



PRIDE-PPPAR VER1.3

MANUAL

GNSS Precise Point Positioning with Ambiguity Resolution

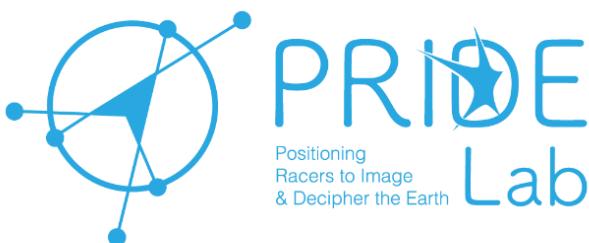
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GNSS RESEARCH CENTER, WUHAN UNIVERSITY

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

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PRIDE-PPPAR ver. 1.3 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 TU Delft (<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 PRIDE Lab 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 Unix-like environment, e.g., Linux and Mac OS. 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.

<i>Linux version (x64 default)</i>	<i>gfortran version</i>	<i>Test result</i>	<i>Notes</i>
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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3. Instructions

3.1 Installation and Validation

Structures of PRIDE-PPPAR

The structure of PRIDE-PPPAR is as follow.

Table 2 PRIDE-PPPAR structures

<i>PRIDE-PPPAR</i>	<i>Instructions</i>
\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
mergesp3	Merge sp3(3 files) into one
xyz2enu	Convert XYZ to ENU
rnx2rtkp	Open source program form RTKLIB(http://www.rtklib.com/)
crx2rnx	Third-party program, 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, mergesp3
\redig	Residual editing
\tedit	Pre-processing RINEX files
\utils	General utility tools
Makefile	Makefile
\table	
igs05_1627.atx	Antenna phase center offsets and variations
igs08_1930.atx	Antenna phase center offsets and variations
igs14_2045.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
orography_ell	Support VMF1 to conduct height correction
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 template
config_partial	Part of configuration file for generating the whole file
\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 Apps and add the CUI Apps 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	<i>static PPP</i>	Static, PPP Float Solution
	<i>static PPP-AR</i>	Static, PPP Ambiguity Resolution
2	<i>kinematic PPP</i>	Kinematic, PPP Float Solution
	<i>kinematic PPP-AR</i>	Kinematic, PPP Ambiguity Resolution
3	<i>kinematic PPP (1 hour)</i>	Kinematic, PPP Float Solution
	<i>kinematic PPP-AR LAMBDA (1 hour)</i>	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 **/project/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.

Select ocean tide model

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

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.

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

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

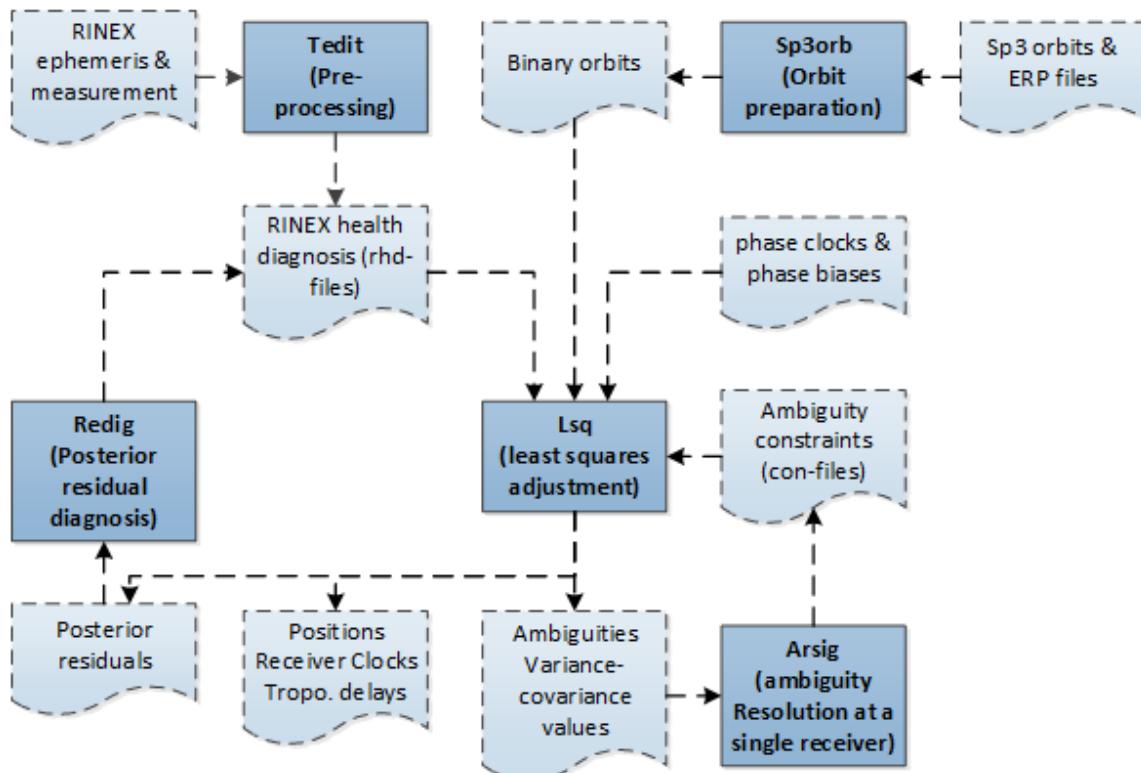


Fig. 1 Module structure of PRIDE-PPPAR

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](#)

<i>-pos/kin</i>	static position / kinematic trajectory
<i>-res</i>	residual information
<i>-ztd</i>	zenith troposphere delay
<i>-rck</i>	receiver clock information
<i>-htg</i>	horizontal troposphere gradients
<i>-rhd</i>	RINEX health diagnosis
<i>-neq</i>	inversed normal matrix
<i>-amb</i>	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:

<i>res_2016001</i>	post-fit residuals file
<i>-jmp jump</i>	if difference residuals between adjacent epochs are larger than <i>jump</i> , add a new ambiguity.
<i>-sht nsht</i>	validity time of ambiguity shorter than <i>nsht</i> will be removed
<i>[-hug huge-residual]</i>	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. The Coordinates don't take the velocities into account, and tens of meters position accuracy is OK, since PRIDE PPP-AR will process iteratively with the newest estimated position. Besides, PRIDE PPP-AR will compute this initial position automatically if the station was not included in *sit.xyz*. 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.

VMF1 height correction File (*orography_ell*)

The table file *orography_ell* is added in latest version to support VMF1 tropospheric mapping function. It's needed by VMF1 to conduct height correction. And it can be downloaded from the website (<http://gcosatm.hg.tuwien.ac.at/DELAY/GRID/>).

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 *igs.atx* file provided by IGS is commonly used. You can refer to Antenna Exchange Format Version 1.4 (ANTEX) for detailed parameters and format. Appropriate ATX file will be chosen and renamed as '*abs_igs.atx*' from *igsYY_WWWW.atx* in the table directory by *pride_pppar* script automatically according to the session time.

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 beginning 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 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
 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
# Explanation for column abbreviations
# NAME: station marker name
# TP: positioning mode
# MAP: tropospheric mapping function (i.e., GMF, VM1, NMF)
# CLKm: precision of initial receiver clock value in meter used in LSQ
# EV: cutoff elevation angle in degree
# ZTDm: a prior tropospheric delay model precision in meter
# PoDm: process noise in  $m/\sqrt{h}$  of the piece-wise zenith tropospheric delay parameter
# HTGm: a prior horizontal tropospheric gradient value precision in meter
# PoDm: process noise in  $m/\sqrt{h}$  of the piece-wise horizontal tropospheric gradient parameter
# RAGm: pseudo-range observation noise in meter used in LSQ
# PHSc: carrier-phase observation noise in cycle used in LSQ
# PoXE PoYN PoZH: a prior precision of initial values of XYZ or ENH coordinates in meter
----- 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			
														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 initial values and corrections.

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										INT / OBS TYPE					
LCPC															
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 ($^{\circ}$). 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
TIM	2016	1 1 0 0	0.0000000	END OF HEADER
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.

sst file

The statistic value of phase residuals are recorded in **sst** 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 sst file

sst 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	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 initial value of dry tropospheric delay and wet tropospheric delay computed from a prior tropospheric models. The last column records the estimated correction of tropospheric delay.

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.

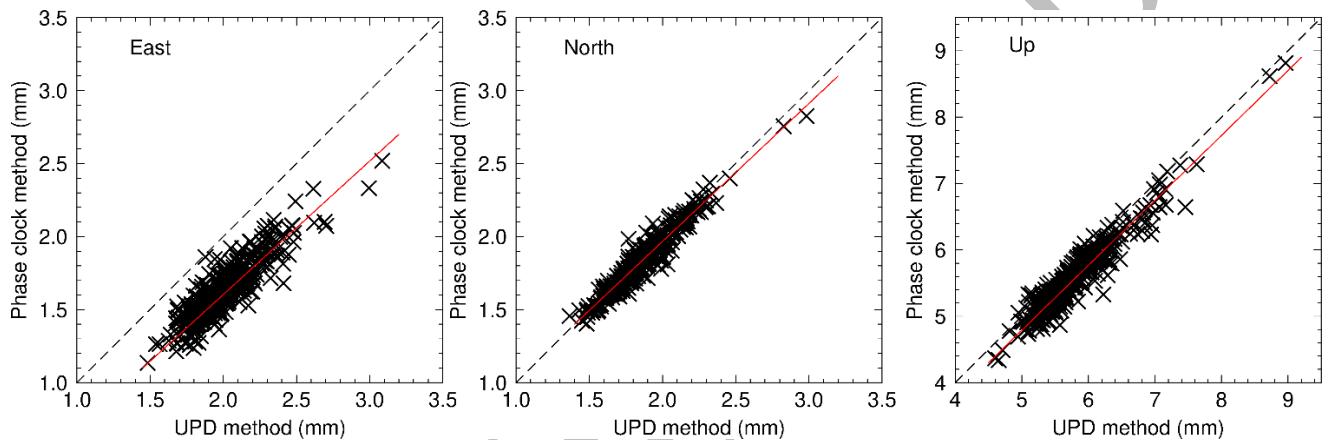


Figure 15: IGS stations coordinates RMS comparison of two types of PPP-AR solutions, i.e. the widely used UPD method and phase clock method (i.e. with our phase bias products), with respect to the IGS weekly SINEX file solutions in 2016.

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 (Diferencial 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;

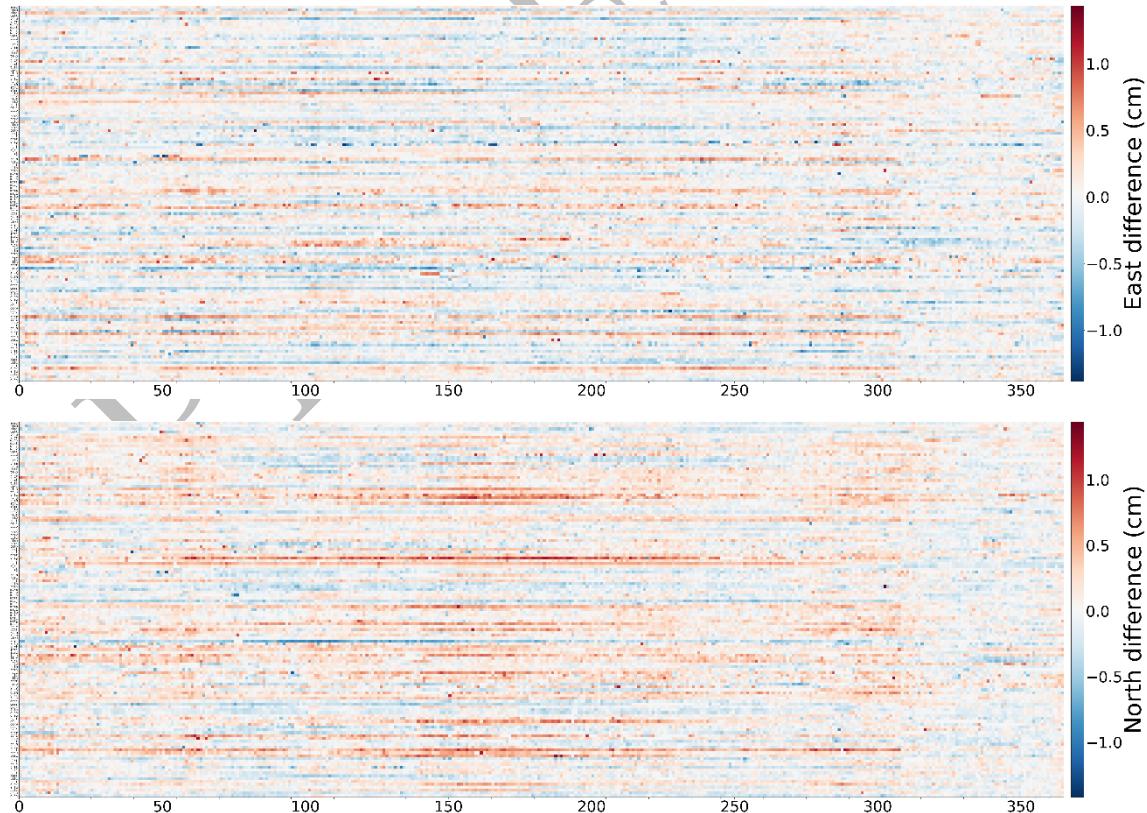
$$\tilde{\Phi}_{true} = \Phi_{observed} - B \quad (1)$$

Where $\tilde{\Phi}_{true}$ 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.



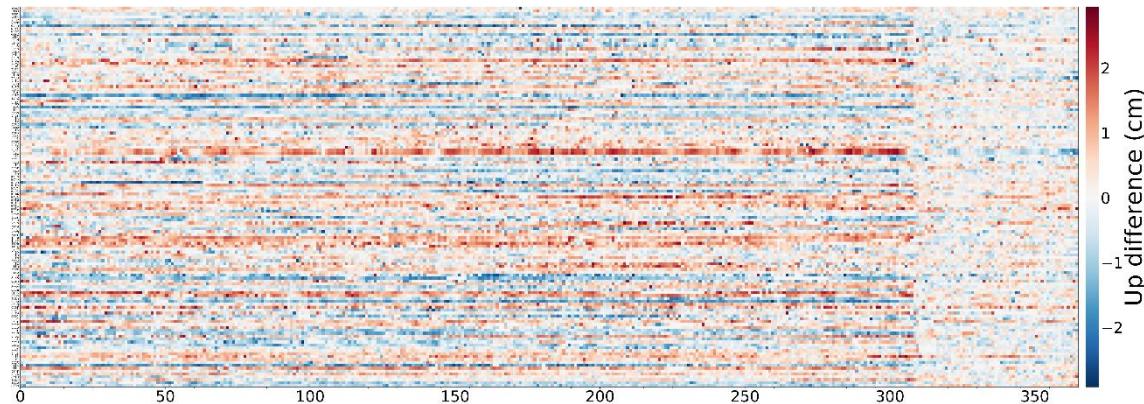


Figure16 Difference between PRIDE-PPPAR solution and IGS SINEX solution of various stations. It is worth noting that there is an obvious vertical boundary around day of year 310. This is because that the phase clock products we produced utilize IGS_05.ATX file. However, IGS utilized relative antenna phase center model before November 2006.

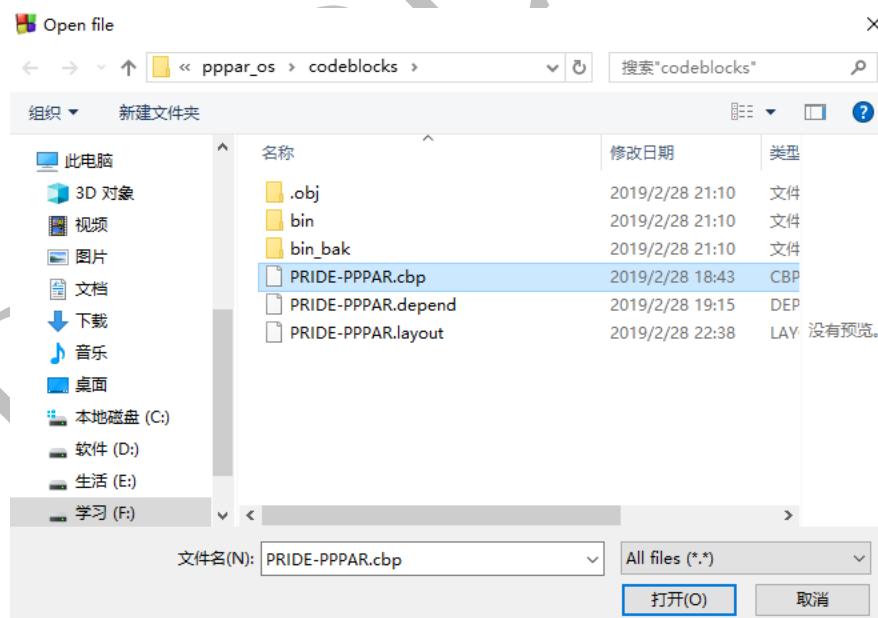
Appendix C IDE Project

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/>.

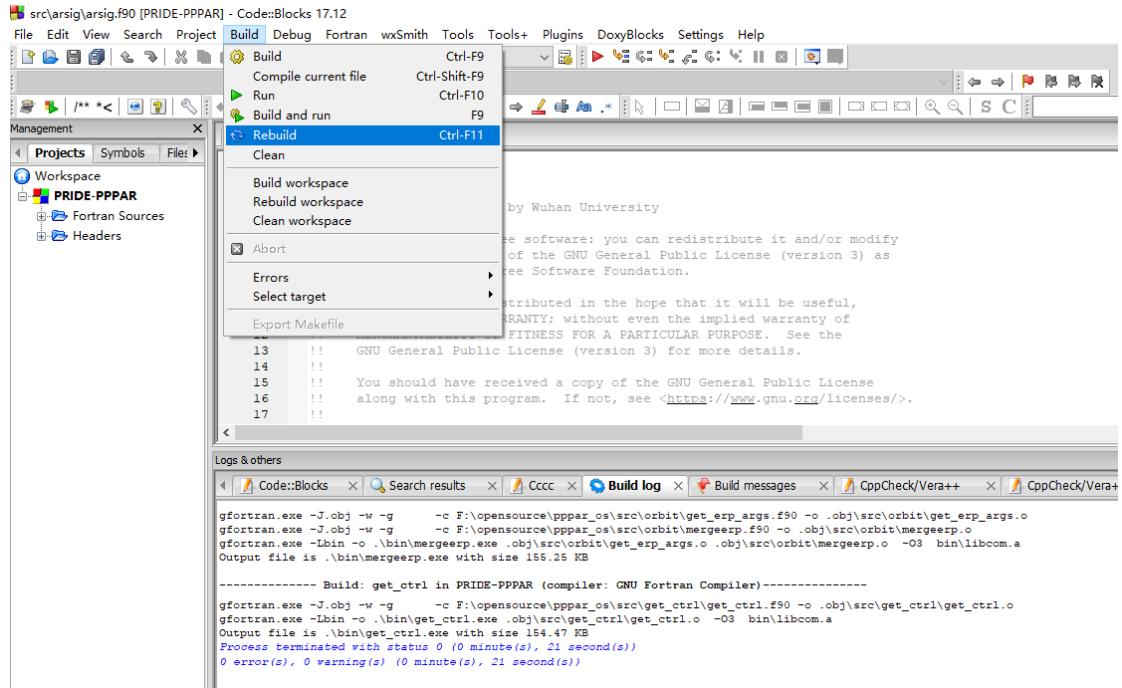
Then, open PRIDE-PPPAR project in Code::Blocks:

Menu: File → open→PRIDE-PPPAR.cbp



Build PRIDE-PPPAR:

Menu: Build



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

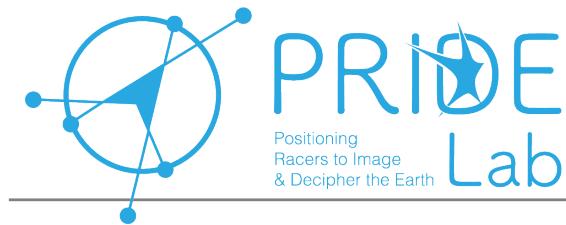
```

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/.

NOTE: the IDE project is mainly used for read and modify the source codes. For compilation and installation, we still recommend to use install.sh in terminal, since we don't guarantee the maintenance of the IDE project.



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

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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

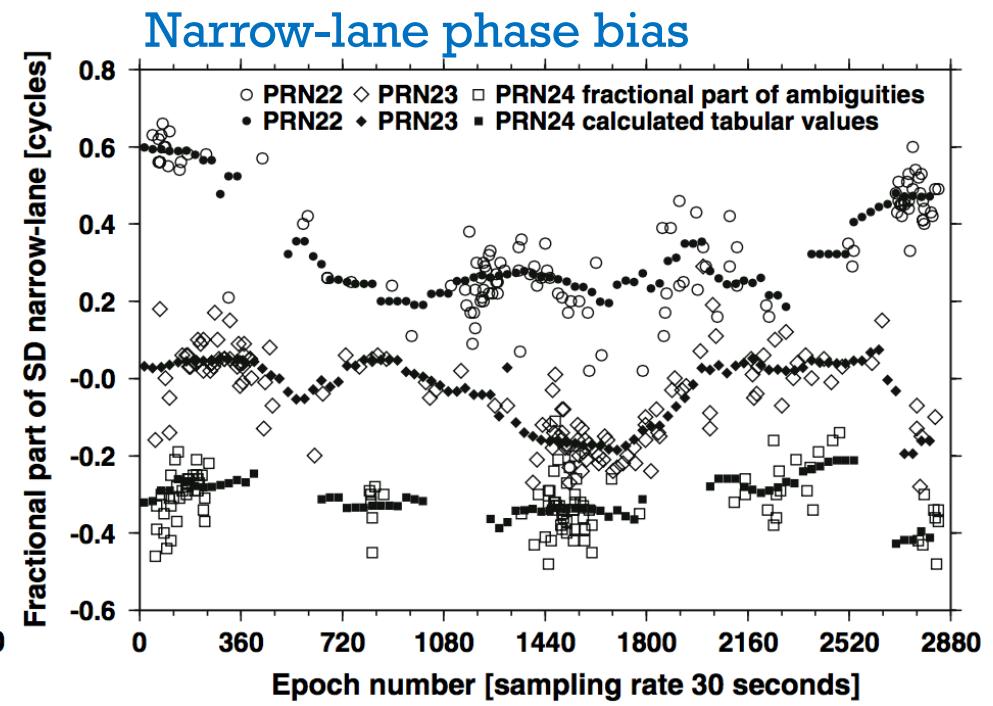
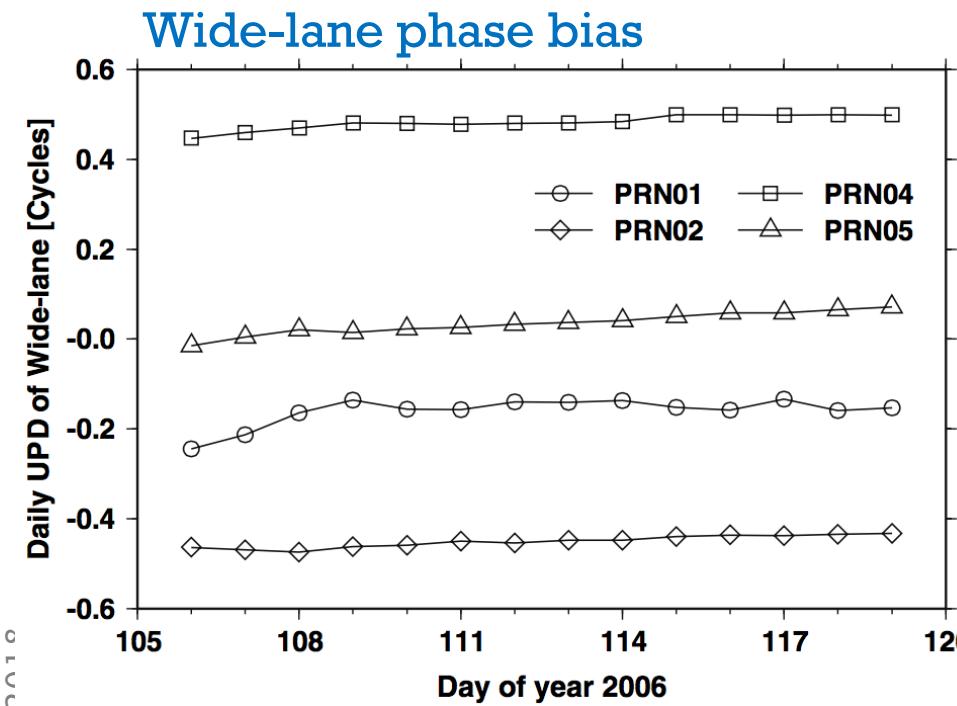
+BIAS/DESCRIPTION									
*KEYWORD		VALUE (S)							
OBSERVATION_SAMPLING		300							
PARAMETER_SPACING		86400							
DETERMINATION_METHOD		INTER-FREQUENCY_BIAS_ESTIMATION							
BIAS_MODE		ABSOLUTE							
TIME_SYSTEM		G							
SATELLITE_CLOCK_REFERENCE_OBSERVABLES		G C1W C2W							
SATELLITE_CLOCK_REFERENCE_OBSERVABLES		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).

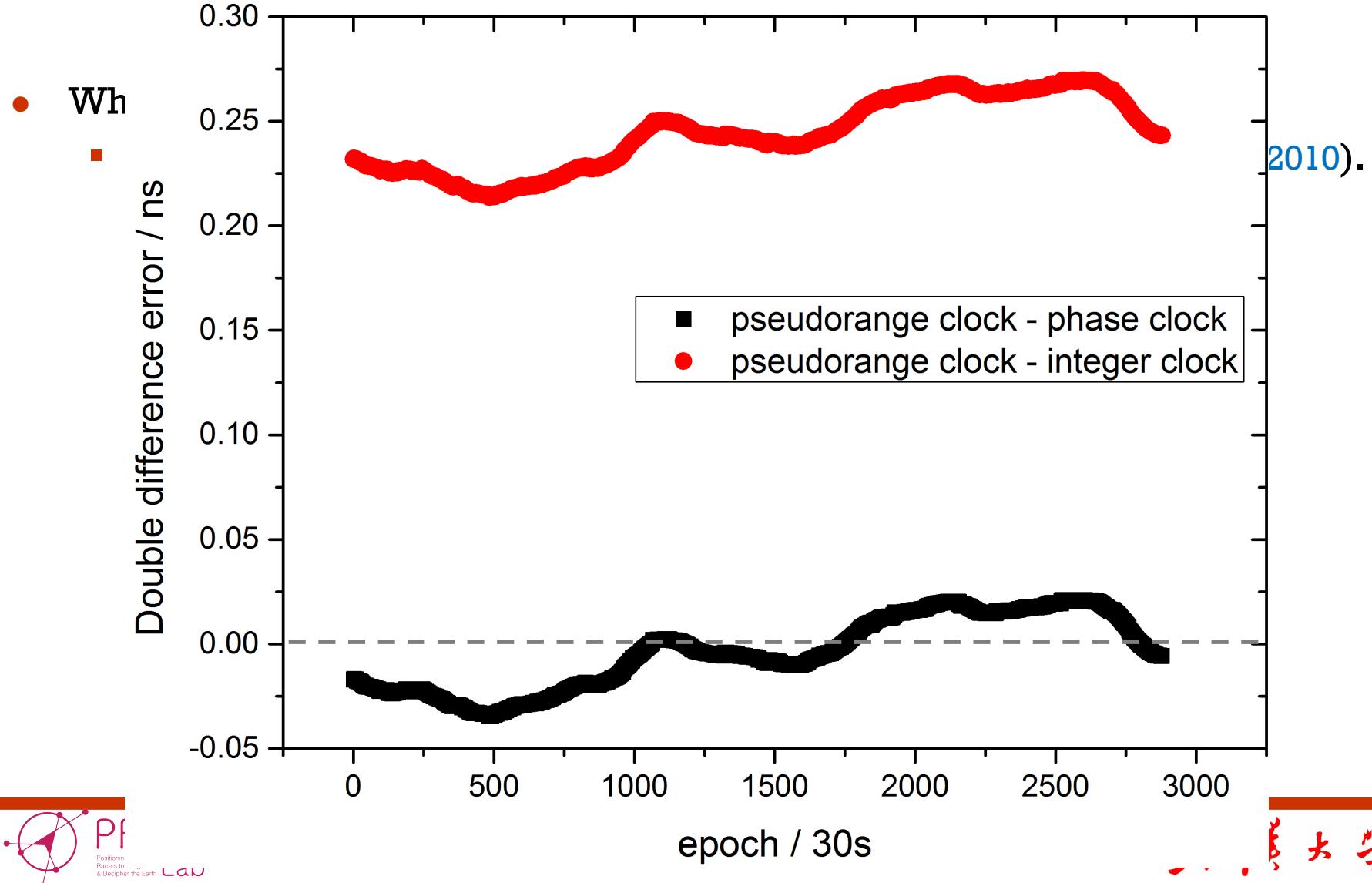


Can we make phase biases always stable?

Solutions: “Better” clocks?

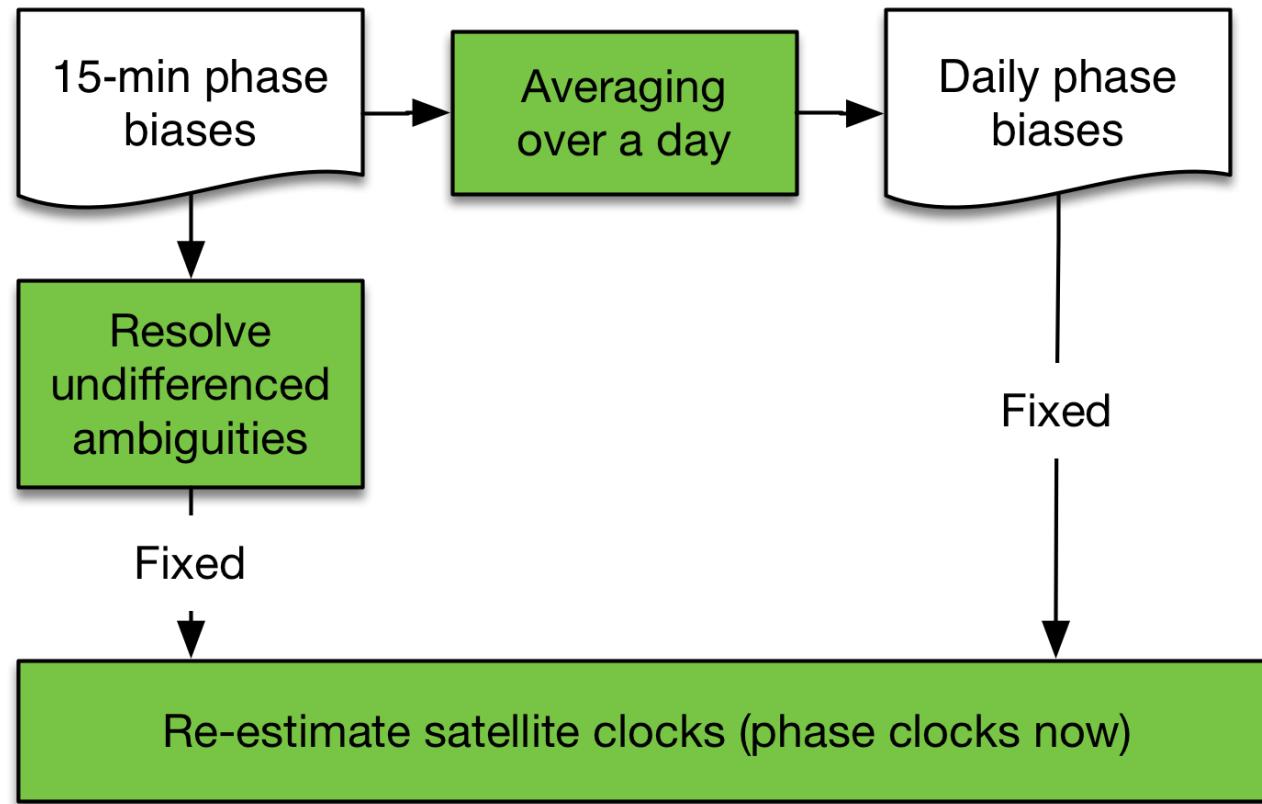
However, integer clocks are not compatible with legacy IGS code biases!

- Because legacy IGS clocks are aligned to pseudorange



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?

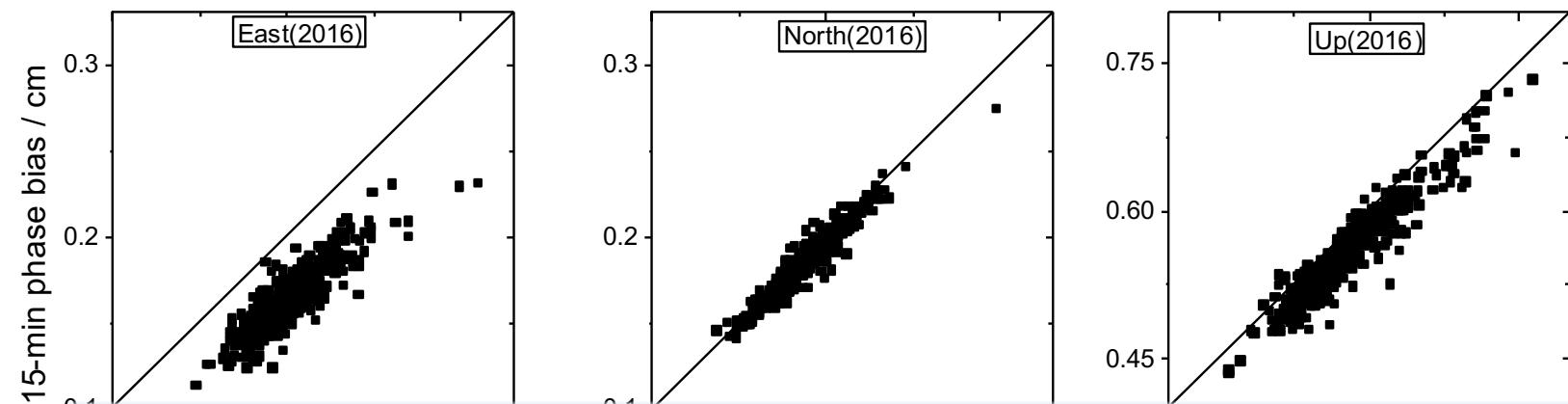
- 180-200 globally distributed stations
- Daily positions in 2006 & 2016 compared to IGS solutions

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
	Phase clock	3.3	2.1	6.1	3.2	1.9
Fixed	15-min phase bias	2.4	2.0	6.0	2.0	1.9
	Daily phase bias	2.1	2.0	5.8	1.6	1.8

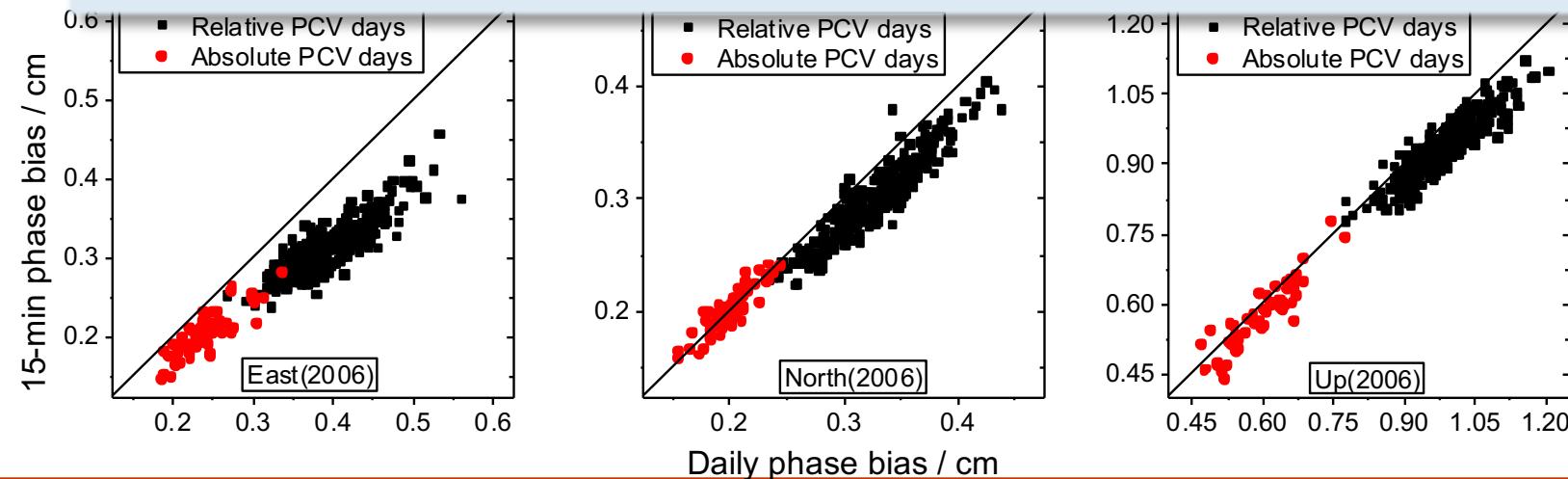
10-20% improvement after applying daily phase biases and code-compatible phase clocks

How do the new phase bias & phase clock work?

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

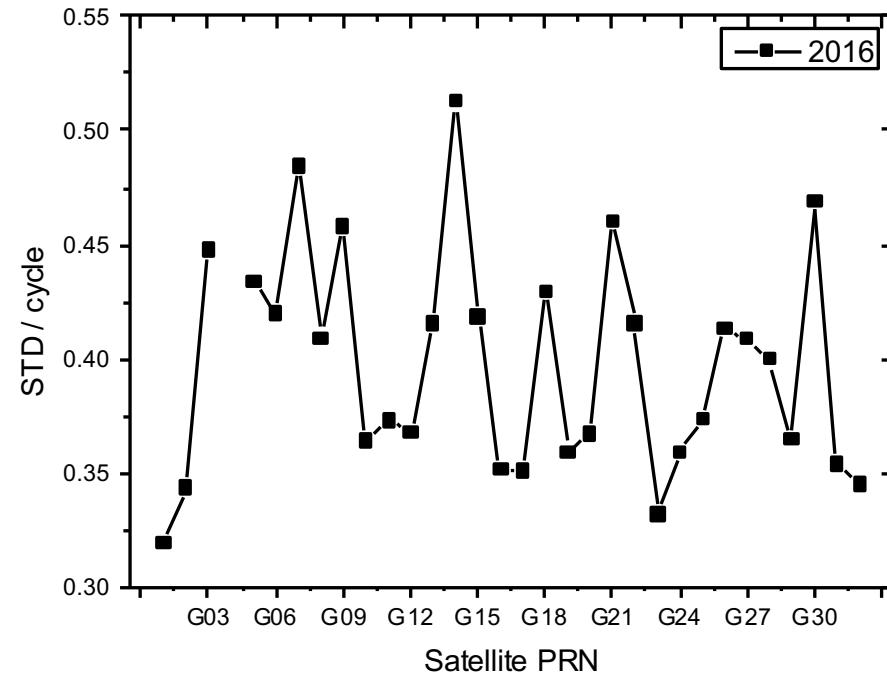
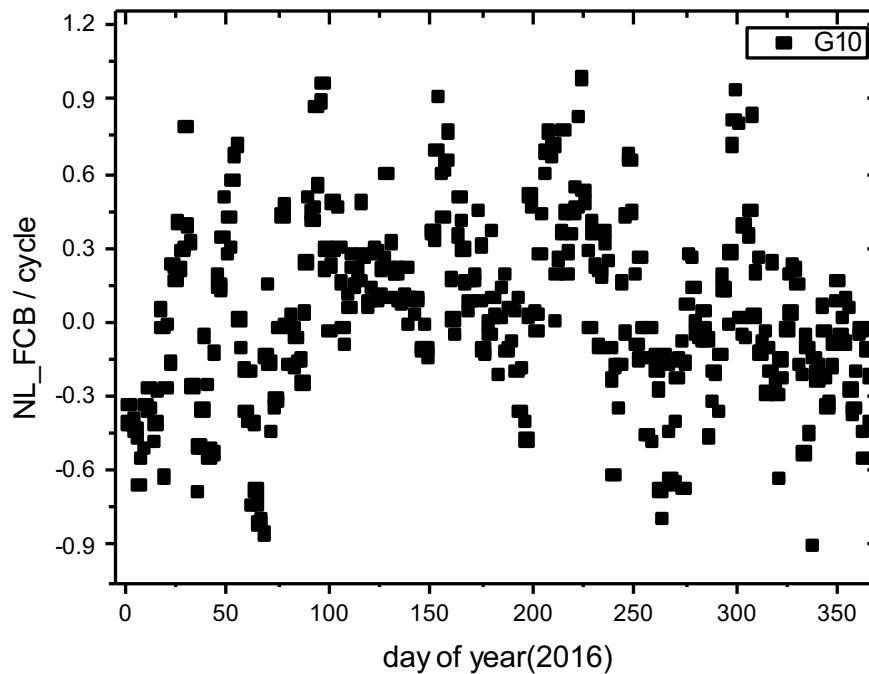


10-20% improvement almost uniformly at all stations.



However, remaining problems with phase biases

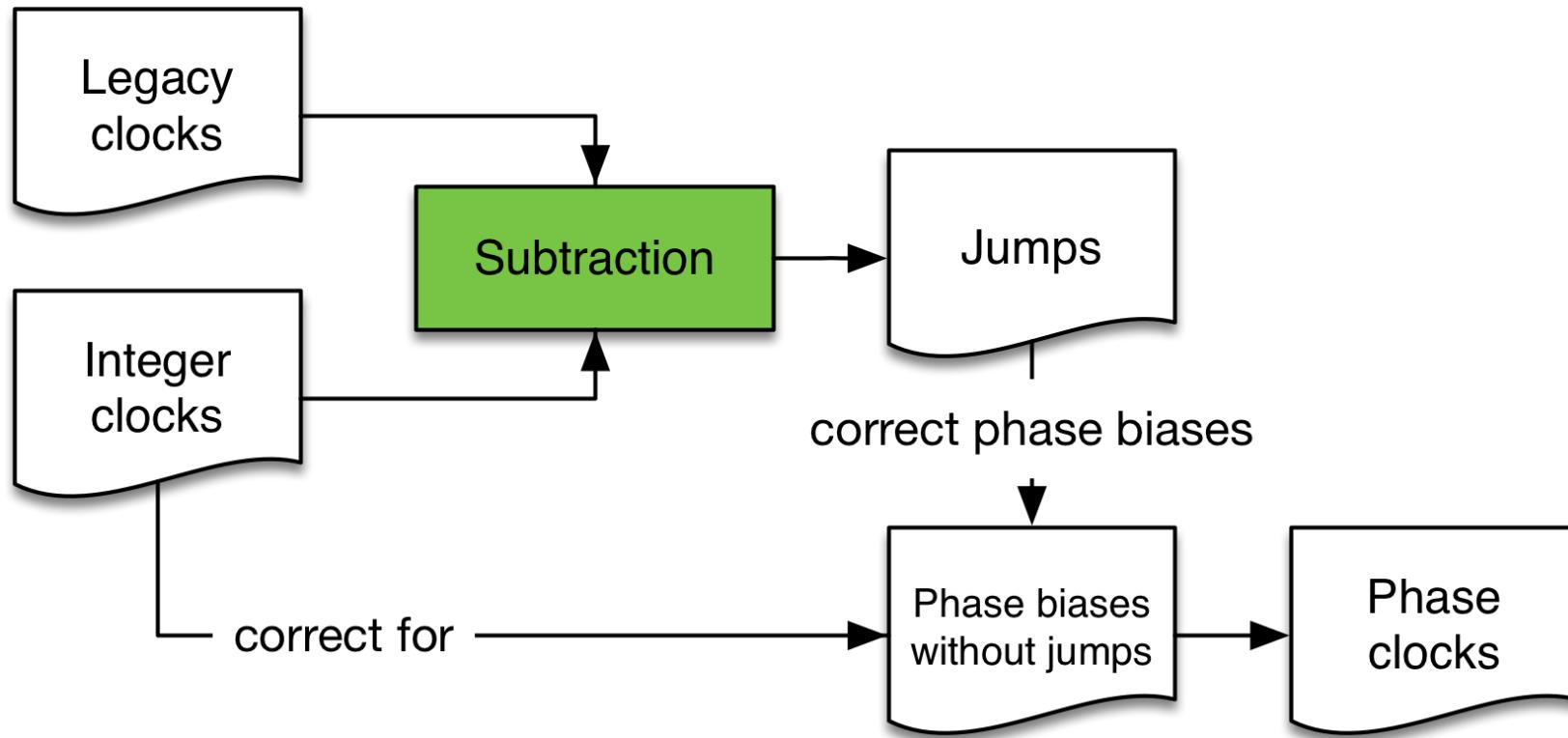
- Discontinuity of our phase biases across days (**Day-boundary jumps**)



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

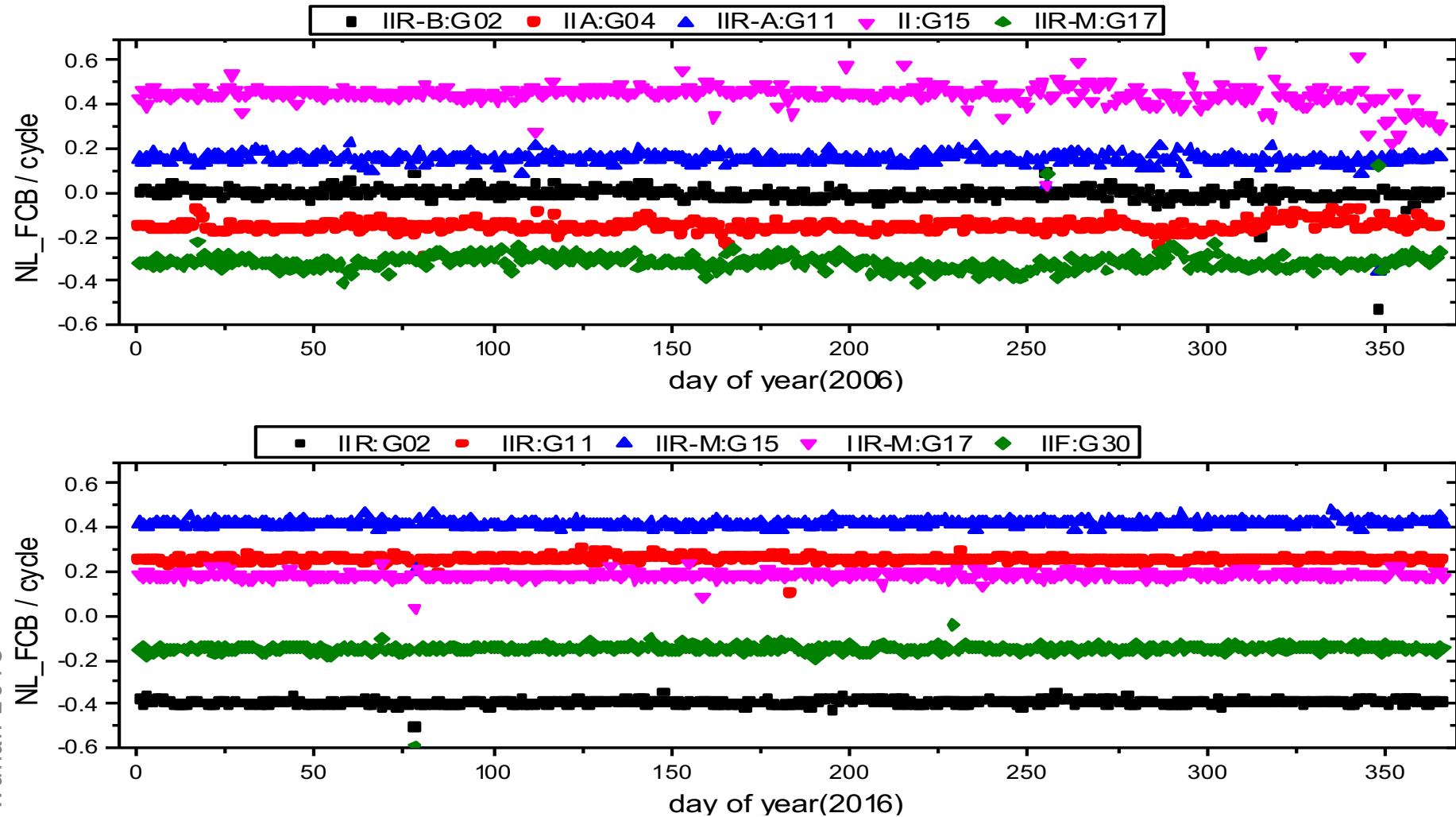
Day-boundary jumps: leveling phase biases

- Calculate the jumps using integer clocks and legacy clocks



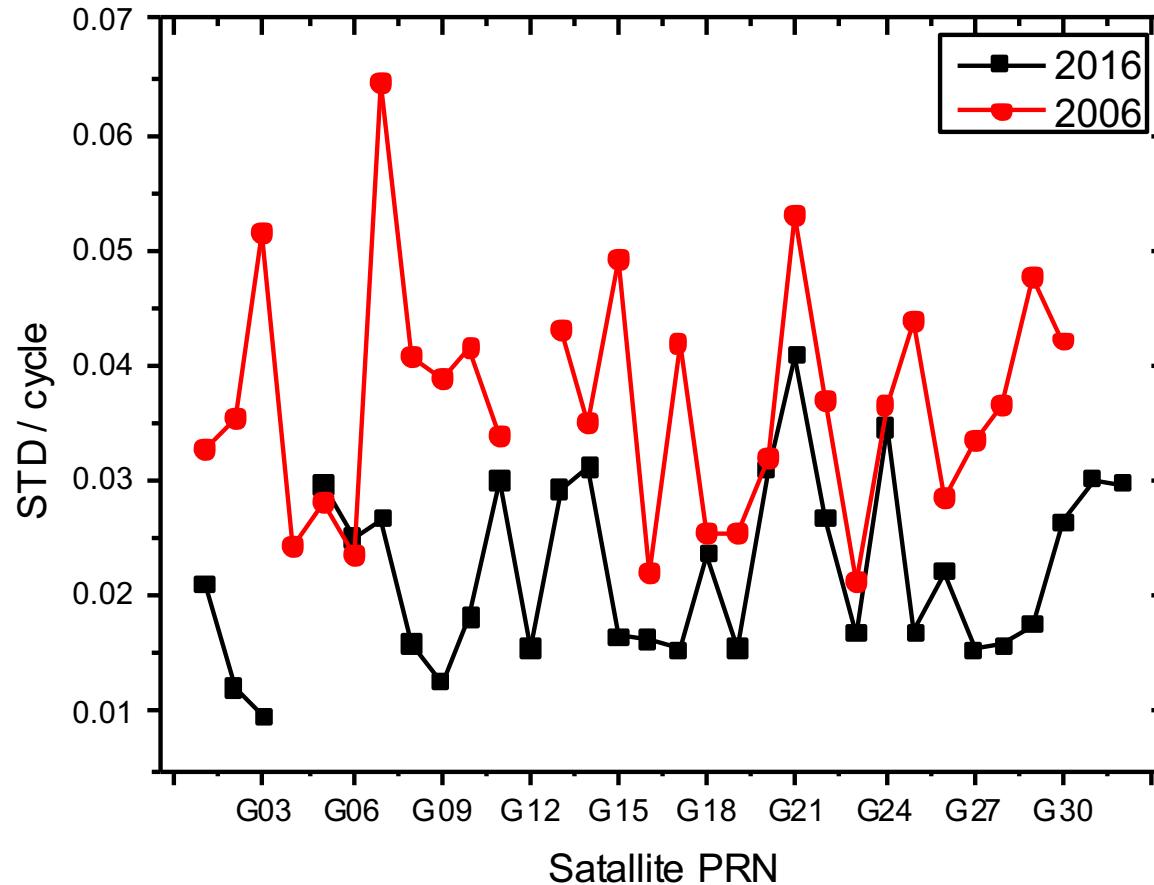
How does the leveling work?

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



How does the leveling work?

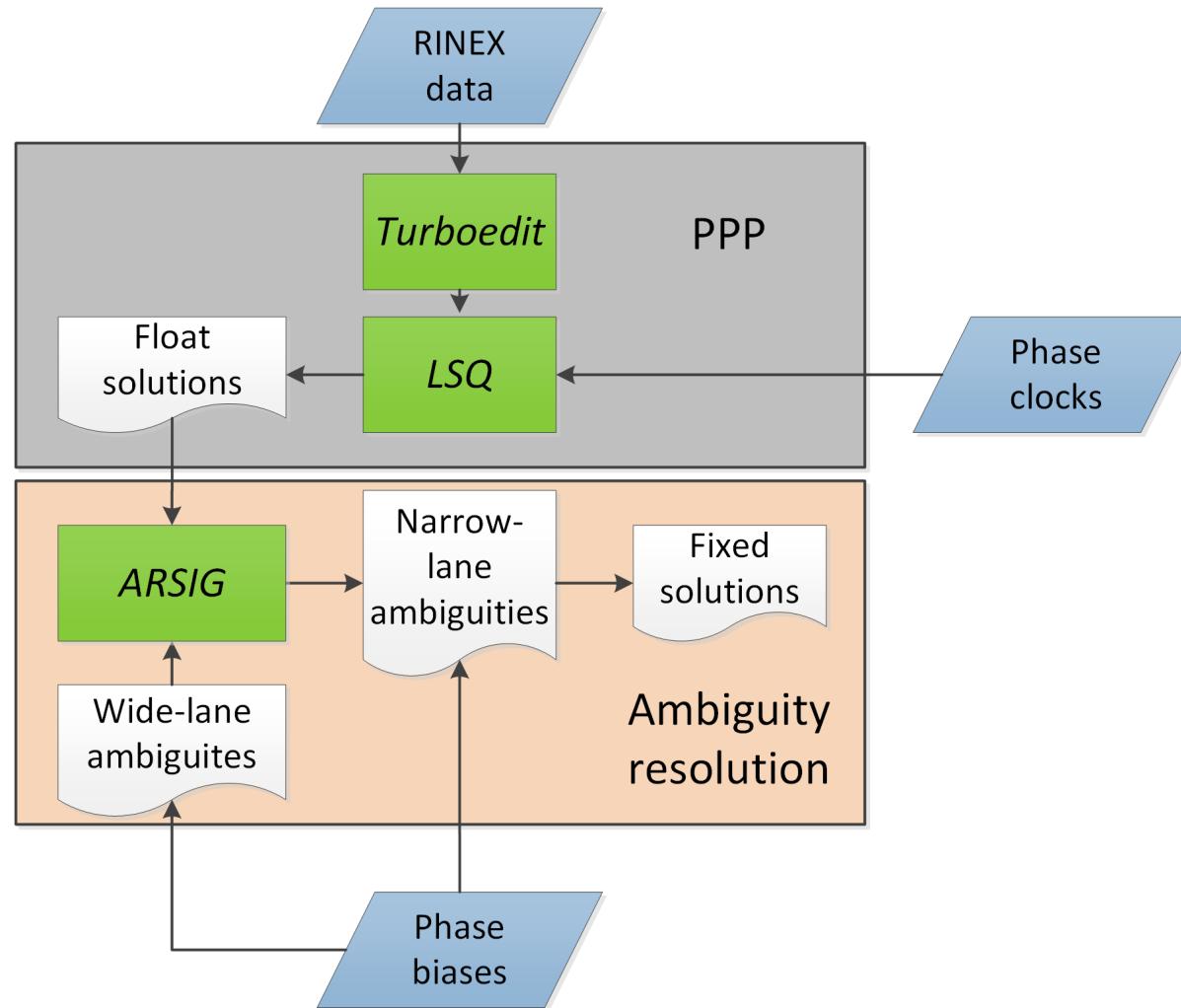
- The yearly STDs of daily phase biases are reduced below 0.1 cycles



The leveling does not impact the positioning performance

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



CENTER 武汉大学卫星导航定位技术研究中心
NSS 国家卫星定位系统工程技术研究中心



Thank you!

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