = XYZ
Remove bias      = NO
Epoch difference = NO    ! especially for static application
#
## model information
IERS Conventions = 2003_SOLID_POLE_OCEAN       ! station displacement
ZTD model        = PWC:60                      ! troposphere estimation. PWC: piece-wise constant, 60: 1 hour
HTG model        = NON                         ! Horizontal Troposphere Gradients
Meteo info       = NO          ! Use rinex meteorology info or not
Antenna PCV      = YES         ! YES or NO
Phase wind-up    = YES         ! Phase wind-up YES or NO
#
## especially for kinematic use
Satellite clock = FIX
Static PWC       = 0   ! minutes 0 means no PWC
#
## ambiguity fixing
Ambiguity fixing    = LAMBDA                    ! Ambiguity fixing or not
Common observing    = 600                      ! common observation time in seconds
Cutoff elevation    = 10                       ! cutoff angles for eligible ambiguities in AR
Widelane decision   = 0.25 0.15 1000.          ! deriation, sigma in WL-cycle
Narrowlane decision = 0.20 0.15 1000.          ! deriation, sigma in NL-cycle
Critical search     = 2 4 1.8 3.0
Clock FIP           = NO

+GPS satellites
*PN (3000m is a priori constraint on satellite clock)
 01 3000
 ...
-GPS satellites

+Station used
*NAME TP MAP CLKm EV ZTDm PoDm HTGm PoDm RAGm PHSc PoXEm PoYNm PoZHm PoXEm PoYNm PoZHm SIGEm SIGNm SIGHm
 antc S  GMF 9000  7 0.20 .020 .005 .002 3.00 .006 10.00 10.00 10.00 10.00 10.00 10.00 1.000 1.000 1.000
-Station used
```

Fig.4 Configure file format (ses.ppp)

A.3 Solution Files

In ***PRIDE-PPPAR***, there are some self-defined solution files, whose format have been listed in the file ***file_name.***

amb file

The values of float ambiguities are recorded in ***amb*** file. Running ***lsq*** will call ***amb*** file to obtain initial value of ambiguity. An example is shown below:

```
ANTC   3     -131936725.864897      -29131916.357563  55247.0000000000  55247.1857638889   0.1140   0.0102  55.9
ANTC   6     -131248708.411520      -28983541.281162  55247.0000000000  55247.1729166667   0.1630   0.0088  59.9
ANTC  16     -131045721.692602      -28945546.897375  55247.0000000000  55247.1142361111   0.0480   0.0144  45.0
ANTC  18     -128922702.497677      -28506558.617294  55247.0000000000  55247.1250000000   0.0615   0.0136  40.2
ANTC  21     -129763760.069741      -28662081.489537  55247.0000000000  55247.1010416667   0.0546   0.0157  31.5
ANTC  22     -128884000.477054      -28497702.489875  55247.0000000000  55247.1940972222   0.0677   0.0123  46.9
ANTC  24     -131043529.409381      -28964471.177790  55247.0000000000  55247.0590277778   0.0697   0.0252  21.9
ANTC  19     -132647087.338052      -29292522.802520  55247.0114583333  55247.2326388889   0.0606   0.0092  47.8
ANTC  26     -128164143.514951      -28338518.721622  55247.0586805556  55247.1930555556   0.0754   0.0161  24.4
ANTC  14     -130641425.941437      -28934954.864244  55247.0659722222  55247.2468750000   0.0539   0.0132  31.2
ANTC  11     -132399227.369457      -29237444.621304  55247.1013888889  55247.3600694444   0.0636   0.0094  45.6
ANTC  18     -128922702.748361      -28506558.317568  55247.1253472222  55247.1288194444   0.0640   0.1308   8.0
ANTC  20     -130449045.461340      -28802846.310990  55247.1468750000  55247.4392361111   0.0544   0.0089  44.9
ANTC  28     -128938202.471296      -28468337.367242  55247.1472222222  55247.2093750000   0.0725   0.0401   9.8
ANTC   6     -131248709.115765      -28983541.308547  55247.1736111111  55247.2017361111   0.3883   0.0364  18.9
ANTC   3     -119333366.431861      -26349356.502631  55247.1861111111  55247.2149305556   0.3741   0.0351  20.4
```

Fig.5 Result file(amb file)

The first column describes the name of station; the second column describes the number of satellite only for GPS; the next two columns record the values of ionosphere-free (IF) ambiguity and wide-lane (WL) ambiguity; and then the start time and end time are recorded in the next two columns in order to declare valid time of ambiguity; the following two columns are RMS of IF ambiguity and WL ambiguity, respectively; the last column records corresponding mean elevation angle during the valid time.

con file

Run ***arsig*** with FCBs products, ***con*** file will be produced. ***con file*** is used to record the values of integer ambiguity. An example is shown below:

```
Single-Difference Ambiguity Constraint                          COMMENT
    SD                                                          TYPE OF CONSTRAINT
                                                                END OF HEADER
SC02 G06 G16 2010  5  1  0  0  0.000000 2010  5  1  0 51  0.000000       -461126     -2215579   0.053
SC02 G08 G23 2010  5  1  0  0  0.000000 2010  5  1  1 45  0.000000        333505      -683000   0.526
SC02 G06 G23 2010  5  1  0  0  0.000000 2010  5  1  1 45  0.000000        984822      -395620  -0.098
SC02 G07 G13 2010  5  1  0  0  0.000000 2010  5  1  1 59  0.000000        758148     -3544460  -0.224
SC02 G05 G06 2010  5  1  0 34  0.000000 2010  5  1  2 23  0.000000       1706455     10057461   0.511
SC02 G03 G19 2010  5  1  0  2  0.000000 2010  5  1  2 47  0.000000       -417696       933227   0.025
SC02 G03 G08 2010  5  1  0  0  0.000000 2010  5  1  2 47  0.000000       -350629      1613502  -0.247
```

Fig.6 con file

The first three lines, as file header, declare the comment message. The file body records the results of integer ambiguity. The first column is station name and the next two columns record satellites of the single-difference ambiguity constraint. And then it is the start time and end time of ambiguity resolution for these difference satellites. The last three columns denote the values of wide-lane ambiguity, narrow-lane ambiguity and narrow-lane FCBs, respectively.

kin file

The results of position are recorded in ***kin*** file when using the **K** model (Kinematic Model). The coordinates in this file are recorded epoch by epoch. An example is shown below:

```
Kinematic Trajectory          robl                          COMMENT
     1.00                                                   INTERVAL
                                                            END OF HEADER
55252     0.00    1742986.399 -5066327.653 -3452981.680
55252     1.00    1742986.397 -5066327.651 -3452981.677
55252     2.00    1742986.397 -5066327.654 -3452981.682
55252     3.00    1742986.398 -5066327.650 -3452981.676
55252     4.00    1742986.396 -5066327.648 -3452981.676
55252     5.00    1742986.397 -5066327.647 -3452981.675
55252     6.00    1742986.402 -5066327.663 -3452981.690
55252     7.00    1742986.397 -5066327.649 -3452981.678
```

Fig.7 kin file

The header recorded the station name, interval and some comment. In the file body, the first two columns record epoch time with MJD and seconds of the day. The following three columns denote the values of coordinates (X, Y, Z) in WGS-84.

pos file

The results of static position are recorded in ***pos*** file using the **S** model (Static Model). Only one coordinate result is recorded as one-day position. An example is shown below:

```
%%% Position Correction : XYZ 55247.4998

ANTC   1608539.6555  -4816369.7596  -3847798.5140
CORR         -0.0011        -0.0009        -0.0015
SIGM          0.0004         0.0005         0.0004
NOBS           23633
```

Fig.8 Static position file(pos file)

In this file, the first line shows processing time in MJD. And then station name and coordinates are recorded next line. The precise coordinates for the MJD need the correct values which start with “CORR”, which means the final coordinates are “X/Y/Z + CORR”, respectively. The “SIGM” records the corresponding STD. The last line records the numbers of observation used for calculating the coordinates.

neq file

This is a binary file which is used to record inversed normal matrix for ambiguity resolution.

rck file

The results of receiver clock are recorded in ***rck*** file. An example is shown below:

```
Receiver Clock                                                  COMMENT
    30.00                                                       INTERVAL
                                                                END OF HEADEF
ANTC 2010  2 20  0  0  0.000000        14.299007     -0.003370
ANTC 2010  2 20  0  0 30.000000        13.976010     -0.003368
ANTC 2010  2 20  0  1  0.000000        14.057061     -0.003364
ANTC 2010  2 20  0  1 30.000000        14.078481     -0.003361
ANTC 2010  2 20  0  1 60.000000        14.074243     -0.003359
ANTC 2010  2 20  0  2 30.000000        14.156756     -0.003356
ANTC 2010  2 20  0  2 60.000000        14.177664     -0.003353
ANTC 2010  2 20  0  3 30.000000        14.280132     -0.003350
ANTC 2010  2 20  0  4  0.000000        14.316266     -0.003347
ANTC 2010  2 20  0  4 30.000000        14.426550     -0.003344
ANTC 2010  2 20  0  4 60.000000        14.438349     -0.003341
ANTC 2010  2 20  0  5 30.000000        14.602913     -0.003338
ANTC 2010  2 20  0  5 60.000000        14.560626     -0.003337
ANTC 2010  2 20  0  6 30.000000        14.479691     -0.003334
```

Fig.9 Receiver clock file(rck file)

The comment and epoch interval are recorded in the part of file header. And in the file body, there are records of station name, epoch time, receiver clock and its STD.

res file

The values of residuals for observation are recorded in ***res*** file. As an output file of ***lsq***, it will be used in ***redig*** . An example is shown below:

```
Residuals                                                       COMMENT
         1        32                                            # OF SIT / SAT
      2962     47289                                           # OF UNKNOWN / OBS
     4.325                                                      WEIGHTED SIGMA (CYCLE)
ANTC                                                            STATION LIST
G 1 G 2 G 3 G 4 G 5 G 6 G 7 G 8 G 9 G10 G11 G12 G13 G14 G15 SATELLITE LIST
G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 SATELLITE LIST
G31 G32                                                         SATELLITE LIST
     30.00               LCPC                                   INT / OBS TYPE
 2010  2 20  0  0  0.0000000    86340.00                       TIME BEG/LEN
                                                                END OF HEADER
TIM 2010  2 20 23 59  0.0000000  55247  86340.00
  1 29     0.102     6.930  0.53882624D+04  0.77806509D-03  0  18.145   83.572  3.1753  3.1952
  1 24     0.022     2.092  0.13888889D+05  0.20055556D-02  0  37.168  131.584  1.6517  1.6537
  1 22    -0.022     5.949  0.13888889D+05  0.20055556D-02  0  36.083   10.624  1.6940  1.6962
  1 21     0.005     6.980  0.13888889D+05  0.20055556D-02  0  58.046  137.887  1.1780  1.1783
  1 18    -0.055     0.990  0.13888889D+05  0.20055556D-02  0  53.217   60.571  1.2477  1.2482
  1 16     0.009    10.227  0.13888889D+05  0.20055556D-02  0  68.359  -96.470  1.0756  1.0757
  1  6    -0.015    -0.607  0.13888889D+05  0.20055556D-02  0  36.970 -124.367  1.6592  1.6612
  1  3     0.019     0.781  0.10657730D+05  0.15389762D-02  0  25.976 -121.586  2.2714  2.2780
TIM 2010  2 20 23 58 30.0000000  55247  86310.00
  1 29     0.057    12.325  0.54753302D+04  0.79063768D-03  0  18.297   83.748  3.1505  3.1699
  1 24     0.009    -1.114  0.13888889D+05  0.20055556D-02  0  37.371  131.659  1.6440  1.6460
```

Fig.10 res file

Some comments have been explained in the part of file header. In the part of file body, the line started with "TIM" records the epoch time of residuals and the next lines record the values of residuals. The first two columns record the station number and the satellite number. And then the values of phase residual (cycle) and pseudorange residual (m) are in next two columns. Their STDs are recorded in next two columns, respectively. The next column records the flag of the data to indicate the statement of the data. And then, the values of satellite elevation and

satellite azimuth are recorded in the next two columns in the unit of angle (°). The last two columns record the values (m) of dry troposphere delay and wet troposphere delay, respectively.

rhd file

The results of RINEX health diagnosis are recorded in ***rhd*** file. An example is shown below:

```
Rinex Health Diagnose     ANTC                                COMMENT
     30.00     30.00                                          INT AMB/DEL
        11        56         7                               AMB MAX/TOT/NEW
     23577       220         3                               EPO AVA/REM/NEW
                                                             END OF HEADER
TIM 2010  2 20  0  0  0.0000000
  3                            2010  2 20  4 27 30.0000000 AMB
 29                                                          DEL
TIM 2010  2 20  0  6 30.0000000
 29                                                          DEL_SHORTPIECE
TIM 2010  2 20  0  7  0.0000000
 29                                                          DEL_LESSTHAN4OBS
TIM 2010  2 20  1 25 30.0000000
 24                                                          DEL_LOWELEVATION
TIM 2010  2 20  1 33  0.0000000
 14                                                          DEL_LESSTHAN4OBS
TIM 2010  2 20  1 33 30.0000000
```

Fig.11 Residual Health Diagnosis file(rhd file)

In the part of file header, the comment “INT AMB/DEL” denotes epoch interval. 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.

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 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.

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. An example is shown below:

```
+RMS OF RESIDUALS---PHASE(MM)
NAME SUMM   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
ANTC   15   0 11 33  9 10 46  8 10 13 12 12 11  9 16  9 17 10 17 11  9  8  9  7 10  0 14 15 12  8  8 10  0
NAME SUMM   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
-RMS OF RESIDUALS---PHASE(MM)
+TIME SERIES OF RESIDUALS---PHASE(MM)
 ANTC   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
    1       -12       -3                          14    -6        3 -1     1
    2        -3       -1                          11    -9        2 -2     1
    3        -9       -1                          11    -7        5 -3     2
    4        -9        0                           9    -8        2 -1     4
    5         0       -2                           6    -7        1  3     0
    6        -4       -2                           9    -9        1  5    -1
    7        -5       -2                           6    -7        8 -3     2
    8         1       -2                           2    -6        2  0     2
    9         2       -4                           5    -5        5 -2     0
   10         1       -2                           4    -2        3  0    -5
   11         3       -5                           4    -5        5 -2    -1
   12         2        0                           5    -7        3 -3     0
```

Fig.12 stt file

stt file is composed of RMS of phase residuals(mm) and time series of residuals(mm).

ztd file

The values of zenith tropospheric delay are recorded in ***ztd*** file. An example is shown below:

```
Zenith Tropospheric Delay                                               COMMENT
    30.00                                                               INTERVAL
                                                                        END OF HEADER
ANTC 2010  2 20  0  0  0.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  0 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  1  0.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  1 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  1 60.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  2 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  2 60.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  3 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  4  0.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  4 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  4 60.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  5 30.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  5 60.000000   2.121903   0.085340   0.000746
ANTC 2010  2 20  0  6 30.000000   2.121903   0.085340   0.000746
```

Fig.13 Zenith tropospheric delay file(ztd file)

The first column records the station name and the following is the time of epoch. The next two columns record the value of dry tropospheric delay and wet tropospheric delay. The last column records the estimate value of troposphere.

A.4 FCB Products Introduction

We have implemented the capability to produce phase bias products routinely, which is aiming to facilitate PPP-AR applications. The products are provided in two components:

1) SINEX-BIAS formatted GPS Fractional Cycle Bias;

2) Ambiguities fixed GPS satellite clocks.

Along with those products, a counterpart software, called “PRIDE-PPPAR”, is released together. With our phase bias products and software, users can conduct PPP-AR easily and focus on the results analysis. A data processing results are provided as below.

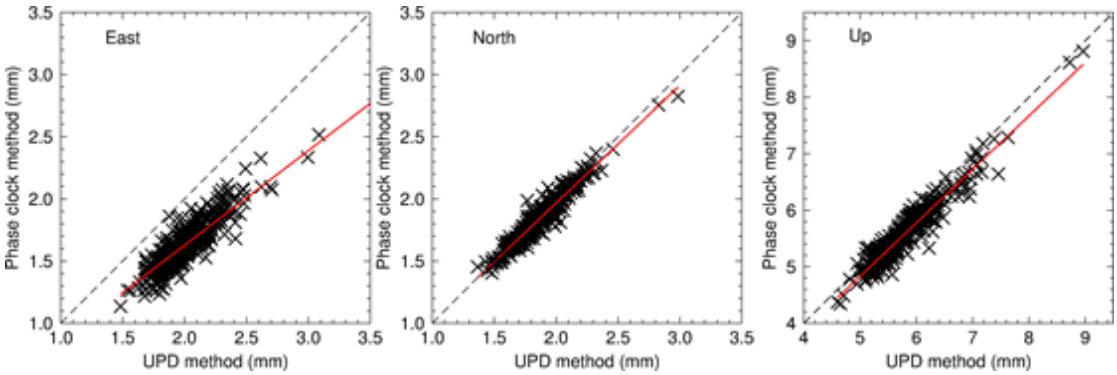


Figure 14: IGS stations coordinates RMS comparison of two types of PPP-AR solutions, i.e. the widely used UPD method and phase clock method (i.e. with our phase bias products), with respect to the IGS weekly SINEX file solutions in 2016.

The products generation strategies are listed as follows:

1. FCBs are obtained from the globally distributed IGS network stations;
2. PPP-AR is complemented with the same network using the FCBs above;
3. Satellite clocks are re-estimated with holding the fixed ambiguities and correcting FCBs.

Currently, the products from 2006 onwards can be publicly accessible from the WHU ftp and the software can be download from the homepage of PRIDELab Group (pride.whu.edu.cn).