PRIDE-PPPAR VER1.0

MANUAL

GNSS Precise Point Positioning with Ambiguity Resolution

Provided by

PRIDELab

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

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

QQ Group: ***971523302***

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GNSS RESEARCH CENTER, WUHAN UNIVERSITY

Dedicated to those

who are devoted to high-precision GNSS

Author:	**Jianghui GENG, Maorong GE**
Compiler:	**Xingyu CHEN, Yuanxin PAN**
Tester:	**Shuyin MAO, Jinning ZHOU, Kunlun ZHANG**
Manual editor:	**Chenghong LI**

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PRIDE-PPPAR ver. 1.0 Manual

1. Overview

1.1 Acknowledgement

PRIDE-PPPAR originates in Dr. Maorong Ge's efforts on PPP-AR and later developed and improved by Dr. Jianghui Geng. 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. 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 National Science Foundation of China (No. 41674033 and 41861134009) and is under the auspices of IAG JWG 4.4.1 "New GNSS Signals for Crustal Motion Studies".

PRIDE-PPPAR (Precise Point Positioning with Ambiguity Resolution) aims at post-processing of GPS data. It is worth noting that PRIDE-PPPAR is capable of processing high-rate GPS data (i.e. 1Hz, 5Hz, 10Hz), which will be useful to GNSS seismology. We are developing multi-GNSS version, and keep an eye on our website for future upgrade. We hope you enjoy the software and will keep attention to the copyright issues.

The copyright of this package is protected by GNU General Public License (version 3). Only a few source code are not open to the public due to technical restrictions and conflicts with existing commercial packages, and thus will be available as a dynamic link library. We note that some source code is from the third party and may be protected by other licenses, though open to the public as well. They are the DE405 which is from NASA JPL (ftp://ssd.jpl.nasa.gov/pub/eph/planets/fortran/) which we believe to be freely open the all; the LAMBDA (Least-squares Ambiguity Decorrelation Adjustment) package from TUDelft (https://www.tudelft.nl/citg/over-faculteit/afdelingen/geoscience-remote-sensing/research/lambda/lambda/). which is a redistribution here. We are grateful to both software packages.

PRIDE-PPPAR requires the phase clock/bias products in the bias-SINEX format computed and released by Wuhan University (ftp://igs.gnsswhu.cn). If you use this software or/and the phase clock/bias products, please acknowledge or cite the following publications,

Geng J et al. (2019) A modified phase clock/bias model for PPP ambiguity resolution. (under revision)

Geng J and Chen X (2018) Phase bias product and open-source software for undifferenced ambiguity resolution at Wuhan University. IGS workshop 2018, Oct. 29-Nov. 2, Wuhan, China.

Geng J et al. (2019) PRIDE PPP-AR: an open-source high-precision GNSS positioning software. (under revision).

The software package is also hosted on Github(https://github.com/PrideLab/) and PRIDELab homepage (http://pride.whu.edu.cn) for efficient access.

1.2 Contact us

You can contact us for **bug reports** and **comments** by sending emails or leave messages on our website.

Email: pride@whu.edu.cn

Website: pride.whu.edu.cn

For Chinese users, we provide Tencent **QQ Group** service. Group Number: **971523302**. Leave your organization and name when applying for admission.

2. User Requirements

2.1 System Requirements

PRIDE-PPPAR is composed of CUI APs. The executable binary CUI APs included in the package require Linux environment. All of the 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. Note that you can also try other Linux distribution and Fortran compiler, and tell us if you have any problems.

Fortran compiler needs to be installed before installing PRIDE-PPPAR.

Table 1 PRIDE-PPPAR test results in different operating systems.

Linux version (x64 default)	***gfortran version***	***Test result***	***Notes***
Ubuntu14.04.4	4.8.4	pass	1. Pre-install 'gfortran' before installation; 2. Test result is consistent with the reference
Ubuntu16.04.11	5.4.0	pass	Test result is consistent with the reference
CentOS 6.5	4.4.7	pass	Test result is consistent with the reference

2.2 License

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This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License (version 3) for more details.

You should have received a copy of the GNU General Public License along with this program. If not, see

3. Instructions

3.1 Installation and Validation

Structures of PRIDE-PPPAR

The structure of PRIDE-PPPAR is as follow.

Table 2 PRIDE-PPPAR structures

PRIDE-PPPAR		*Instructions*
\bin		**Executable program**
	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
	xyz2enu	Convert XYZ to ENU
	rnx2rtkp	Open source program form RTKLIB(http://www.rtklib.com/)
	teqc, crxrnx	Third-party programs, refer to UNAVCO(https://www.unavco.org/) and http://sopac.ucsd.edu/hatanaka.shtml
\scripts		**Some scripts for efficient data processing**
	rtk2xyz.sh	Get initial coordinates of stations
	leap.sh	Update leap second file (leap.sec)
	pride_pppar.sh	Automatic processing Shell script
\src		**Source programs**
	\header	Header files

	\arsig	Ambiguity resolution
	\de405	JPL planetary ephemeris
	\get_ctrl	Get configuration parameters
	\lambda	LAMBDA
	\lib	Library functions, and 'libpride_pppar.so'
	\lsq	Least squares adjustment
	\orbit	Sp3orb, mergeerp, mergesp3
	\redig	Residual editing
	\tedit	Pre-processing RINEX files
	Makefile	Makefile
\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
\example		**Examples**
	test.sh	Test script
	\data	Example data
	config_template	Configuration files
	\results_ref	Reference results for examples
\codeblocks	PRIDE-PPPAR project of Code::Blocks for IDE users(cross-platform)	

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 (**~/.PRIDE_PPPAR_BIN/***))
Step 3: **Restart terminal**.

Validation

Step 1: $ Change directory into **/example**, conduct **./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 and execution. Run test.sh, then the examples of PPP and PPP-AR are conducted. The data processing procedure is conducted and some information is printed to the screen. After that, results files are created. Then compare the solution files between results and reference results to make sure the software installation is correct and valid.

Three examples are conducted by script **test.sh**. '**static**' mode denotes that we regard the station as a static station, and estimate only one set of coordinates in the whole observation period. '**kinematic**' denotes that we regard the station as a kinematic station, and estimate one set of coordinates every epoch. '**PPP**' means precise point positioning without ambiguity resolution, as we call float solution, while '**PPP-AR**' achieves ambiguity resolution by utilizing phase bias products provided by **PRIDELab**, together with the open source program **PRIDE-PPPAR**. '**PPP-AR LAMBDA**' denotes the ambiguity resolution process is conducted by **LAMBDA** (Least-squares Ambiguity Decorrelation Adjustment) method. The default method is round directly. The one-hour example is conducted by utilizing LAMBDA methods for efficient ambiguity resolution, while the traditional rounding method cannot retrieve ambiguity correctly.

Table 3 PRIDE-PPPAR test examples.

No.	Examples	Explanation
1	*static PPP*	Static, PPP Float Solution
	static PPP-AR	Static, PPP Ambiguity Resolution
2	*kinematic PPP*	Kinematic, PPP Float Solution
	kinematic PPP-AR	Kinematic, PPP Ambiguity Resolution
3	*kinematic PPP (1 hour)*	Kinematic, PPP Float Solution
	kinematic PPP-AR LAMBDA (1 hour)	Kinematic, PPP Ambiguity Resolution with LAMBDA

3.2 Quick Start

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

& pride_pppar config_template 20160101 20160101 Y/N

config_template denotes session configuration file, and the parameters and formats of these files are described in *Appendix A.2*. ***20160101*** and ***20160101*** denote start time and ending time of data processing, respectively. According to the time format (YYYYMMDD), you can set the processing time as required. Moreover, multi-day data processing is accomplished. The last parameter ***Y/N*** denotes the ambiguity resolution switch, which has two options, ***Y*** or ***N.***

N – PPP Float Solution

Y – PPP Ambiguity Resolution

The automatic processing script **pride_pppar** contains the information of processing procedures, you can read the script for details.

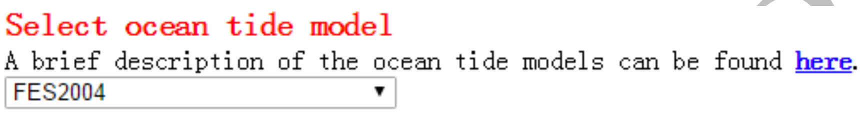
PPP

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

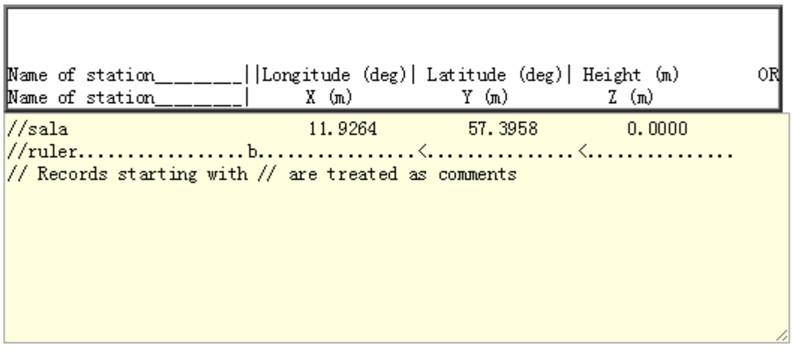
1. The PRIDE-PPPAR software directory is as below:

2. Create a working folder **/project**, and its subfolder **/data**.

3. Copy RINEX Observation Files and Navigation Files to **/project/data/YEAR/DOY** (/project/data/2016/001, for example).
4. Copy configuration file 'config_template' to **/project** directory.
5. Edit configuration file to set proper processing parameters.
   The specific definition and instruction of some parameters is listed in '*config_template*'.
6. Change into **/project/data** directory, run $ **./rtk2xyz.sh 2016/001/** to get **sit.xyz**, which records the appropriate coordinates of the stations (XYZ). Then append the coordinates to the file **/table/sit.xyz** as the format required.
7. **[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/). Choose the model **FES2004**, and leave the rest of the options as default.



   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 **/table/oceanload** as the original format.



8. Change into **/project**, Run the script to start data processing.
   $ pride_pppar config_template 20160101 20160101 N
9. After processing, the solution files will be in the **/project/2016/001** directory.

PPP with Ambiguity Resolution

1. Conduct procedure 1~7 listed above.
2. Change into **/project** directory, run the script to start data processing.
   $ pride_pppar config_template 20160101 20160101 Y
3. After processing, the solution files will be in the **/project/2016/001** directory.

4. Modules of PRIDE PPP-AR

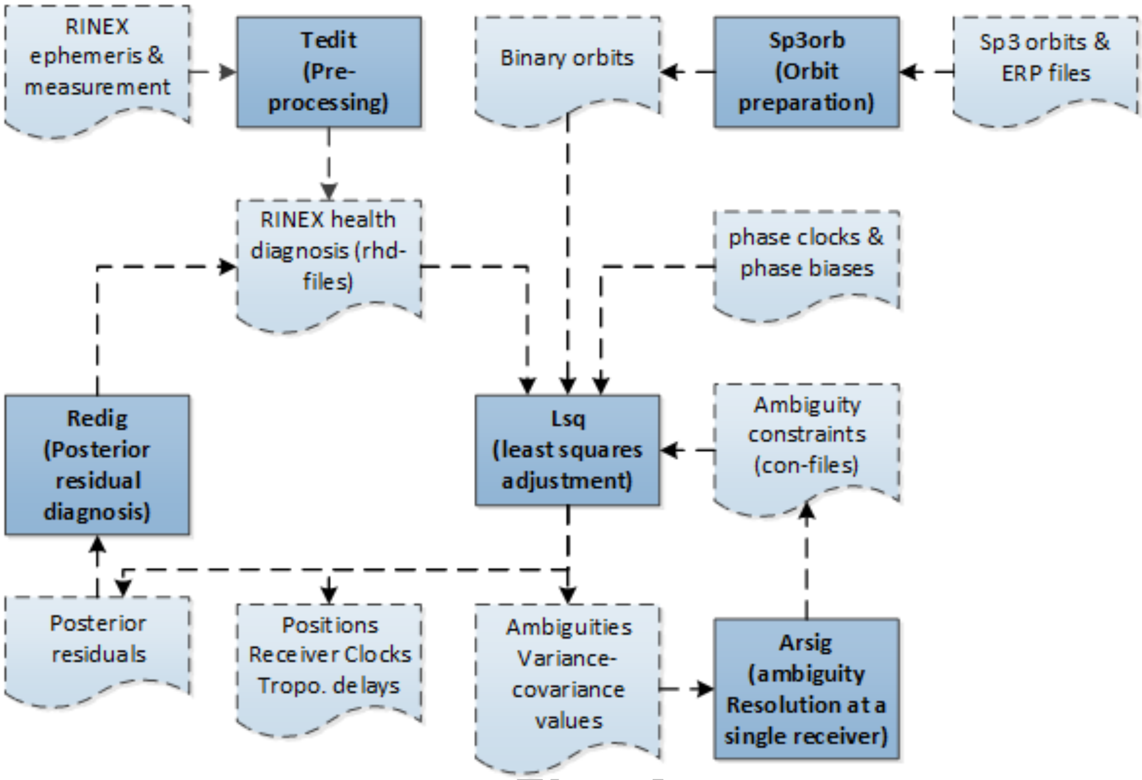


Fig. 1 Module structure of PRIDE-PPPAR

4.1 Data Preparation

Merge Precise Ephemeris Files with mergesp3

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

& mergesp3 cod19000.eph cod19001.eph cod19002.eph mer_cod19001.eph

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

cod19000.eph cod19001.eph cod19002.eph

Output: three-day SP3 orbit product result

mer_cod19001.eph

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 cod18775.eph -cfg config_template [–erp igserp]

Input:

cod18775.eph	SP3 orbit file
–cfg config_template	session configuration file
[–erp igserp]	ERP file

Output:

orb_2016001	Binary format orbit product

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

4.2 Data Pre-processing

Pre-processing with tedit

tedit which is based on the pre-processing algorithms by Blewitt (1990)[1] 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 2016 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 2016 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 IONO no = edit WL and IONO and try to connect WL and IONO 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

[1] Blewitt G. An Automatic Editing Algorithm for GPS Data [J]. Geophysical Research Letters, 1990, 17(3):199-202.

4.3 Data Post-processing

Parameters Estimation with lsq

lsq conducts least squares adjustment. The module ***lsq*** is used to estimate unknown parameters.

& lsq config_template

Input: configuration file

config_template	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
-neq	inversed normal matrix
-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 acquired.

& redig res_2016001 -jmp jump -sht nsht [-hug huge-residual]

Input:

config_template	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** aims to retrieve the integer properties of ambiguities to ambiguity-fixed solutions.

& arsig config_template

Input:

config_template	session configuration file

Output: solution files with ambiguity resolution

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:

```
aber    3466278.0901    -125904.0175    5334675.8707
abmf    2919787.8930   -5383750.2606    1774607.9692
abpo    4097221.8858    4429124.5373   -2065774.0482
acor    4594496.4689    -678369.4428    4357074.2691
ade1   -3939188.3910    3467081.0602   -3613226.8036
ade2   -3939188.2645    3467080.9291   -3613226.6181
```

Fig.2 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 required. 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
 57753  37          ! 31 DEC 2016 LEAP SEC INCREMENT
 58200  38          ! 28 December 2017
-leap sec
```

Fig.3 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 MJD date of RINEX O file processed should be smaller 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). Furthermore, we provide a shell script ***leap.sh*** to update the ***leap.sec*** file automatically.

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. You can change the '**igs05/08/14_****.atx'** file on your own to suit the frame by soft links to file '***abs_igs.atx***'.

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 (pride.whu.edu.cn). Caution: The binary file **'jpleph_de405'** is generated by '**/src/de405**' based on Linux operating systems. If there are related errors reported about '**jpleph_de405**', you can rebuild this file on your own operating systems.

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-
con        con_-YYYY--DDD-
fcb        fcb_-YYYY--DDD-
htg        htg_-YYYY--DDD-
kin        kin_-YYYY--DDD-
neq        neq_-YYYY--DDD-
orb        orb_-YYYY--DDD-
pos        pos_-YYYY--DDD-
rck        rck_-YYYY--DDD-
res        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-
ztd        ztd_-YYYY--DDD-
```

Fig.4 Format of file_name

A.2 Configuration File

configuration file (*config_template*)

The session configuration file (***config_template***) 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:

```
# configuration template for PRIDE-PPPAR

# The following options can be kept for all data processing (except for 'Station used' list)
# For Ambiguity fixing, it can always be 'FIX' in configuration file.  Actually, AR is
# controlled by the command line arguments of pride_pppar.


## Session config
# User should modify this part configuration to suit their own directory
Interval = 30
Session time    = -YYYY- -MM- -DD- 00 00 00 86360              ! -YYYY- -MM- -DD- is placeholder for automatic multi-days processing
Rinex directory = /home/username/path-to-data/-YEAR-/-DOY-/    ! -YEAR- -DOY- is placeholder for automatic multi-days processing
Sp3 directory   = /home/username/path-to-product/product/
Table directory = /home/username/path-to-table/table/

## strategies
Remove bias      = YES                       ! change to NO if AR method is LAMBDA
ZTD model        = PWC:60                    ! troposphere estimation. PWC: piece-wise constant, 60: 1 hour
HTG model        = PWC:720                   ! troposphere horizontal gradient. PWC, 720: 12h

## ambiguity fixing options
Ambiguity fixing    = FIX                    ! Ambiguity fixing: NO/FIX/LAMBDA
Common observing    = 600                    ! common observation time in seconds
Cutoff elevation    = 15                     ! cutoff angles for eligible ambiguities in AR
Widelane decision   = 0.20 0.15 1000.        ! deriation, sigma in WL-cycle
Narrowlane decision = 0.15 0.15 1000.        ! deriation, sigma in NL-cycle
Critical search     = 2 4 1.8 3.0

# Insert # at the begining of individual GPS PRN means not to use this satellite

## Satellite list
+GPS satellites
*PN
 01
 02
 03
 04
 05
...
 26
 27
 28
 29
 30
 31
 32
-GPS satellites

# User can add more station in the following table. Stations will be processed one by one.
# Available positiioning mode: S -- static
#                              K -- kinematic
# Ohter arguments can be kept.

# Station list
+Station used
*NAME TP MAP CLKm EV ZTDm PoDm HTGm PoDm RAGm PHSc PoXEm PoYNm PoZHm
 algo S  GMF 9000  7 0.20 .020 .005 .002 3.00 .006 10.00 10.00 10.00
 zimm S  GMF 9000  7 0.20 .020 .005 .002 3.00 .006 10.00 10.00 10.00
-Station used
```

Fig.5 Configure file format (config_template)

The explanation of the processing parameters are listed below. The content after '#' denotes the explicit explanation of the options.

---***configuration template***---

 # configuration template for PRIDE-PPPAR

 # The following options can be kept for all data processing (except for 'Station used' list)

 # For Ambiguity fixing, it can always be 'FIX' in configuration file. Actually, AR is

 # controlled by the command line arguments of pride_pppar.

Session configuration

 # User should modify to suit their own directory

Interval = 30

```
# The processing interval of Rinex data.
Session time        = -YYYY- -MM- -DD- 00 00 00 86360
# -YYYY- denotes the year of RINEX data, i.e. 2016; -MM- and –DD- denote month and day, i.e. 02 14; the following
# is the format of time( hour, minute,second, and length of time to be processed).
# Actually, the Shell script 'pride_pppar' recognize –YYYY-, -MM- and –DD- as the identifier of actual data, so you
# don't need to modify them when processing using the script, so as '-YEAR-', '-DOY-' below .
#
Rinex directory = /home/username/path-to-data/-YEAR-/-DOY-/
# Example: /home/username/pride_pppar/example/data/-YEAR-/-DOY-/
# -YEAR- and –DOY- indicate 'year' and 'day of year', respectively.
Sp3 directory     = /home/username/path-to-product/product/
Table directory = /home/username/path-to-table/table/
# Example: Sp3: /home/username/pride_pppar/example/product
# Example: Table: /home/ username /pride_pppar/table

## strategies
Remove bias          = YES                          ! change to NO if AR method is LAMBDA
HTG model            = PWC:720                      ! troposphere horizontal gradient. PWC, 720: 12h
ZTD model            = PWC:60                       ! troposphere estimation. PWC: piece-wise constant, 60: 1 hour

## ambiguity fixing options
Ambiguity fixing          = FIX                     ! Ambiguity fixing: NO/FIX/LAMBDA
Common observing          = 600                     ! common observation time in seconds
Cutoff elevation          = 15                      ! cutoff angles for eligible ambiguities in AR
Widelane decision         = 0.20 0.15 1000.         ! deriation, sigma in WL-cycle
Narrowlane decision       = 0.15 0.15 1000.         ! deriation, sigma in NL-cycle
Critical search           = 2 4 1.8 3.0

# Insert '#' at the beginning of individual GPS PRN to exclude this satellite

## Satellite list
+GPS satellites
*PN (3000m is a priori constraint on satellite clock)
 01 3000
 02 3000
 03 3000
 04 3000
 05 3000
 ……
 29 3000
 #30 3000
 #31 3000
 32 3000
-GPS satellites
```

 # User can add more station in the following table as the format below. Stations will be processed one by one.
 # Available positioning mode: S -- static
 #   K -- kinematic
 # Other arguments can be kept.

 # Station list
+Station used
***NAME TP MAP CLKm EV ZTDm PoDm HTGm PoDm RAGm PHSc PoXEm PoYNm PoZHm**
 algo S GMF 9000 7 0.20 .020 .005 .002 3.00 .006 10.00 10.00 10.00
-Station used
--- *configuration template* ---

A.3 Solution Files

In ***PRIDE-PPPAR***, there are some self-defined solution files, whose formats 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:

```
algo   3          27.483317        5.852690  57388.0000000000  57388.0413194444   0.0136   0.0182  35.0
algo  14          85.193325       13.877722  57388.0000000000  57388.0180555556   0.0417   0.0700  12.2
algo  16          64.148038        9.911176  57388.0000000000  57388.0413194444   0.0124   0.0098  55.4
algo  23         -33.822958       -0.167024  57388.0000000000  57388.0413194444   0.0109   0.0165  40.0
algo  26          65.200260        1.848015  57388.0000000000  57388.0413194444   0.0106   0.0068  76.1
algo  29         -17.029738       -3.042716  57388.0000000000  57388.0413194444   0.0153   0.0307  21.9
algo  31          34.102786        2.965842  57388.0000000000  57388.0413194444   0.0110   0.0107  46.2
algo  32          12.232779       -0.094372  57388.0000000000  57388.0413194444   0.0177   0.0324  26.2
algo   9          -4.117896       -6.102921  57388.0267361111  57388.0413194444   0.0536   0.0831  13.8
```

Fig.6 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***, ***con*** file will be produced. ***con file*** records the values of integer ambiguity. An example is shown below:

```
Single-Difference Ambiguity Constraint                               COMMENT
    SD                                                               TYPE OF CONSTRAINT
                                                                     END OF HEADER
algo G03 G32 2016  1  1  0  0  0.000000 2016  1  1  1 19  0.000000            6            6  0.000
algo G16 G32 2016  1  1  0  0  0.000000 2016  1  1  1 19  0.000000           10           57  0.000
algo G26 G29 2016  1  1  0  0  0.000000 2016  1  1  1 39 30.000000            5          129  0.000
algo G29 G31 2016  1  1  0  0  0.000000 2016  1  1  1 39 30.000000           -6          -70  0.000
algo G16 G26 2016  1  1  0  0  0.000000 2016  1  1  3 44  0.000000            8          -30  0.000
algo G09 G23 2016  1  1  0 38 30.000000 2016  1  1  4 28 30.000000           -6           74  0.000
algo G23 G28 2016  1  1  4 13  0.000000 2016  1  1  4 28 30.000000           -5          -40  0.000
algo G11 G16 2016  1  1  3 38 30.000000 2016  1  1  4 58  0.000000            1          -86  0.000
algo G09 G27 2016  1  1  0 52  0.000000 2016  1  1  5 21  0.000000            3           -2  0.000
algo G01 G27 2016  1  1  4 31 30.000000 2016  1  1  6 10 30.000000           12            8  0.000
algo G11 G13 2016  1  1  4 53 30.000000 2016  1  1  7 22  0.000000            7           30  0.000
algo G13 G30 2016  1  1  4 53 30.000000 2016  1  1  7 22  0.000000            5          -52  0.000
algo G03 G08 2016  1  1  7  0  0.000000 2016  1  1  7 31 30.000000          -13          -42  0.000
```

Fig.7 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 next two columns denote the values of wide-lane ambiguity and narrow-lane ambiguity, 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          algo                              COMMENT
    30.00                                                       INTERVAL
                                                                END OF HEADER
57388      0.00      918129.198 -4346071.299  4561977.900
57388     30.00      918129.200 -4346071.305  4561977.895
57388     60.00      918129.203 -4346071.305  4561977.896
57388     90.00      918129.202 -4346071.301  4561977.898
57388    120.00      918129.198 -4346071.299  4561977.902
57388    150.00      918129.197 -4346071.297  4561977.898
57388    180.00      918129.198 -4346071.307  4561977.903
57388    210.00      918129.196 -4346071.289  4561977.888
57388    240.00      918129.196 -4346071.301  4561977.899
57388    270.00      918129.202 -4346071.307  4561977.900
57388    300.00      918129.202 -4346071.307  4561977.904
57388    330.00      918129.201 -4346071.309  4561977.899
57388    360.00      918129.198 -4346071.311  4561977.903
57388    390.00      918129.197 -4346071.298  4561977.897
57388    420.00      918129.195 -4346071.302  4561977.905
```

Fig.8 Kinematic solution file (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 57388.4998

ALGO    918129.1969  -4346071.3098   4561977.9039
CORR         0.0007         0.0014        -0.0009
SIGM         0.0001         0.0002         0.0002
NOBS          26480
```

Fig.9 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 HEADER
ALGO 2016  1  1  0  0  0.000000    -49577.113048      3.174095
ALGO 2016  1  1  0  0 30.000000    -49577.113048      3.178918
ALGO 2016  1  1  0  1  0.000000    -49577.113048      3.209869
ALGO 2016  1  1  0  1 30.000000    -49577.113048      3.215861
ALGO 2016  1  1  0  2  0.000000    -49577.113048      3.100381
ALGO 2016  1  1  0  2 30.000000    -49577.113048      3.099673
ALGO 2016  1  1  0  3  0.000000    -49577.113048      3.156952
ALGO 2016  1  1  0  3 30.000000    -49577.113048      3.181552
ALGO 2016  1  1  0  4  0.000000    -49577.113048      3.208602
ALGO 2016  1  1  0  4 30.000000    -49577.113048      3.227612
ALGO 2016  1  1  0  5  0.000000    -49577.113048      3.210683
ALGO 2016  1  1  0  5 30.000000    -49577.113048      3.206571
ALGO 2016  1  1  0  6  0.000000    -49577.113048      3.187737
ALGO 2016  1  1  0  6 30.000000    -49577.113048      3.187500
```

Fig.10 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
        31                                                  # OF SIT / SAT
      2967     53031                                        # OF UNKNOWN / OBS
     1.914                                                  WEIGHTED SIGMA (CYCLE)
ALGO                                                        STATION LIST
G 1 G 2 G 3 G 5 G 6 G 7 G 8 G 9 G10 G11 G12 G13 G14 G15 G16 SATELLITE LIST
G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 SATELLITE LIST
G32                                                         SATELLITE LIST
     30.00              LCPC                                INT / OBS TYPE
 2016  1  1  0  0  0.0000000    86340.00                    TIME BEG/LEN
                                                            END OF HEADER
TIM 2016  1  1 23 59  0.0000000  57388  86340.00
  1 31     0.015    -5.511  0.13888889D+05  0.20055556D-02  0  37.058 -144.976
  1 30     0.002    -1.148  0.13888889D+05  0.20055556D-02  0  56.128   61.637
  1 28    -0.076     7.668  0.85174527D+04  0.12299202D-02  0  23.051   66.888
  1 25    -0.007     2.566  0.13888889D+05  0.20055556D-02  0  70.145  168.594
  1 24     0.042    -5.507  0.10465986D+04  0.15112884D-03  0   7.889   42.328
  1 22     0.014     3.646  0.13192298D+05  0.19049678D-02  0  29.163  -54.009
  1 15    -0.008    -7.188  0.13888889D+05  0.20055556D-02  0  41.631 -162.112
  1 13     0.089     4.432  0.42572382D+04  0.61474519D-03  0  16.071  127.226
  1  3     0.002    -1.939  0.13888889D+05  0.20055556D-02  0  41.335  -97.037
TIM 2016  1  1 23 58 30.0000000  57388  86310.00
  1 31     0.002    -4.027  0.13888889D+05  0.20055556D-02  0  37.260 -144.827
  1 30     0.013    -0.988  0.13888889D+05  0.20055556D-02  0  56.321   61.427
  1 28    -0.046    -1.815  0.85000121D+04  0.12274017D-02  0  23.026   67.123
  1 25     0.002     0.112  0.13888889D+05  0.20055556D-02  0  69.919  168.931
  1 24     0.056    -6.314  0.10981406D+04  0.15857151D-03  0   8.082   42.321
  1 22    -0.003    -0.828  0.13028827D+05  0.18813627D-02  0  28.965  -54.027
  1 15    -0.005    -5.012  0.13888889D+05  0.20055556D-02  0  41.379 -162.158
  1 13     0.004     1.129  0.43593950D+04  0.62949663D-03  0  16.268  127.112
  1  3     0.015    -2.863  0.13888889D+05  0.20055556D-02  0  41.410  -96.737
```

Fig.11 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 (cycle) 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 states 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      ZIMM                                                    COMMENT
     30.00      30.00                                                              INT AMB/DEL
        12         68          0                                                   AMB MAX/TOT/NEW
     25611       2528        453                                                   EPO AVA/REM/NEW
                                                                                   END OF HEADER
TIM 2016   1   1   0   0   0.0000000
  2                                 2016   1   1   1 10 30.0000000 AMB
 12                                 2016   1   1   1  2  0.0000000 AMB
 14                                                                  DEL
 21                                                                  DEL
 25                                 2016   1   1   0 43  0.0000000 AMB
 26                                 2016   1   1   5 24  0.0000000 AMB
 29                                 2016   1   1   3 55  0.0000000 AMB
 31                                 2016   1   1   0 43  0.0000000 AMB
TIM 2016   1   1   0   0 30.0000000
 14                                                                  DEL
 21                                                                  DEL_LESSTHAN4OBS
TIM 2016   1   1   0   1   0.0000000
 14                                                                  DEL
 21                                                                  DEL
TIM 2016   1   1   0   1 30.0000000
 14                                                                  DEL
 21                                                                  DEL
TIM 2016   1   1   0   2   0.0000000
 14                                                                  DEL
 21                                                                  DEL
```

Fig.12 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   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
ALGO    7   9   5   7   4   5   9   8   8   6   6   7   8   7   5   5   8   5   6   6   9   7   7  13  10   7   8   6   8   7   5   7
NAME SUMM   1   2   3   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)
 ALGO   1   2   3   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           8                                      1       2                          -3          -4          -6       0   0
    2           5                                    -11       0                           5          -4           1       2  -3
    3           5                                     -8       2                           9          -6          -8       1  -3
    4           3                                     -8       4                           6          -6         -11       1   2
    5           1                                      2       3                           0          -3         -11       0   5
    6           5                                      2       0                          -1           0          -8      -1   1
    7           3                                     13      -3                           4          -3          -7       1  -1
    8           4                                    -10      -2                          -4           3          -7       1   4
    9           1                                     -1       1                          -1          -1          -2       0   1
   10           1                                     -7       2                           8          -4          -2      -4  -1
   11           2                                     -1       2                           6          -3          -3      -5   0
   12          -3                                     -5      -1                          10          -2           1      -3  -1
```

Fig.13 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
ALGO 2016  1  1  0  0  0.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  0 30.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  1  0.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  1 30.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  2  0.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  2 30.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  3  0.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  3 30.000000   2.248719   0.017134   0.034126
ALGO 2016  1  1  0  4  0.000000   2.248719   0.017134   0.034126
```

Fig.14 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 of troposphere.

Appendix B Phase Bias Products

B.1 Algorithm and Usage

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 below.

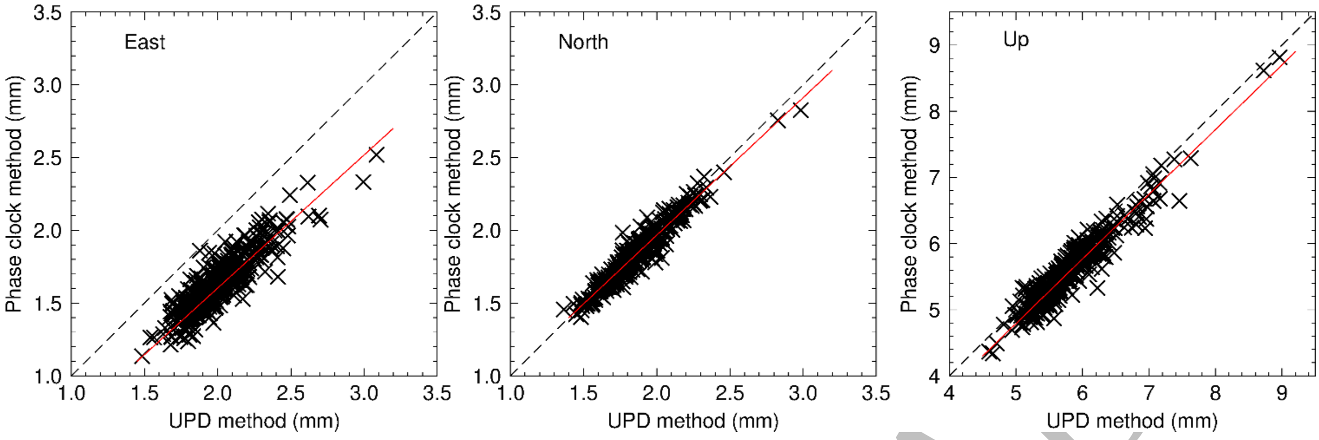


Figure 15: IGS stations coordinates RMS comparison of two types of PPP-AR solutions, i.e. the widely used UPD method and phase clock method (i.e. with our phase bias products), with respect to the IGS weekly SINEX file solutions in 2016.

The products generation strategies are listed as follows:

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

Currently, the products from 2006 onwards can be publicly accessible from the WHU ftp (ftp://igs.gnsswhu.cn/pub/whu/phasebias/) and the software can be download from the homepage of PRIDELab (pride.whu.edu.cn).

For more information, please refer to the attached 2018 IGS Report: Phase bias product and open-source software for undifferenced ambiguity resolution at Wuhan University.

B.2 Product Usage

In order to keep homogeneity with phase clocks and phase bias products, users should use CODE final products (except the satellite clock) while using our phase clock and phase bias products to achieve ambiguity resolution with PRIDE-PPPAR. The usage of phase bias product is similar to DCB (Differencial Code Bias). You can simply subtract the phase biases from the original observations equations for correction. The procedures of ambiguity resolution are as follow:

1) Before realizing PPP float solution with ionosphere free (IF) combination, phase biases in L1C, L2W, C1W and C2W measurements should be corrected. Note that our phase biases only target L1C, L2W, C1W and C2W observations, so users need to remove DCB with other biases products;

$$\Phi_{true} = \Phi_{observed} - B \qquad (1)$$

Where Φ_{ture} denotes true (or unbiased) observation; $\Phi_{observed}$ denotes original observation; B denotes phase biases (L1C, L2W, C1W and C2W).

2) Estimate wide-lane ambiguity and realize float PPP;

3) Fix wide-lane ambiguities and narrow-lane ambiguities without any biases correction;

4) Calculate IF ambiguities values with the fixed wide-lane ambiguities and narrow-lane ambiguities, then achieve PPP ambiguity resolution.

B.3 Result Comparison with IGS SINEX Solution

Utilizing the phase bias products we released, we test a series of IGS static stations from 2006 to 2016. Then we compare the static PPP-AR results with IGS SINEX solutions. The figures listed below 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 365. The Y axis denotes different stations. The color map, which ranges from blue to red, represents the difference value in the unit of centimeter.

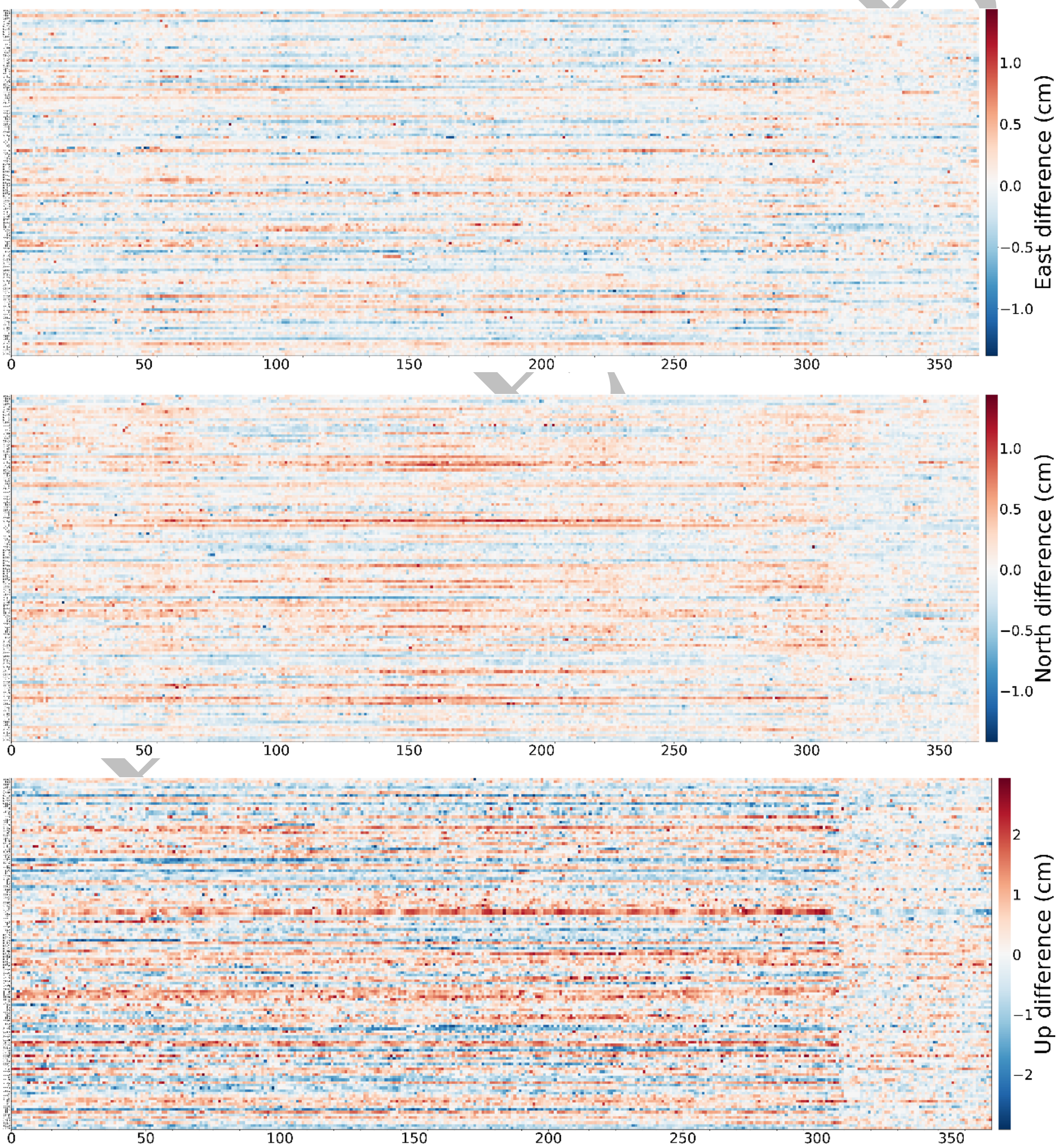
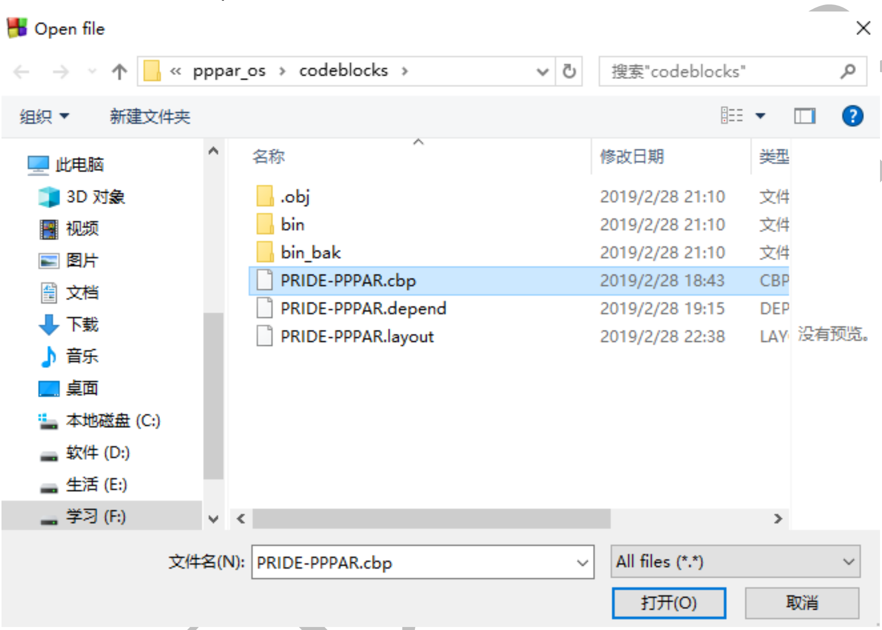


Figure16 Difference between PRIDE-PPPAR solution and IGS SINEX solution of various stations. It is worth noting that there is an obvious vertical boundary around day of year 310. This is because that the phase clock products

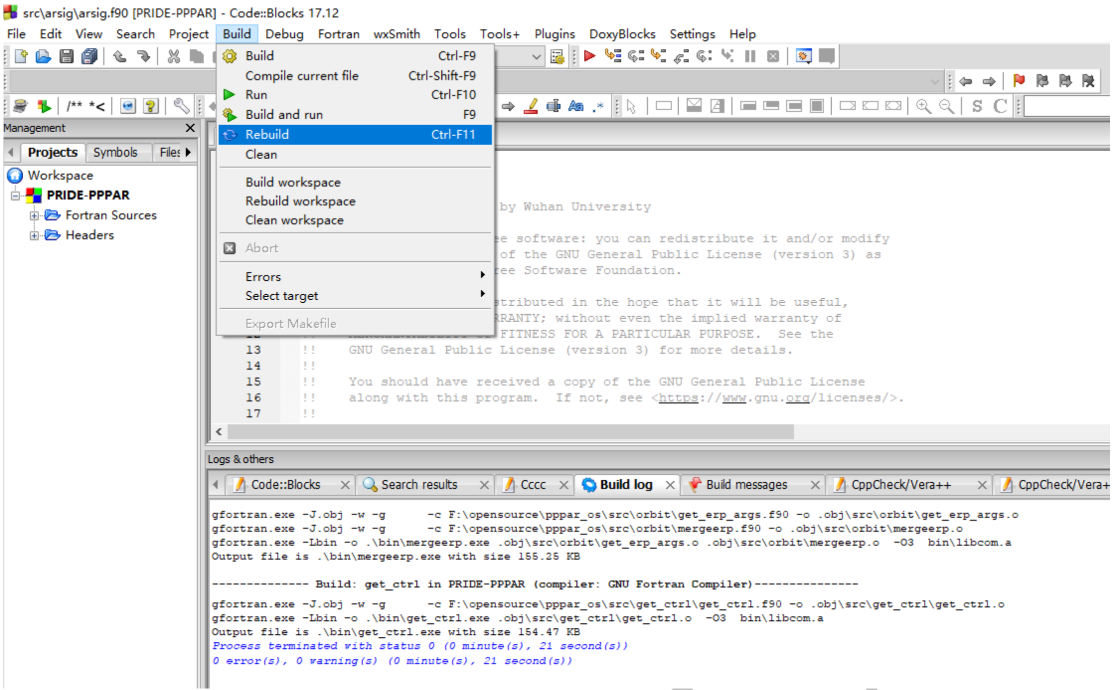
we produced utilize IGS_05.ATX file. However, IGS utilized relative antenna phase center model before November 2006.

Appendix C IDE Project

Besides command-line tools, we also provide an IDE project using Code::Blocks, which is a **cross-platform** free C, C++ and Fortran IDE. Users can view, edit and compile source codes with Code::Blocks conveniently.
First, install Code::Blocks from http://www.codeblocks.org/downloads/.
Then, open PRIDE-PPPAR project in Code::Blocks:
Menu: File → open→PRIDE-PPPAR.cbp



Build PRIDE-PPPAR:
Menu: Build



Normally, you will get the message below if the project is successfully rebuilt.

```
Process terminated with status 0 (0 minute(s), 21 second(s))
0 error(s), 0 warning(s) (0 minute(s), 21 second(s))
```

Copy executable binaries of PRIDE-PPPAR to where your system can find. For Linux users, it's /home/your-user-name/.PRIDE_PPPAR_BIN/.

Phase bias product and open-source software for undifferenced ambiguity resolution at Wuhan University

Jianghui GENG (耿江辉), Xingyu CHEN

GNSS Research Center, Wuhan University, China

IGS Workshop 2018

31 Oct 2018

Wuhan China

GNSS biases and IGS Bias-SINEX file

- Code biases across GNSS systems, frequencies and observables.
  - Align pseudorange to obey IGS "conventions";
  - Resolve Melbourne-Wübbena ambiguities.
- IGS has been standardizing bias products since 2012 (Schaer 2018)
  - to address flourishing observables due to multi-GNSS;
  - to formulate IGS conventions on bias products.
- However, phase biases are seldom discussed.

SINEX_BIAS—Solution (Software/technique) INdependent EXchange Format for GNSS Biases Version 1.00

Stefan Schaer
swisstopo/AIUB
stefan.schaer@aiub.unibe.ch

June 29, 2011 (Draft Version 0.01)
December 7, 2016 (Finalized Version 1.00)
October 3, 2018

```
+BIAS/DESCRIPTION
*KEYWORD________________________________ VALUE (S) ______________________________
 OBSERVATION_SAMPLING                          300
 PARAMETER_SPACING                           86400
 DETERMINATION_METHOD                   INTER-FREQUENCY_BIAS_ESTIMATION
 BIAS_MODE                              ABSOLUTE
 TIME_SYSTEM                            G
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  G  C1W  C2W
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  R  C1P  C2P
-BIAS/DESCRIPTION
*-------------------------------------------------------------------------------
+BIAS/SOLUTION
*BIAS SVN_ PRN STATION__ OBS1 OBS2 BIAS_START____ BIAS_END______ UNIT __ESTIMATED_VALUE____ _STD_DEV___
 OSB  G063 G01           C1C       2017:001:00000 2017:002:00000 ns                 10.7141      0.0000
 OSB  G063 G01           C1W       2017:001:00000 2017:002:00000 ns                 11.8171      0.0000
 OSB  G063 G01           C2C       2017:001:00000 2017:002:00000 ns                 18.3161      0.0000
 OSB  G063 G01           C2W       2017:001:00000 2017:002:00000 ns                 19.4621      0.0000
 OSB  G061 G02           C1C       2017:001:00000 2017:002:00000 ns                -12.5893      0.0000
 OSB  G061 G02           C1W       2017:001:00000 2017:002:00000 ns                -13.9193      0.0000
 OSB  G061 G02           C2W       2017:001:00000 2017:002:00000 ns                -22.9243      0.0000
 OSB  G069 G03           C1C       2017:001:00000 2017:002:00000 ns                  5.6814      0.0000
 OSB  G069 G03           C1W       2017:001:00000 2017:002:00000 ns                  7.2464      0.0000
 OSB  G069 G03           C2C       2017:001:00000 2017:002:00000 ns                 12.2914      0.0000
 OSB  G069 G03           C2W       2017:001:00000 2017:002:00000 ns                 11.9344      0.0000
 OSB  G034 G04           C1C       2017:001:00000 2017:002:00000 ns                  0.3623      0.0000
 OSB  G034 G04           C1W       2017:001:00000 2017:002:00000 ns                  0.7543      0.0000
 OSB  G034 G04           C2W       2017:001:00000 2017:002:00000 ns                  1.2423      0.0000
 OSB  G050 G05           C1C       2017:001:00000 2017:002:00000 ns                 -5.4140      0.0000
 OSB  G050 G05           C1W       2017:001:00000 2017:002:00000 ns                 -4.2770      0.0000
 OSB  G050 G05           C2C       2017:001:00000 2017:002:00000 ns                 -6.6360      0.0000
 OSB  G050 G05           C2W       2017:001:00000 2017:002:00000 ns                 -7.0440      0.0000
 OSB  G067 G06           C1C       2017:001:00000 2017:002:00000 ns                  8.3530      0.0000
 OSB  G067 G06           C1W       2017:001:00000 2017:002:00000 ns                 10.0410      0.0000
```

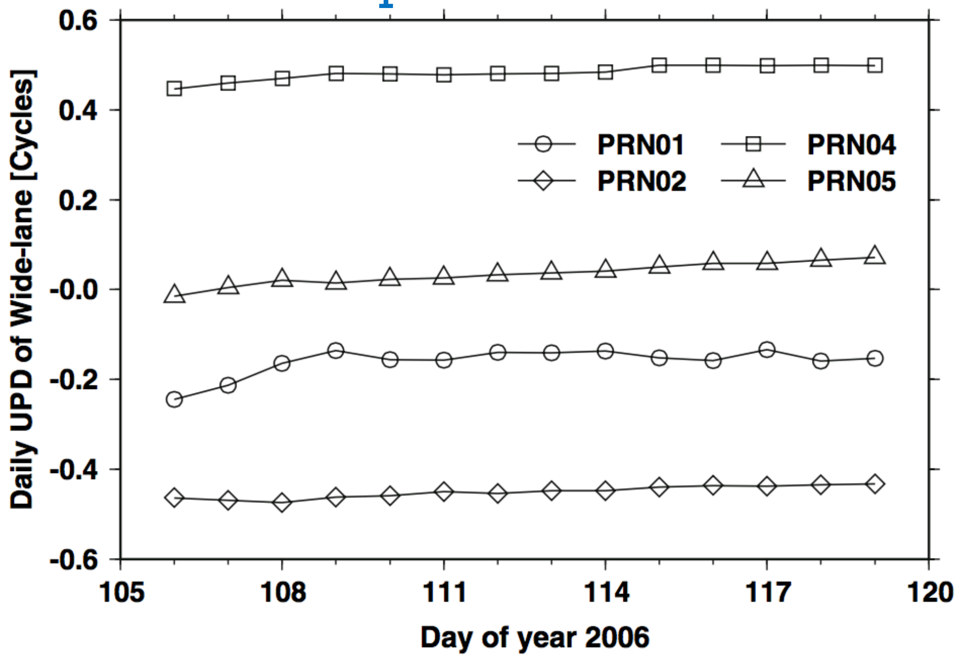
Phase biases

- Phase biases are relevant
  - not only in ambiguity resolution,
  - but also in highly accurate positions.
- Uncalibrated phase delays/fractional-cycle biases (UPD/FCB)
  - Satellite specific
  - for undifferenced ambiguity resolution.
- Code-phase biases (CPB) for GLONASS (Sleewaegen et al. 2012; Geng et al. 2017)
  - Station specific
  - for double-difference/undifferenced ambiguity resolution
  - See the poster by Pan et al. (PS06-04).
- Inter-system phase biases (ISPB) (Odijk et al. 2013; Geng et al. 2017)
  - Station specific
  - for double-difference/undifferenced ambiguity resolution.
- We focus on UPD/FCB, or simply phase bias for brevity, in this presentation.

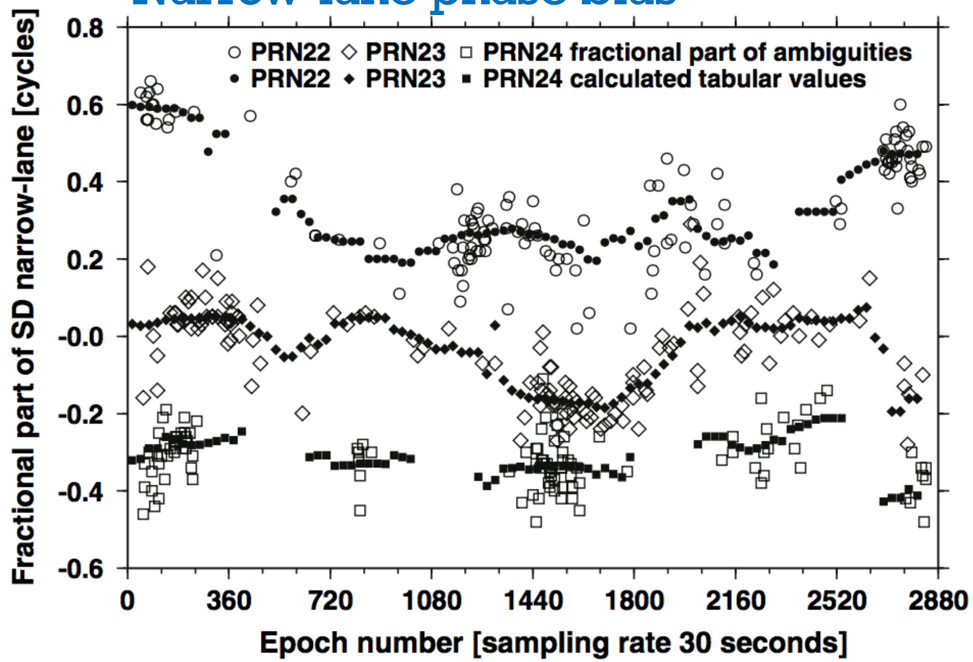
Problems with phase biases (UPDs/FCBs)

- Phase biases are not always stable over time.
  - Wide-lane phase biases are quite stable over days or even months;
  - But narrow-lane phase biases have significant subdaily signatures.
- In 2006, daily wide-lane and 15-min narrow-lane phase biases (Ge et al. 2006).

Wide-lane phase bias



Narrow-lane phase bias



Can we make phase biases always stable?

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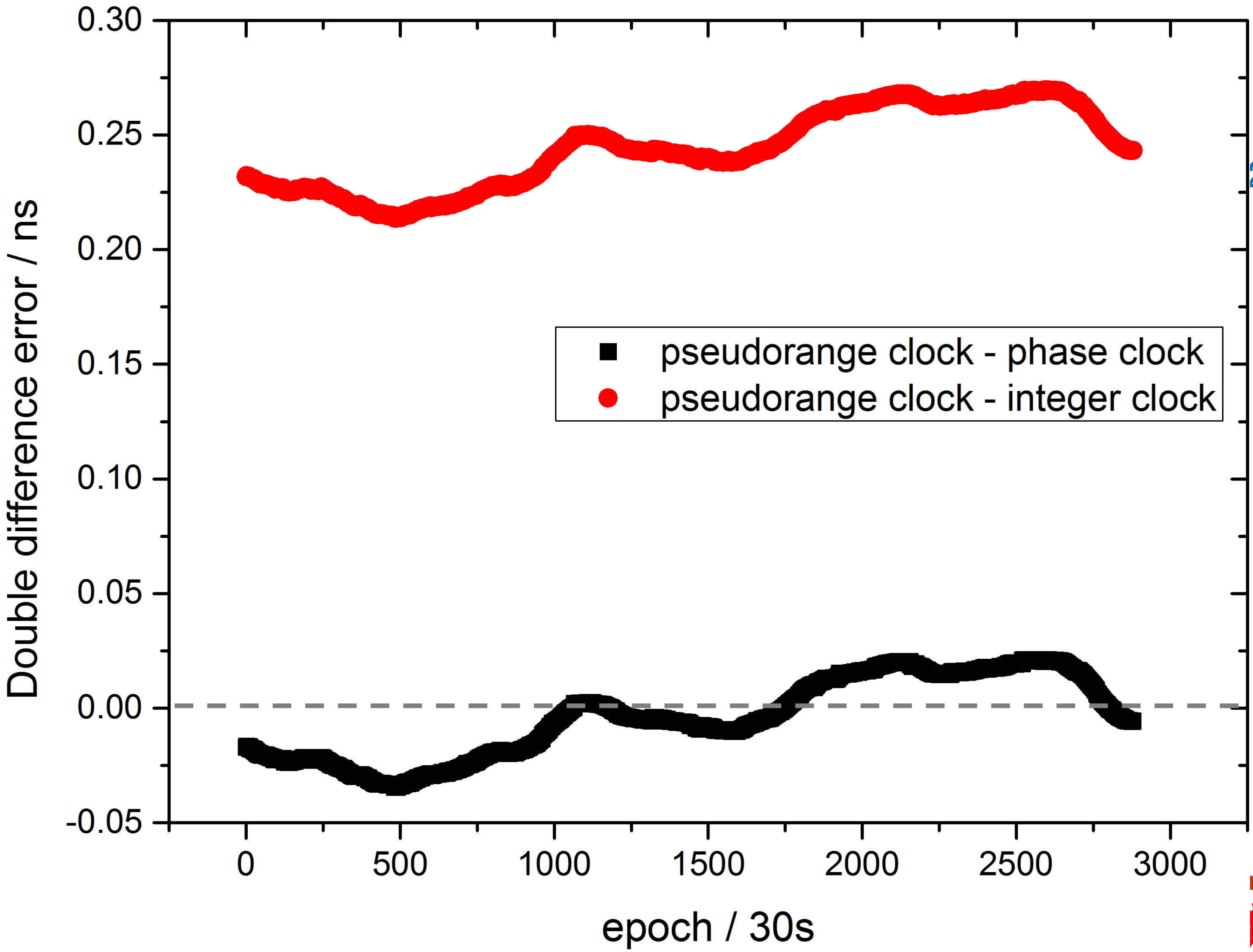
Solutions: "Better" clocks?

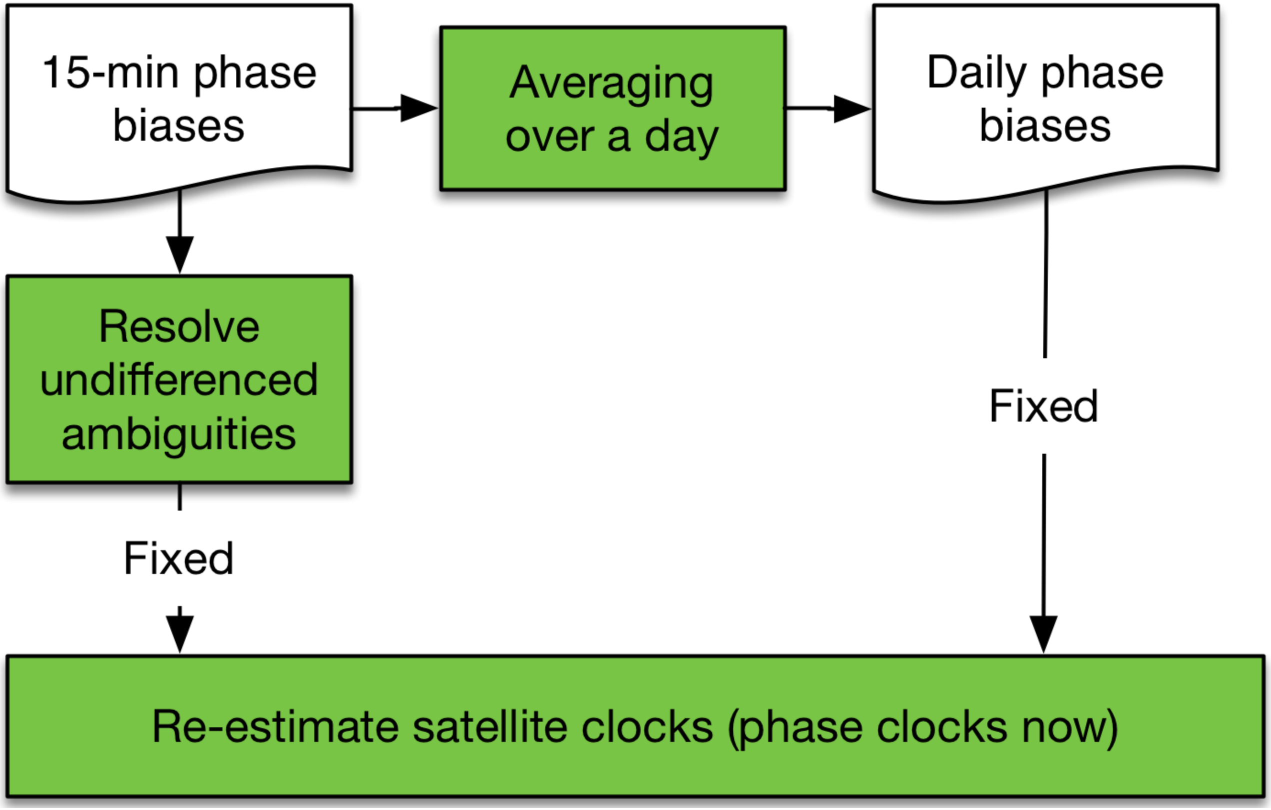
However, integer clocks are not compatible with legacy IGS code biases!

- Because legacy IGS clocks are aligned to pseudorange
- Wh
  - 2010).



New phase bias & phase clock products

- We derive
  - stable phase biases (daily, instead of 15-min, calculations),
  - phase clocks (like integer clocks),
  - and compatibility with IGS code biases.



How do the new phase bias & phase clock work?

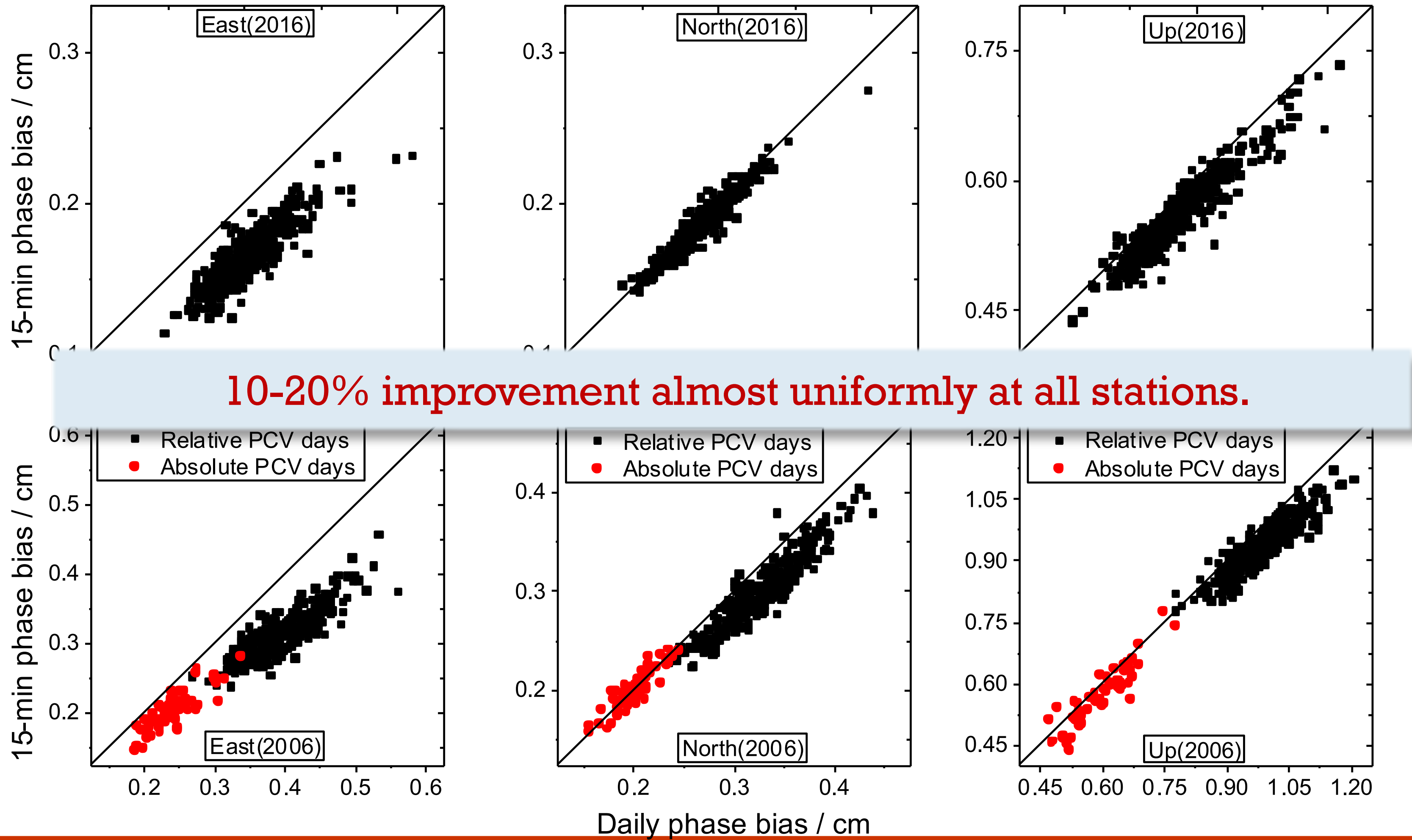
- 180-200 globally distributed stations
- Daily positions in 2006 & 2016 compared to IGS solutions

Solution types		2006 (mm)			2016 (mm)		
		East	North	Up	East	North	Up
Float	IGS clock	3.3	2.1	6.2	3.2	1.9	6.2
Float	Phase clock	3.3	2.1	6.1	3.2	1.9	6.1
Fixed	15-min phase bias	2.4	2.0	6.0	2.0	1.9	5.8
Fixed	Daily phase bias	2.1	2.0	5.8	1.6	1.8	5.6

10-20% improvement after applying daily phase biases and code-compatible phase clocks

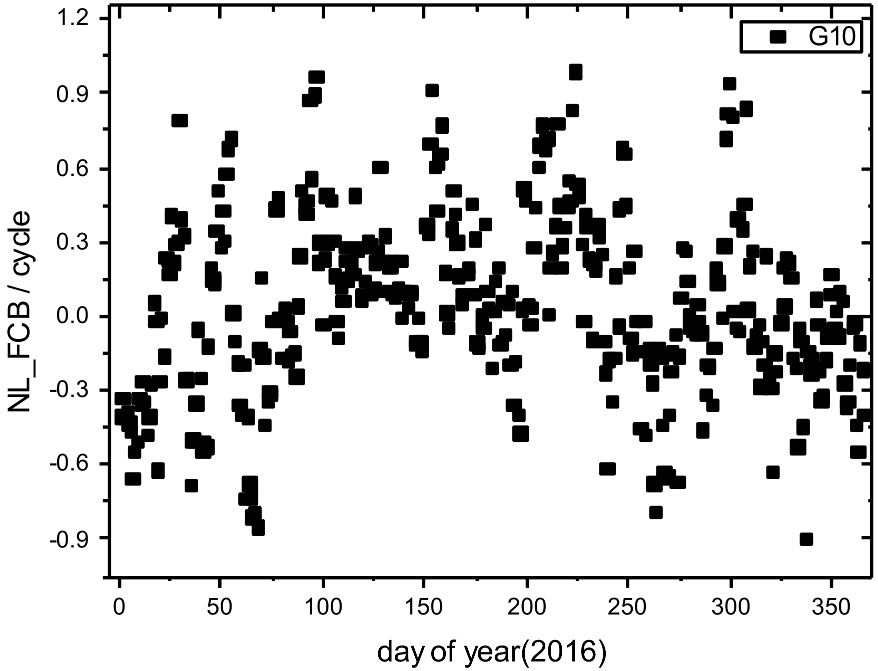
How do the new phase bias & phase clock work?

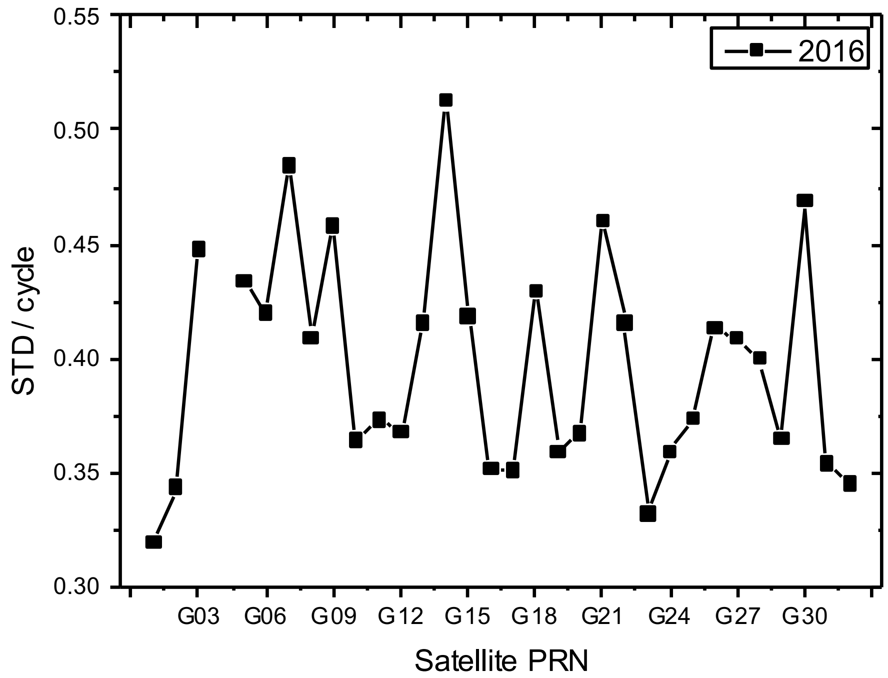
- 180-200 globally distributed stations
- Daily positions in 2006 & 2016 compared to IGS solutions



However, remaining problems with phase biases

- Discontinuity of our phase biases across days (Day-boundary jumps)





Day-to-day phase bias variations are due to pseudorange again.

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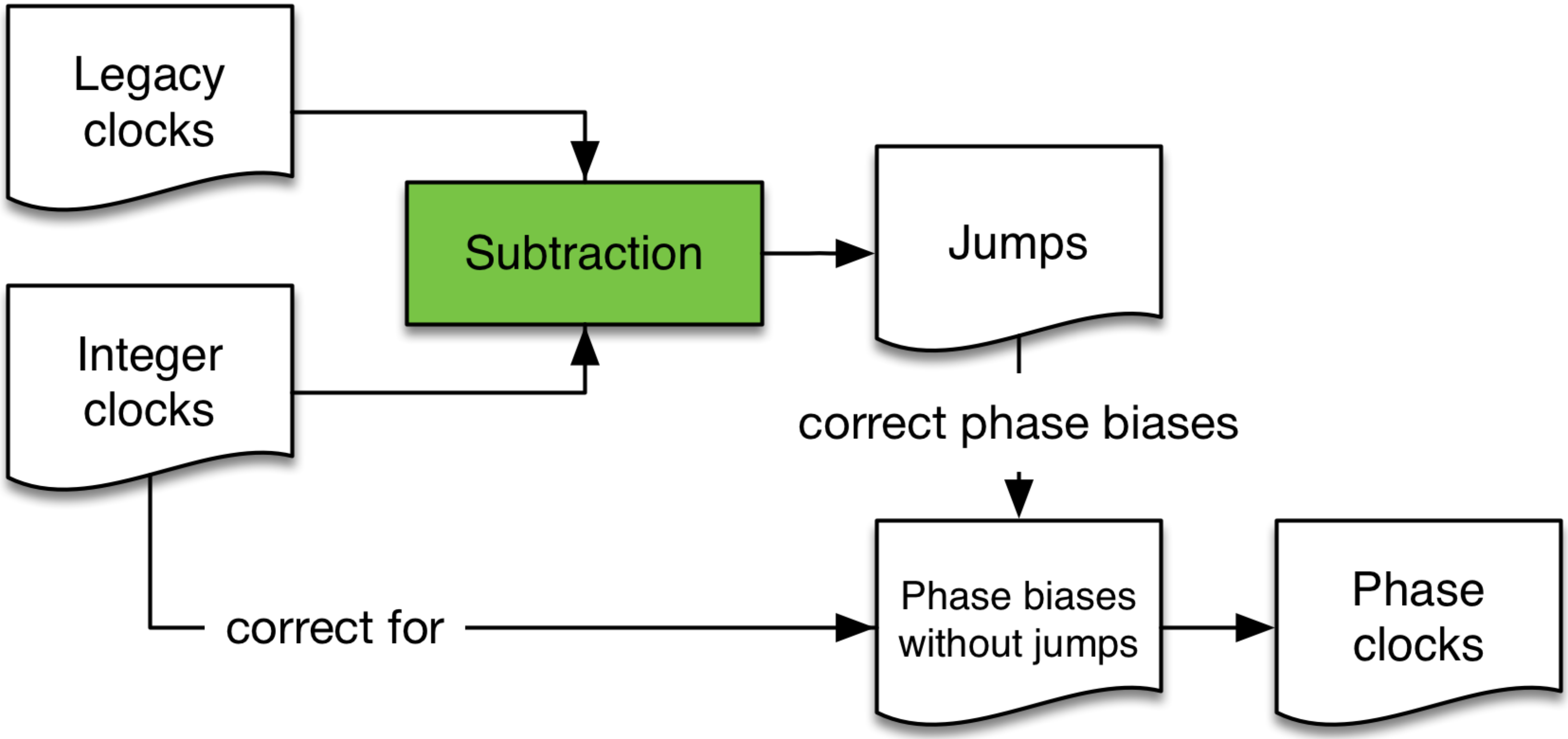
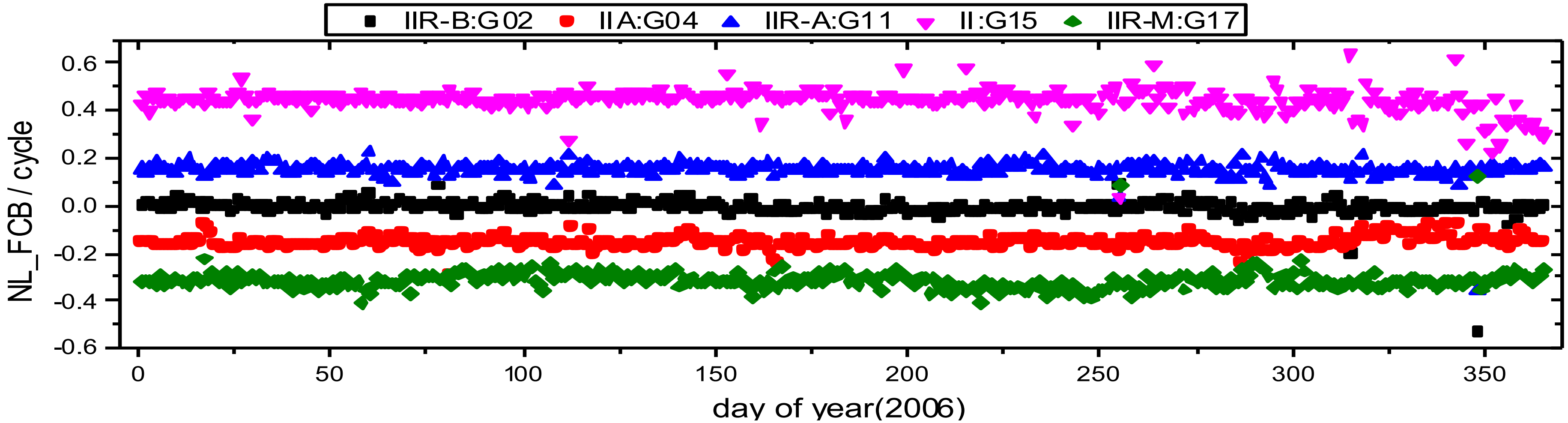
Day-boundary jumps: leveling phase biases

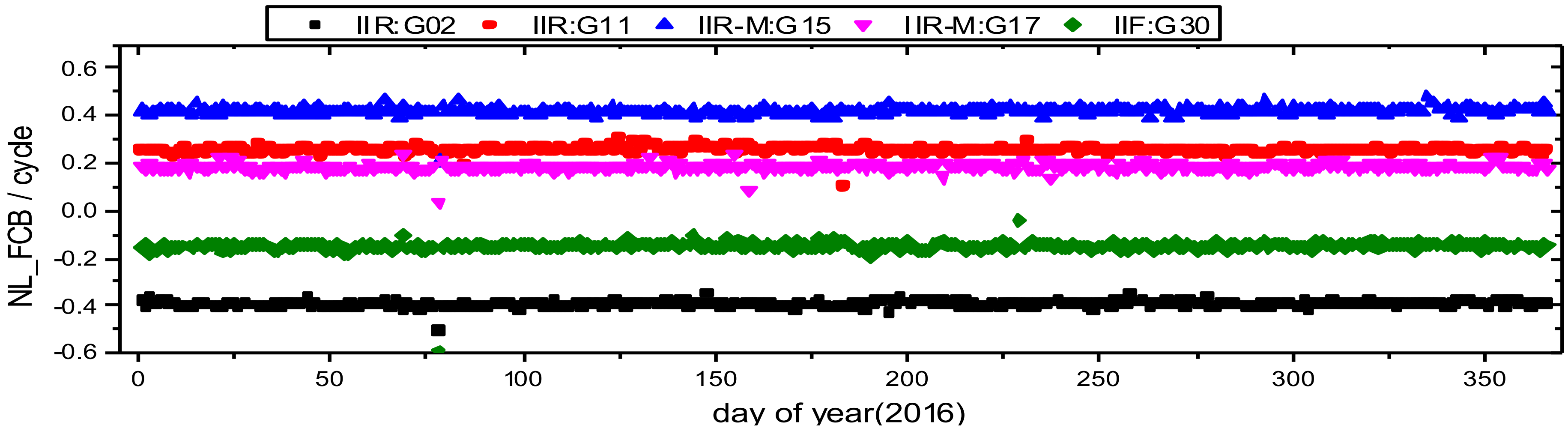
- Calculate the jumps using integer clocks and legacy clocks



How does the leveling work?

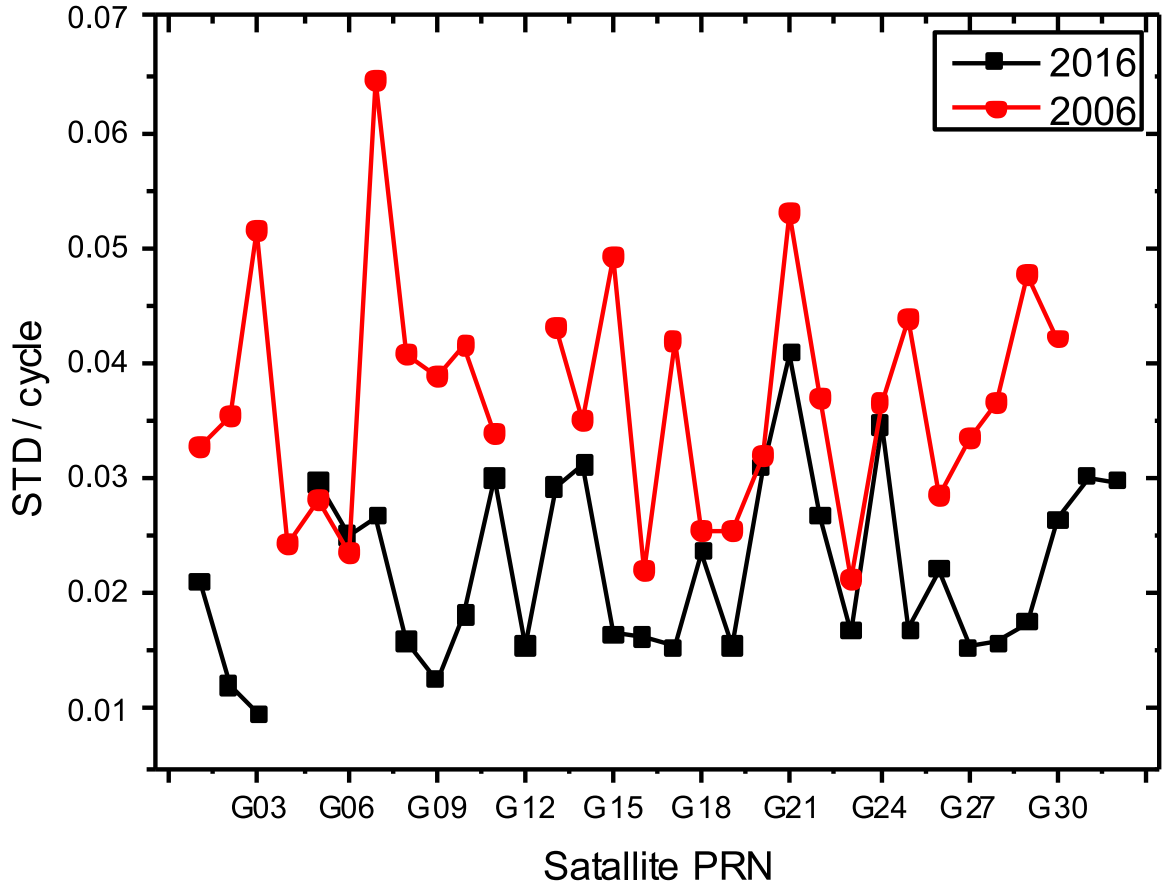
- Phase bias products in 2006 & 2016 without day-boundary jumps





How does the leveling work?

- The yearly STDs of daily phase biases are reduced below 0.1 cycles



The leveling does not impact the positioning performance

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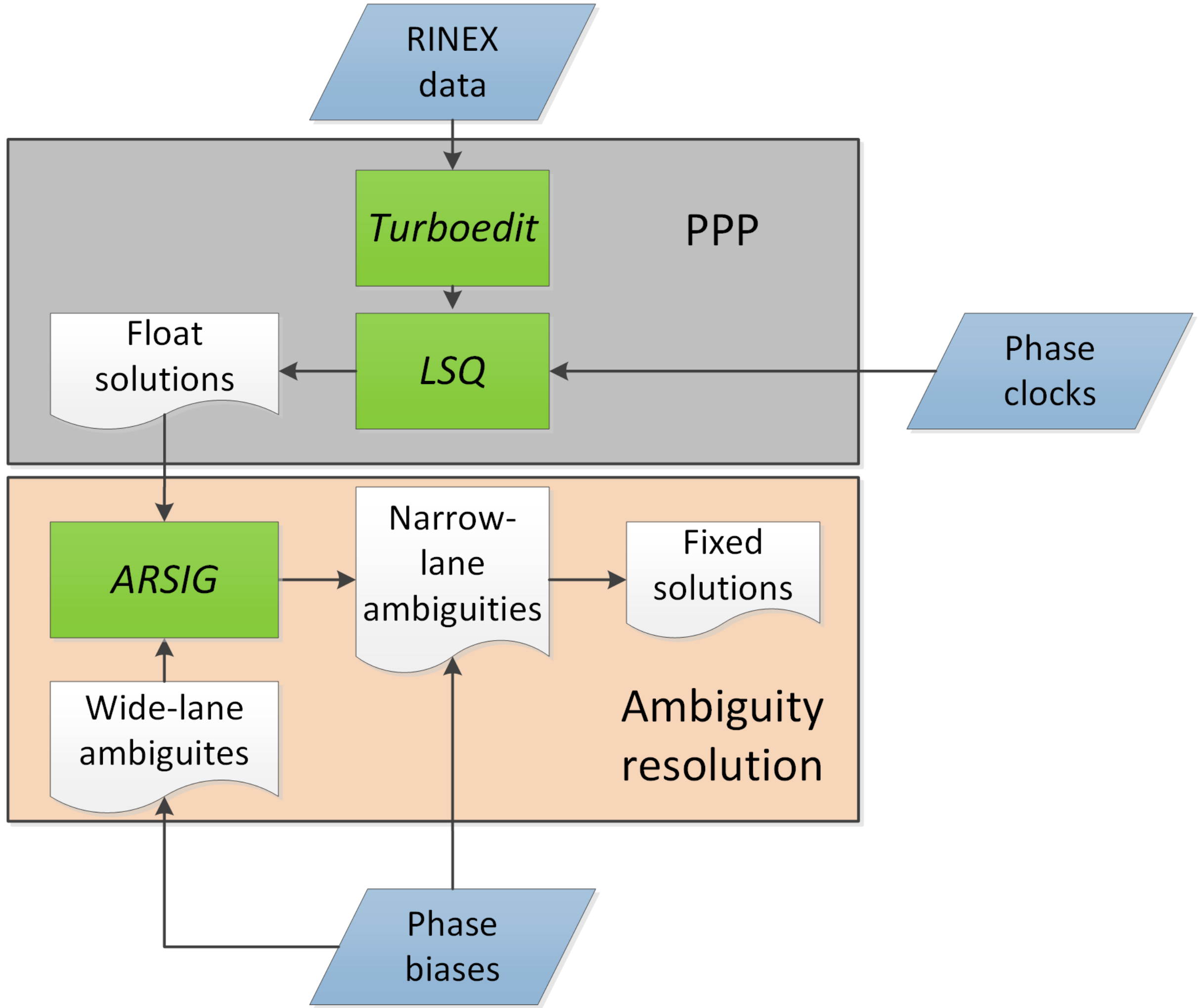
Open-source software for undifferenced ambiguity resolution

- Package name: "PRIDE PPP-AR" in Fortran 95



Summary and outlook

- 10-year (2006-2016) GPS phase bias and phase clock products at Wuhan
  - In the form of L1 & L2 biases
  - Under final validation using PRIDE PPP-AR software
  - Preliminary release of products and software before 2019
  - Also include GLONASS DCPBs, BeiDou, Galileo phase bias on the way
  - News on http://pride.whu.edu.cn
- Phase bias products
  - Daily values
  - No day-boundary jumps
- Phase clocks
  - Compatible with IGS code biases
  - Identical performance to "integer clocks"
- Positioning differences from IGS solutions in terms of RMS
  - 1.6mm, 1.8mm and 5.6mm for the east, north and up components
- Remaining questions: how to combine phase products from different ACs?
  - New "PPP-AR WG" for phase biases/phase clocks

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Thank you!

Jianghui GENG (耿江辉)

jgeng@whu.edu.cn

Homepage: pride.whu.edu.cn