PPPx User Manual

Version 1.2.0

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Contents

1 Introduction

1.1 Overview

PPPx is a software package developed for multi-GNSS data processing. Its main component pppx, dedicated to multi-GNSS positioning, is introduced in this manual. Its primary features are listed as follows:

1. Support four solution modes:
   (a) SPP: Single Point Positioning
   (b) PPP: Precise Point Positioning
   (c) RTK: short baseline processing
   (d) TDP: Time-Differenced Positioning
2. Support multi-GNSS: GPS, GLONASS, Galileo, Beidou-2/3, and QZSS
3. Support multiple solvers: Extended Kalman Filter (EKF), Factor Graph Optimization (FGO), and Least-Square Estimator (LSQ)
4. Support PPP-AR with Observable-specific Signal Bias (OSB) products
5. Flexible frequency selection (L1/L2/E1/E5a/...)
6. High-precision and efficiency: Capable of processing 2880 epochs within 1-2 s
7. Unified input/output for different solution modes

NOTE: Kinematic GNSS data collected on moving vehicles are not tested with pppx yet.

1.2 Licnese

This software is distributed under the GPL-3.0 license.

2 Getting started

In this section, the system requirements and installation steps for pppx on different platforms (Linux, macOS, and Windows) are introduced.

2.1 System requirements

Generally, there is no specific hardware requirement for pppx. To process a 24-h GNSS observation file of 30 s sampling rate, pppx consumes around 150 MB resident memory and 1 CPU core. However, the consumed resident memory may change with the number of GNSS systems used and the sampling rate of data.

2.2 Installation

2.2.1 Linux

Users are recommended to use pppx on Ubuntu 22.04, since the binary was built with gcc 11 on a computer running Ubuntu 22.04. However, the binary should work on most modern Linux systems with gcc 11 and libceres-dev (version >= 2.0.0) available. Note that this requirement only applies to the dynamically linked pppx executable. You can always use `pppx_static` on a Linux machine without the support for FGO.

The installation on Linux can be done with the following commands:

```
$ git clone git@github.com:YuanxinPan/PPPx_bin.git
$ sudo apt install libceres-dev

$ mkdir -p ${HOME}/.local/bin
$ cp PPPx_bin/bin/pppx ${HOME}/.local/bin/
$ echo "export PATH=\${HOME}/.local/bin:\$PATH" >> ${HOME}/.bashrc
# Restart your terminal afterward
```

2.2.2 macOS

macOS will be supported in the future.

2.2.3 Windows

The easiest way to run pppx on Windows is using the Windows Subsystem for Linux (WSL). Please follow the instructions in Section 2.2.1.

3 Usage

In this section, the usage of the pppx software is introduced. The general steps to run pppx is:

1. Prepare input files, including a GNSS observation file in the Receiver Independent Exchange (RINEX) format and necessary products (either broadcast ephemeris or precise products from IGS)
2. Modify the configuration file *pppx.ini* if necessary
3. Execute pppx with command line:
   `pppx path-to-rnxobs [rnxobs-of-base] pppx.ini`
4. Check output files

Here are some example commands to run pppx:

```
# SPP/PPP/TDP
# (Note: TDP is suitable for high-frequency data, e.g., 1 Hz)
$ pppx rinex/ZIM200CHE_R_20221000000_01D_30S_MO.rnx pppx.ini

# RTK
# (ZIMM is the base station in this example)
$ pppx rinex/ZIM200CHE_R_20221000000_01D_30S_MO.rnx \
  rinex/ZIMM00CHE_R_20221000000_01D_30S_MO.rnx pppx.ini
```

3.1 Input

The complete list of input files is provided below:

- GNSS observations in the RINEX format, specified by command line arguments
- Configuration file `pppx.ini`, specified by command line argument
- Satellite products (either brdc or precise), specified by `pppx.ini`
- Table files (already provided in the table/ directory), specified by `pppx.ini`

The configuration file and satellite products will be explained in detail in subsequent sections.

3.1.1 Configuration

The configuration file `pppx.ini` is the main interface of the pppx software. It is written in the `ini` format and is friendly for human reading. Users can specify the general GNSS positioning strategies (Table 3.1) with it.

Some example configuration files are provided in the folder "example/pppx/". Most settings in `pppx.ini` is self-explained. Usually, users just need to modify the following settings and keep the rest as default:

Table 3.1: Available sections of the configuration file `pppx.ini`.

Section	Description
session	The desired sampling rate and start and end time for data processing
constellation	The GNSS systems to be used and specific satellites to be excluded
observation	Selection of signal frequency and observable priority
model	The tropospheric and ionospheric models
estimation	Various estimation strategies, including solution mode, positioning mode, solver type and etc.
product	The choice of satellite product source and the path to each product
table	The paths to table files
output	The output path and log level

```
[constellation]: system
[estimation]: sol_mode, pos_mode, solver
[product]: src, nav, sp3, clk
```

The following paragraphs demonstrate how to set the "key-value" pair for each section of the configuration file.

session Here, "interval" specifies the required interval for data processing, it should be no smaller than the sampling rate of the RINEX file and should be integer number times of it. "date" denotes the year and day of year (DOY) for data processing, and it will be used to replace the placeholders in the "[product]" section. By default, it can be read from the first epoch of the RINEX file. "start" and "end" denote the start and end epoch for data processing within the day (closed interval).

A screenshot of example settings is shown in Figure 3.1. Note that this figure just shows how to correctly configure these fields. Usually, users can leave all the fields of this section as blank. Then, pppx will process the whole RINEX file epoch by epoch.

```
[session]
interval = 300              ; interval (sec)    [ RINEX ]
date     = 2020 100         ; year DOY          [ RINEX ]
start    = 02 15 30         ; hour min sec      [ none ]
end      = 23 45 00         ; hour min sec      [ none ]
```

Figure 3.1: The "session" section of configuration.

constellation This section defines the GNSS systems to be used for data processing and problematic satellites to be excluded. An example is shown in Figure 3.2. Note that the order of letters (i.e., GRECJ) does not matter and there should be no space between them. The GPS system is not mandatory; for example, Galileo-only solutions are also possible. The excluded PRNs should be separated by white space.

```
[constellation]
system  = GE                        ; opt: GRECJ        [ GRECJ ]
exclude = E14 E18 G04               ; excluded PRNs     [ none ]
```

Figure 3.2: The "constellation" section of configuration.

observation This section is well explained in the configuration file. Note that the observation noise represents the noise level of uncombined observations. For ionosphere-free combination, observation noises will be automatically computed based on the uncombined ones. A screenshot of example settings is provided in Figure 3.3.

```
[observation]
noise = 0.3 0.002                   ; observation noise of code/phase (m) [ 0.3 0.002 ]
; G/R/E/C/J = f1 f2 obs_priority: high -> low
G = 1 2 WPCLSXYMN                   ; default: [ 1 2 WPCLSXYMN ]
R = 1 2 PCIQX                       ; default: [ 1 2 PCIQX ]
E = 1 5 XCIQB                       ; default: [ 1 5 XCIQB ]
C = 2 6 IQX                         ; default: [ 2 6 IQX ]
J = 1 2 SLXCZ                       ; default: [ 1 2 SLXCZ ]
```

Figure 3.3: The "observation" section of configuration.

model This section specifies the tropospheric and ionospheric models. An example is provided in Figure 3.4. Users should choose an option (case-sensitive) from the values listed in the comment. Note that this section is not effective for RTK, since tropospheric and ionospheric delays are ignored for short baselines; "iono" can only be IF for PPP.

Currently, the tide model cannot be configured via `pppx.ini`. Solid earth tide, ocean tidal loading, and pole tide are applied for PPP whenever possible, but they are not applied for spp/rtk/tdp.

```
[model]
trop = GMF                          ; opt: GMF/VMF1/GPT2w/none       [ GMF ]
iono = IF                           ; opt: IF/brdc/IONEX/none        [ IF ]
```

Figure 3.4: The "model" section of configuration.

estimation This is the most important section of the configuration file. Here, you can choose the solution mode (spp/ppp/rtk/tdp), positioning mode (kinematic/static/fixed) and solver (ekf/fgo/lsq) used for adjustment. An example is provied in Figure 3.5. Most settings are self-explained.

The fields "sol_mode", "pos_mode", and "solver" are well explained in the configuration file. However, spp and tdp can only support kinematic positioning mode, and not all the solvers are supported for each solution mode (i.e., lsq and fgo for spp and tdp, ekf and fgo for ppp, ekf for rtk). The software will output an error message if specific configuration is not supported.

"site_pos" specifies the approximate station coordinates in XYZ format (unit: meters). If it is not specified, the approximate coordinates will be automatically computed using

SPP. This rule also applies for the field "base_pos" for rtk.

"ppp_ar" is a switch for PPP-AR. Ambiguity resolution can be enabled by setting it to "yes", and a valid phase bias product must be provided using the field "[product] bia". The LAMBDA and rounding methods will be used to resolve integer ambiguities if "solver" is set to "ekf" and "fgo", respectively. Note that GLONASS is disabled for AR and GPS L5 signal is not supported for PPP-AR.

""sf_ppp" is designed to run single-frequency PPP with GIM products, i.e., the ionospheric delays are not estimated but fixed to GIM corrections. In this way, the accuracy of GIM products can be evaluated. However, the dual-frequency observations are still required for cycle slip detection. "ppp_ar" should be set to "no" when sf_ppp is enabled.

"slip_det" specifies the methods used for cycle slip detection for ppp. The option "TDCP" represents time-differenced carrier phase. You can set "slip_det" to "ALL" for most stations, but "MW" should not be used for stations with noisy pseudorange, such as smartphones. "LLI" could be problematic at some point since some stations set a lot of wrong LLI flags, but it is recommended for processing smartphone GNSS data. Note that rtk and tdp always use LLI and GF for cycle slip detection, and currently it is not configurable.

'pos_pri', "clk_pri", "isb_pri", and "ztd_pri" specify a-prior uncertainties and process noises of station position, receiver clock, receiver inter-system bias (ISB), and tropospheric delay for EKF, respectively. Note that only one receiver clock is estimated for one GNSS system and ISBs are estimated for other systems using EKF. When FGO is chosen as the solver, only "ztd_pri" is effective and other "pri" settings are not used. Individual receiver clock errors (instead of ISB) are estimated as white noise for different constellations, and station position is estimated as white noise for kinematic mode.

"glonass_ar" can be set to "yes" for rtk if rover and base stations share the same receiver type. Otherwise, keep it as "no".

```
[estimation]
sol_mode    = ppp                   ; opt: spp/ppp/rtk/tdp          [ spp ]
pos_mode    = kinematic             ; opt: kinematic/static/fixed   [ kinematic ]
solver      = ekf                   ; opt: ekf/fgo/lsq              [ ekf ]
weight_opt  = elev                  ; opt: elev/snr                 [ elev ]
elev_mask   = 7                     ; elevation mask (°)            [ 10 ]
snr_mask    = 25                    ; SNR mask (dB-Hz)              [ 25 ]
site_pos    =                       ; initial position in xyz (m)   [ spp ]
; ppp only
ppp_ar      = no                    ; PPP ambiguity resolution      [ no ]
sf_ppp      = no                    ; single-frequency PPP          [ no ]
slip_det    = ALL                   ; opt: off GF MW LLI TDCP ALL   [ ALL ]
pos_pri     = 100 1                 ; uncertainty  process_noise    [ 1E+02 1 ]
clk_pri     = 100 100               ;      m          m/sqrt(s)     [ 1E+02 1E+02 ]
isb_pri     = 50  3.2E-04           ;                               [ 5E+01 3.2E-04 ]
ztd_pri     = 0.5 3E-05             ;                               [ 0.5 3E-05 ]
; rtk only
rtk_ar      = yes                   ; RTK ambiguity resolution      [ yes ]
glonass_ar  = no                    ; AR for GLONASS                [ no ]
base_pos    =                       ; base position in xyz (m)      [ spp ]
```

Figure 3.5: The "estimation" section of configuration.

product This section specifies the paths to various products. If "src = brdc", then "nav" should be set to a valid path to a broadcast ephemeris. If "src = precise", then "sp3" should be set to a valid path to a SP3 product and all other products are not necessary. If you use relative paths for products, paths are relative to the directory where pppx is executed, not where pppx.ini is located. Besides, placeholders (see Figure 3.6) can be used to specify product names, making it easier to process GNSS data across multiple days. More details on products are introduced in Section 3.1.2.

```
; available placeholder:
;   -YEAR-   : year
;   -YR-     : 2-digit year
;   -DOY-    : day of year
;   -WEEK-   : GPS week
;   -DOW-    : day of GPS week
[product]
src = precise                                  ; opt: brdc/precise
nav = rinex/BRDC00IGS_R_-YEAR--DOY-0000_01D_MN.rnx ; broadcast ephemeris       (brdc)
sp3 = products/cod-WEEK--DOW-.sp3              ; precise oribt             (precise)
clk = products/cod-WEEK--DOW-.clk              ; precise clock             (precise)
erp = products/cod-WEEK--DOW-.erp              ; earth rotation parameters (precise)
bia = products/cod-WEEK--DOW-.bia              ; satellite bias            (precise)
obx = products/cod-WEEK--DOW-.obx              ; satellite attitude        (precise)
ion = products/cod-WEEK--DOW-.ion              ; global ionospheric map    (common)
vmf = products/VMFG_-YEAR--DOY-                ; VMF1 grid                 (common)
```

Figure 3.6: The "product" section of configuration.

table This section specifies the paths to table files. An example is provided in Figure 3.7. More details can refer to Section 3.1.3. If you use relative paths for tables, the paths in the configuration are relative to the directory where pppx is executed.

```
[table]
igsatx     = ../../table/igs14.atx
oceanload  = ../../table/oceanload
channel    = ../../table/glonass_chn
gpt2w      = ../../table/gpt2_1wA.grd
orography  = ../../table/orography_ell
```

Figure 3.7: The "table" section of configuration.

output This section specifies the output path and log level. An example is provided in Figure 3.8. More details can refer to Section 3.2.

```
[output]
path  = ./                          ; the folder where results will be stored
level = info                        ; opt: off/critical/error/warn/info/debug/trace
```

Figure 3.8: The "output" section of configuration.

3.1.2 Product

There are two options of satellite products for each solution mode: "brdc" and "precise", controlled by the configuration field: "[product] src". The "brdc" option uses satellite orbits and clocks computed from broadcast ephemeris, while the "precise" option uses orbits and clocks from IGS precise products. Note that "[table] igsatx" is required if "[product] src" is set to "precise".

Here are some clarifications:

- All products labeled "precise" will not be used if "[product] src" is set to "brdc"
- Precise orbits and clocks can be used for SPP, but the Diffential Code Bias (DCB) issue is not handled for single-frequency SPP. In this case, it is recommended to set "[model] iono = IF"
- Only the SP3 file is necessary for the "precise" option. Other precise products are optional. If the CLK product is missing, the clock corrections from the SP3 file will be used
- "ion" and "vmf" are only mandatory when the corresponding models are specified
- PPP specific:
  - Broadcast ephemeris can also be used for PPP. Precise products will not be used in this case
  - The nominal attitude will be used if the OBX product is missing
  - The BIA product will be used if "[estimation] ppp_ar" is set to "yes"
  - Pole tide corrections will not be applied if the ERP product is missing, but this is fine for most applications.

3.1.3 Table

Several table files are required when specific models are used for data processing. These mainly include the antenna model, tropospheric model, and tide model. A complete list of the required table files is provided in Table 3.2. Instructions for downloading each table file are provided in Appendix A.3.

Table 3.2: List of table files.

Table	Description
channel	Frequency channel numbers for GLONASS satellites
gpt2w	Coefficients of the GPT2w tropospheric model
igsatx	Satellite and receiver antenna models in the IGS ANTEX format
oceanload	Ocean tide loading coefficients for stations
orography	Ellipsoidal station heights of the VMF1 grid points

Here are the clarifications:

- "channel" is only needed when GLONASS carrier phase measurements are used for data processing (i.e., ppp/rtk/tdp)

- "gpt2w" should be set when "[model] trop" is set to "GPT2w"
- "igsatx" is mandatory if "[product] src" is set to "precise". When "igstax" is specified, the satellite and station PCO corrections will be applied for all "sol_mode", but satellite and station PCV corrections will only be applied for PPP and RTK.
- "oceanload" is optional. Ocean tide loading will not be corrected if coefficients for the processed station are missing
- "orography" is needed when "[model] trop" is set to "VMF1"

Although the table files are not always required, it is recommended to properly set all the table paths to simplify the process and avoid potential issues.

3.2 Output

This section introduces the output files generated by the pppx software. An overview of these files is provided in Table 3.3. The function and format of each file are described in detail in the following sections.

Table 3.3: List of output files.

Output	Description
pos file	Receiver position, clock (GPS) and ZTD estimates for each epoch
log file	Information for debugging, including cycle slip detection, a-prior and postfit residuals
stat file	Postfit residuals and various estimates in the RTKLIB stat format, intended for visualization with RTKLIB

3.2.1 pos file

The primary output of pppx is the pos file, which contains main estimates for each processed epoch. These include station coordinates in the Earth-centered, Earth-fixed (ECEF) coordinate system, standard deviations of the coordinate estimates, receiver clock errors for the GPS system, and Zenith Total Delays (ZTD).

Figure 3.9 shows the beginning part of a sample pos file. The units used for coordinates, clock errors, and ZTD estimates are meters. Note that the coordinate system will align with the satellite orbit products used for data processing. By default, the standard deviations of coordinates are not included in the output when "fgo" is selected as the solver due to the long computation time required.

3.2.2 log file

A log file will be generated if the "[output] level" in the configuration file is not set to "off". This file contains debugging information such as cycle slip detection, outlier detection, and a-prior and postfit residuals. Each log message generally begins with a

```
  mjd      sod  nsat        x              y             z           stdx     stdy     stdz    rck(m)   zhd     zwd     dzwd
59679     0.00  17   4331298.023    567538.192   4633133.548    0.795    0.278    0.797     -9.8   2.081   0.025   0.2127
59679    30.00  17   4331299.398    567538.409   4633134.059    0.494    0.196    0.471     -8.9   2.081   0.025   0.1388
59679    60.00  17   4331299.590    567538.000   4633134.399    0.370    0.159    0.339     -8.4   2.081   0.025   0.0210
59679    90.00  17   4331299.938    567538.075   4633134.310    0.298    0.137    0.265     -8.2   2.081   0.025   0.0189
59679   120.00  17   4331299.981    567538.018   4633134.309    0.253    0.122    0.221     -8.1   2.081   0.025   0.0125
59679   150.00  17   4331299.899    567537.991   4633134.164    0.219    0.111    0.187     -8.0   2.081   0.025   0.0160
59679   180.00  17   4331299.918    567538.003   4633134.082    0.191    0.103    0.160     -8.0   2.081   0.025   0.0129
59679   210.00  17   4331299.932    567538.003   4633134.040    0.169    0.095    0.139     -8.1   2.081   0.025   0.0147
59679   240.00  17   4331299.774    567537.826   4633134.008    0.151    0.090    0.121     -8.1   2.081   0.025   0.0187
59679   270.00  17   4331299.776    567537.830   4633133.938    0.136    0.085    0.107     -8.2   2.081   0.025   0.0248
```

Figure 3.9: The screenshot of a sample pos file.

letter that indicates the message type: 'T' for Trace, 'D' for Debug, 'I' for Information, 'W' for Warning, 'E' for Error, and 'C' for critical.

Figure 3.10 shows the screenshot of a sample log file. For example, a cycle slip was detected at epoch 86370.0 (seconds of the day). Following the PRN number, the azimuth, elevation, and between-epoch difference of geometry-free (GF) combination of the satellite are provided. The subsequent line indicates that a new ambiguity parameter (numbered 410) was introduced at that epoch. The following lines provide information for all available satellites at that epoch. These include the a-prior residuals of pseudorange and carrier phase, the corresponding postfit residuals, ambiguity estimates in cycles, as well as the azimuth and elevation for each satellite, listed after its PRN and epoch time.

```
I ## 86370.00
I  GfJump: 86370.0 G30 -170.3 10.2  val: 16.07
I +++ G30 410 86370.00
I E04 86370.00   -0.432   -0.005     -0.423      0.004    187.118 -100.0   63.8
I E09 86370.00    3.216    0.011      3.222      0.016      0.179 -109.7   11.2
I E11 86370.00    0.231   -0.006      0.240      0.003     -4.188  -83.7   54.4
I E12 86370.00   -0.064   -0.009     -0.059     -0.004      1.739 -168.9   39.2
I E18 86370.00   -0.479   -0.016     -0.471     -0.008      3.720  -63.6   10.7
I E19 86370.00   -0.077   -0.011     -0.069     -0.003      7.753   59.7   52.5
I E21 86370.00    1.853    0.001      1.856      0.004     -2.511   93.7   14.4
I E27 86370.00    0.895   -0.015      0.901     -0.008     14.281   43.2   12.0
I E36 86370.00    0.604   -0.014      0.613     -0.005      5.998  -37.7   18.2
I G02 86370.00    1.937   -0.007      1.946      0.002     -2.125  -48.7   29.3
I G03 86370.00   -1.312    0.014     -1.309      0.017     47.787  106.7   26.2
I G04 86370.00   -0.193   -0.016     -0.185     -0.008    369.198   57.6   51.2
I G06 86370.00   -0.409   -0.012     -0.401     -0.004     54.960 -104.9   62.2
I G07 86370.00    0.904   -0.011      0.907     -0.008    -28.983  173.3   31.9
I G09 86370.00    0.800   -0.002      0.808      0.007    246.278  -20.0   86.5
I G11 86370.00   -1.175   -0.009     -1.166      0.000    -10.412  -49.6   30.7
I G19 86370.00    3.370   -0.005      3.373     -0.001     39.702 -129.2    9.7
I G26 86370.00   -1.855   -0.011     -1.850     -0.005     46.984   44.9    7.4
I G30 86370.00   -0.267   24.679     -0.266      0.000    354.394 -170.3   10.2
```

Figure 3.10: The screenshot of a sample log file.

3.2.3 stat file

A stat file is always generated for visualization with the RTKLIB software. For detailed information on the format, you can refer to the RTKLIB source code. Currently, pppx only outputs messages with the keywords "$POS", "$CLK", and "$SAT". The only difference is that the "$CLK" values are expressed in meters (instead of nanoseconds) and represent absolute clock errors for each GNSS system (rather than inter-system biases). Figure 3.11 shows a screenshot of a sample stat file.

```
$POS,2205,0.000,6,4331298.0228,567538.1921,4633133.5484,0.7955,0.2775,0.7969
$CLK,2205,0.000,6,-9.811,0.000,1.618,0.000,0.000
$SAT,2205,0.000,E03,1,-108.9,30.2,0.8635,0.0000,0,45.300,0,0,0,0,0,0
$SAT,2205,0.000,E05,1,-62.4,83.0,-0.2401,0.0000,0,52.100,0,0,0,0,0,0
$SAT,2205,0.000,E09,1,62.2,39.7,0.2750,0.0000,0,47.500,0,0,0,0,0,0
$SAT,2205,0.000,E15,1,-49.4,34.3,-0.5920,0.0000,0,47.300,0,0,0,0,0,0
$SAT,2205,0.000,E24,1,119.5,7.2,0.8040,0.0000,0,38.900,0,0,0,0,0,0
$SAT,2205,0.000,E31,1,74.2,15.2,-0.4149,0.0000,0,41.800,0,0,0,0,0,0
$SAT,2205,0.000,E36,1,177.0,24.0,-0.3656,0.0000,0,43.300,0,0,0,0,0,0
$SAT,2205,0.000,G02,1,-47.8,28.1,1.0852,0.0000,0,44.700,0,0,0,0,0,0
```

Figure 3.11: The screenshot of a sample stat file.

3.3 Visualization

This section explains how to visualize the solutions generated by pppx.

3.3.1 With Python

A Python script named "plot_ppppos.py" is included in the software package and is located in the "scripts/" folder. This script can generate plots of either (1) the positioning time-series in the east, north, and up components (relative to the mean position) or (2) additional time-series of the receiver clock, and ZTD estimates. The general usage of the script is demonstrated with the commands below, and the corresponding figures are shown in Figure 3.12:

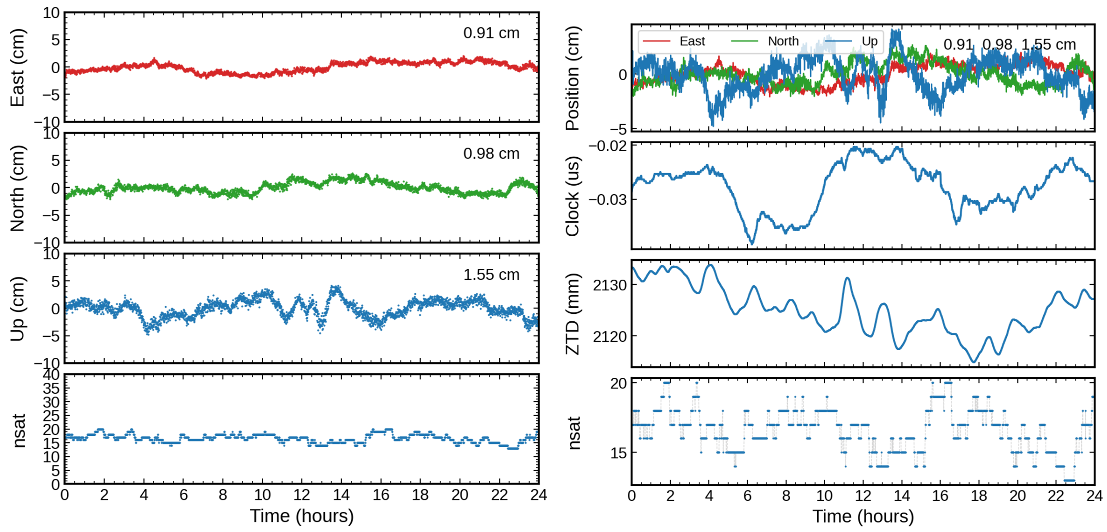
```
# (1) plot position estimates only
$ ../../scripts/plot_ppppos.py pos_file -s

# (2) plot position, receiver closk, and ZTD estimates
$ ../../scripts/plot_ppppos.py pos_file -a

# Options:
# -a  Plot position, receiver clock, and ZTD estimates
# -i  Interactive mode
# -s  Fixed scale for the y-axis; otherwise, the scale is set automatically
```

3.3.2 With RTKLIB

The RTKLIB software is recommended for enhanced interactive viewing of various plots and the visualization of postfit residuals. However, a limitation is that the RTKLIB author provides executables only for Windows users. Linux users need to compile the GUI applications by themselves using the Qt library.

Using RTKLIB for visualization is straightforward:

1. Open the application "rtkplot.exe"
2. Click the menu "File" > "Open Solution-1" > Select the generated stat file
3. Interactively view the various plots

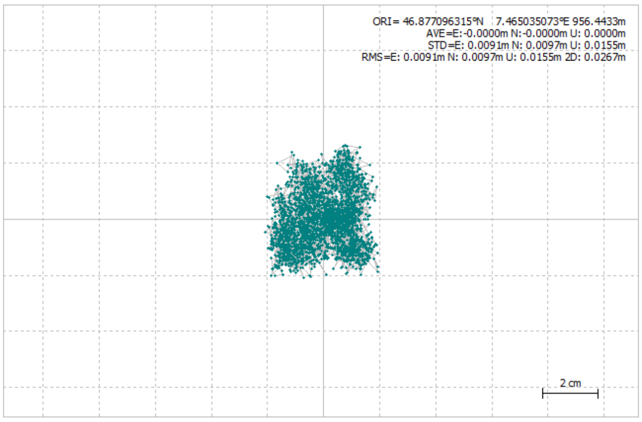


(a) Plotted with option "-s"

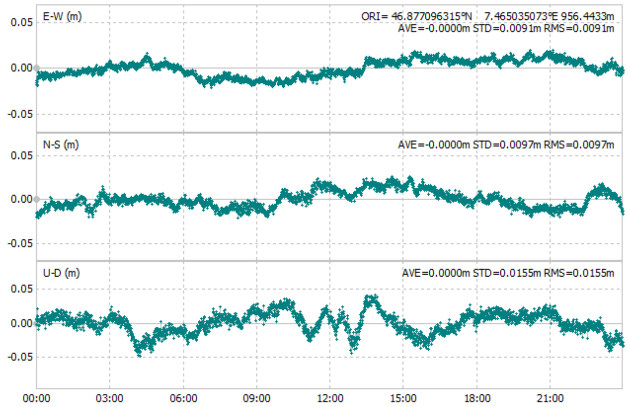
(b) Plotted with option "-a"

Figure 3.12: Visualization of an FGO-based PPP solution with the Python script.

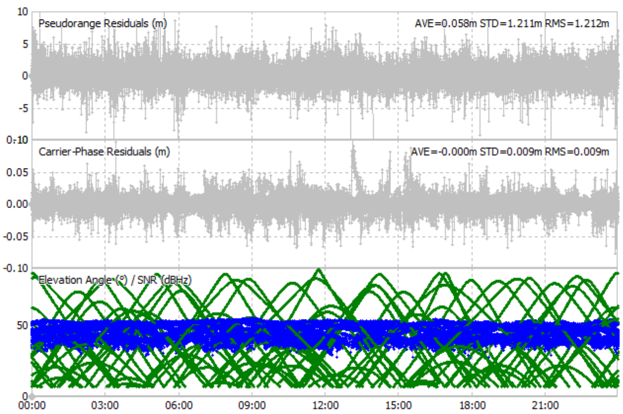
Figure 3.13 shows some example visualizations. A useful tip: you can open two solutions within the same window for easy comparison.



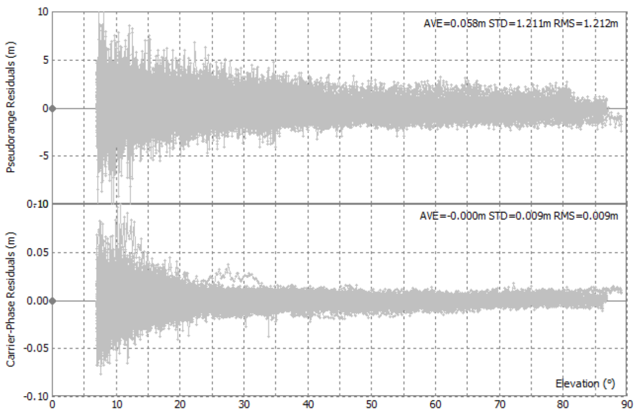
(a) Ground track plot.



(b) Positioning time-series plot.



(c) Residual time-series plot.



(d) Residual-elevation plot.

Figure 3.13: Visulization of an FGO-based PPP solution with RTKLIB.

4 Examples

This section provides some examples of using pppx for various types of data processing. The corresponding folder is ‘example/pppx/‘. Specifically, two RINEX files and some products are provided in "example/pppx/rinex/" and "example/pppx/products/", respectively. The basic information of the observation and product files can be found in Table 4.1 and Table 4.2, respectively. Note that the VMF1 grid product is a spliced file of the epoch 00 h, 06 h, 12 h, 18 h of the current day and the 00 h of the next day. By default, GPS and Galileo observations are used for each example, except that the RTK example is GPS only.

Table 4.1: GNSS data used in examples.

Data	Description
ZIM200CHE_R_20221000000_01D_30S_MO.rnx	Rover station (GREC)
ZIMM00CHE_R_20221000000_01D_30S_MO.rnx	Reference station (G)

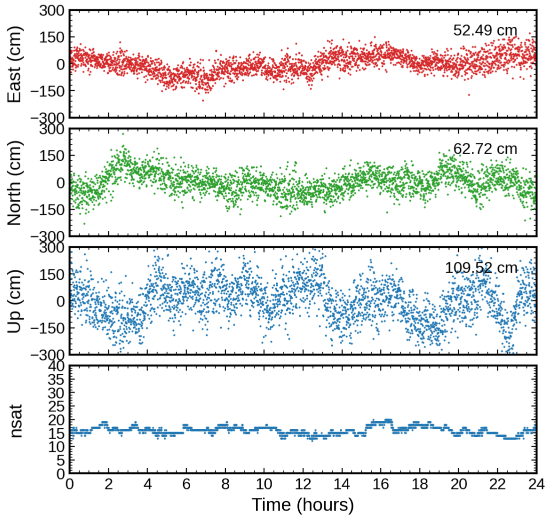
Table 4.2: Products used in examples.

Product	Description
BRDC00IGS_R_20220010000_01D_MN.rnx	Broadcast ephemeris for multi-GNSS
COD0MGXFIN_20221000000_01D_05M_ORB.SP3	Precise orbit from CODE
COD0MGXFIN_20221000000_01D_30S_CLK.CLK	Precise clock from CODE
COD0MGXFIN_20221000000_01D_15M_ATT.OBX	Satellite attitude from CODE
COD0MGXFIN_20221000000_01D_01D_OSB.BIA	Satellite bias from CODE
COD0MGXFIN_20221000000_03D_12H_ERP.ERP	ERP from CODE
codg1000.22i	GIM from CODE
VMFG_2022100	spliced VMF1 grid from TU Vienna

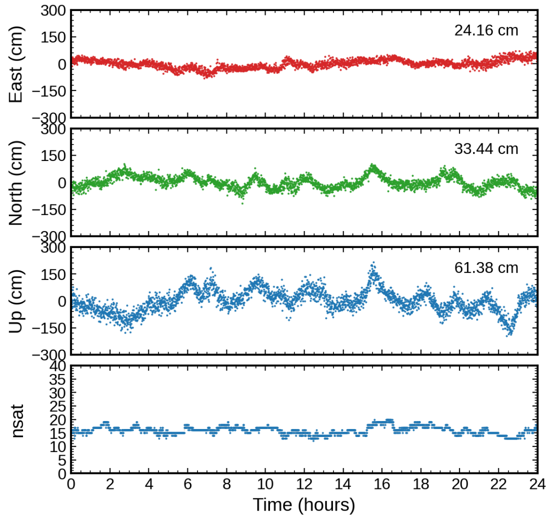
4.1 SPP: Single Point Positioning

The pppx software supports multi-GNSS SPP, including GPS, GLONASS, Galileo, BeiDou, and QZSS, with either broadcast ephemeris or precise satellite products. Various tropospheric and ionospheric models are supported. However, only kinematic mode is currently supported with either LSQ or FGO as a solver. Note that LSQ- and FGO-based SPP are both epoch-wise solutions (i.e., no constraints between epochs), and the only difference is that FGO utilize the Huber loss function (2 m threshold) to improve robustness. Here, the LSQ solver is used since the GNSS data used in the examples are from geodetic-grade receivers.

Here, SPP solutions with IF combination and single-frequency observations are demonstrated. Both examples use broadcast ephemeris, which is the most common case for SPP users. Specifically, GMF model and IF combination are used to correct tropospheric and ionospheric delays for the IF solution, and GMF and a GIM product and are used



(a) IF solution



(b) SF solution

Figure 4.1: Positioning results of SPP solutions.

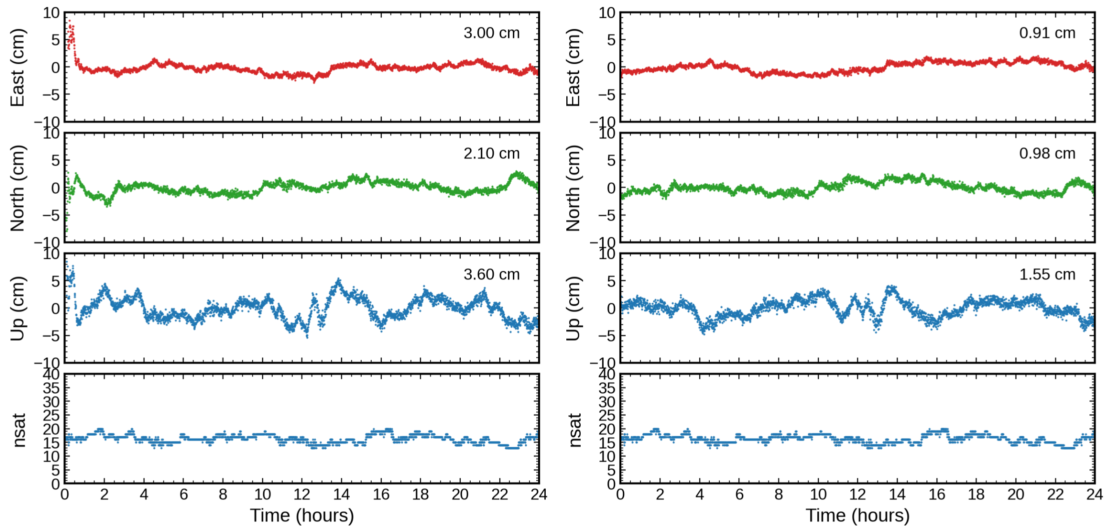
for the single-frequency solution. The other settings are just kept as defaults. The corresponding configuration files can be found as "example/pppx/00_spp_if.ini" and "example/pppx/01_spp_sf.ini", respectively.

The positioning results are shown in Figure 4.1. It is found that the single-frequency solution is better then IF solution. It is attributed to the fact that the IF combination amplifies the noise of pseudorange by about three times, and the ionospheric delays can be well corrected with the GIM product for the station ZIM2, which locates at middle altitude.

4.2 PPP: Precise Point Positioning

Here, PPP solutions with Kalman filter or FGO as the solver are demonstrated. The corresponding configuration files can be found as "example/pppx/02_ppp_ekf.ini" and "example/pppx/03_ppp_fgo.ini", respectively. The Kalman filter-based solution simulate the real-time scenario and output a forward only solution. The FGO-based solution is dedicated to post-processing and output a batch processing solution, i.e., no convergence period. Besides, FGO utilize Huber loss function to improve robustness, i.e., thresholds of 2 m and 0.02 m for pseudorange and carrier phase observations, respectively.

The positioning results are displayed in Figure 4.2. It is observed that there is no convergence period for the FGO-based solution, but the EKF solution takes approximately 15 min to get converged. It is attributed to that all the GNSS observations are used to form a large LSQ problem and all the parameters are solved together with FGO, while parameters are solved epoch-by-epoch with EKF.



(a) EKF solution

(b) FGO solution

Figure 4.2: Positioning results of PPP solutions.

4.3 RTK: Real-Time Kinematic

The pppx software only supports short baseline solutions. Thus, "[model] trop" and "[model] iono" are always "none". Only "ekf" is supported for RTK. The corresponding configuration file can be found as "example/pppx/06_rtk.ini".

The positioning result is shown in Figure 4.3. The precision is 0.24 cm, 0.28 cm, and 0.48 cm for the east, north, and up components, respectively. It is typical precision for short baseline solutions with ambiguity resolved.

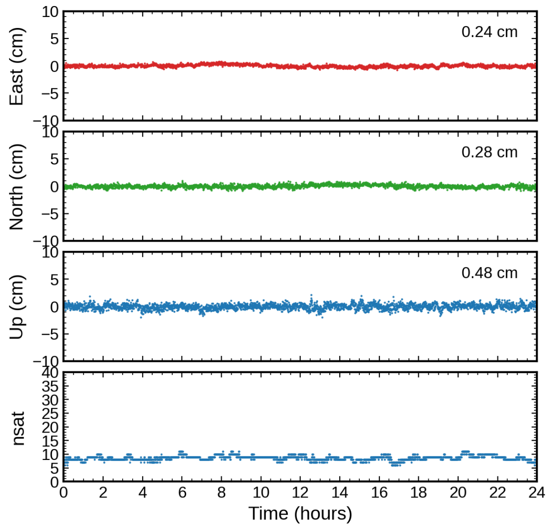


Figure 4.3: Positioning results of a short baseline solution between ZIM2 and ZIMM.

4.4 TDP: Time-Differenced Positioning

TDP is useful for earthquake studies. An example will be provided in the future.

5 Troubleshooting

Text

6 FAQs

Text

A File Download

A.1 Download GNSS observations

1. CDDIS: https://cddis.nasa.gov/archive/gnss/data
2. EPN: ftp://ftp.epncb.oma.be/pub/obs
3. PBO: https://data.unavco.org/archive/gnss/
4. GA: https://data.gnss.ga.gov.au/docs/home/gnss-data.html
5. Curtin: http://saegnss2.curtin.edu/ldc
6. Hongkong: https://rinex.geodetic.gov.hk

A.2 Download IGS Products

Available HTTP sites for downloading GNSS products

1. CDDIS: https://cddis.nasa.gov/archive/gnss/
2. CODE: http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/
3. ESA: http://navigation-office.esa.int/products/gnss-products/
4. CNES: http://www.ppp-wizard.net/daily.html

FTP sites:

1. CDDIS: ftps://gdc.cddis.eosdis.nasa.gov/gnss/
2. CODE: ftp://ftp.aiub.unibe.ch/CODE_MGEX/CODE/
3. WHU: ftp://igs.gnsswhu.cn/pub/
4. IGN: ftp://igs.ign.fr/pub/igs

Other products:

1. VMF1: http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/

A.3 Download Table Files

Ocean tide loading

Old portal: http://holt.oso.chalmers.se/loading/index-aside-2404271219.html

New portal: https://barre.oso.chalmers.se/loading/l.php

Here, we use the old portal to download oceanload coefficients:

1. Ocean tide model -> select **"FES2004"**
2. Keep other options as default values
3. Enter the station list: either XYZ or BLH
4. Enter and email address and click **"Submit"**

The required oceanload coefficients will be sent to you by email, and then you need to append the coefficients to the table file "table/oceanload".

ANTEX

`https://files.igs.org/pub/station/general`