

Introduction of RTKLIB

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Contents

1. Introduction of RTKLIB
2. GNSS Positioning Theory &
Example of using RTKLIB

1 RTKLIB

- Open source program package for standard and precise positioning with GNSS (global navigation satellite system).
- Developed by Mr. Tomoji Takasu at TUMSAT.
- Since 2006, latest version is ver. 2.4.3 b31.
- API(Application Programming Interface)+APs (application programs).

1 Features of RTKLIB

(1) It supports multi-GNSS satellites:

GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS (no IRNSS/Navic)

(2) It supports various positioning modes with GNSS for both real-time- and post-processing:

Single, DGPS/DGNSS, Kinematic, Static, Moving-Baseline, Fixed,
PPP-Kinematic, PPP-Static and PPP-Fixed

(3) It supports many standard formats/protocols and receivers:

RINEX 2/3, RTCM 2/3, BINEX, NTRIP 1.0, NMEA 0183, SP3, CLK, ANTEX, IONEX, NGS PCV and EMS ...

NovAtel, u-blox, SkyTraq, JAVAD, Septentrio, NVS, Hemisphere ...

1 Features of RTKLIB

(4) It supports real-time communication via:

Serial, TCP/IP, NTRIP, and file streams.

(5) It provides many library functions and APIs

(6) It provides many GUIs and CUI(command-line user interface) APIs:

Function	GUI AP	CUI AP
(a) AP Launcher	RTKLAUNCH	-
(b) Real-Time Positioning	RTKNAVI	RTKRCV
(c) Communication Server	STRSVR	STR2STR
(d) Post-Processing Analysis	RTKPOST	RNX2RTKP
(e) RINEX Converter	RTKCONV	CONVBIN
(f) Plot Solutions and Obs Data	RTKPLOT	-
(g) Downloader of GNSS Data	RTKGET	-
(h) NTRIP Browser	NTRIPSRCBROWS	-

1 Package of RTKLIB

```
rtklib_<ver>
./src          source programs of RTKLIB library *
./rcv         source programs depending on GPS/GNSS receivers *
./bin         executable binary APs and DLLs for Windows
./data        sample data for APs
./app         build environment of APs *
  ./rtknavi   RTKNAVI      (GUI) *
  ./rtknavi_mkl RTKNAVI_MKL (GUI) *
  ./strsvr    STRSVR      (GUI) *
  ./rtkpost   RTKPOST    (GUI) *
  ./rtkpost_mkl RTKPOST_MKL (GUI) *
  ./rtkplot   RTKPLOT    (GUI) *
  ./rtkconv   RTKCONV    (GUI) *
  ./srctblbrows NTRIP Browser (GUI) *
  ./rtkget    RTKGET     (GUI) *
  ./rtklaunch RTKLAUNCH  (GUI) *
  ./rtkrcv    RTKRVC     (CUI) *
  ./rnx2rtkp  RNX2RTKP    (CUI) *
  ./pos2kml   POS2KML    (CUI) *
  ./convbin   CONVBIN    (CUI) *
  ./str2str   STR2STR    (CUI) *
  ./appcmn    common routines for GUI APs *
  ./icon      icon data for GUI APs *
./lib         library generation environment *
./test        test programs and data *
./util        utilities *
./doc         document files
```

* not included in the binary package rtklib_<ver>_bin.zip

1 RTKLIB version and download

Version	Date	Binary AP Package for Windows	Full Package with Source Programs
0.2.0	2006/12/16	-	rtklib_0.2.0.zip (2.8MB)
1.0.0	2007/01/25	-	rtklib_1.0.0.zip (10.5MB)
1.1.0	2007/03/20	-	rtklib_1.1.0.zip (6.2MB)
2.1.0	2008/07/15	-	rtklib_2.1.0.zip (22.9MB)
2.2.0	2009/01/31	rtklib_2.2.0_bin.zip (10.7MB)	rtklib_2.2.0.zip (23.4MB)
2.2.1	2009/05/17	rtklib_2.2.1_bin.zip (15.3MB)	rtklib_2.2.1.zip (30.6MB)
2.2.2	2009/09/07	rtklib_2.2.2_bin.zip (21.4MB)	rtklib_2.2.2.zip (33.8MB)
2.3.0	2009/12/17	rtklib_2.3.0_bin.zip (26.7MB)	rtklib_2.3.0.zip (35.8MB)
2.4.0	2010/08/08	rtklib_2.4.0_bin.zip (17.4MB)	rtklib_2.4.0.zip (26.5MB)
2.4.1	2011/06/11	rtklib_2.4.1_bin.zip (16.5MB)	rtklib_2.4.1.zip (26.4MB)
2.4.2	2013/04/29	rtklib_2.4.2_bin.zip (30.4MB)	rtklib_2.4.2.zip (55.2MB)

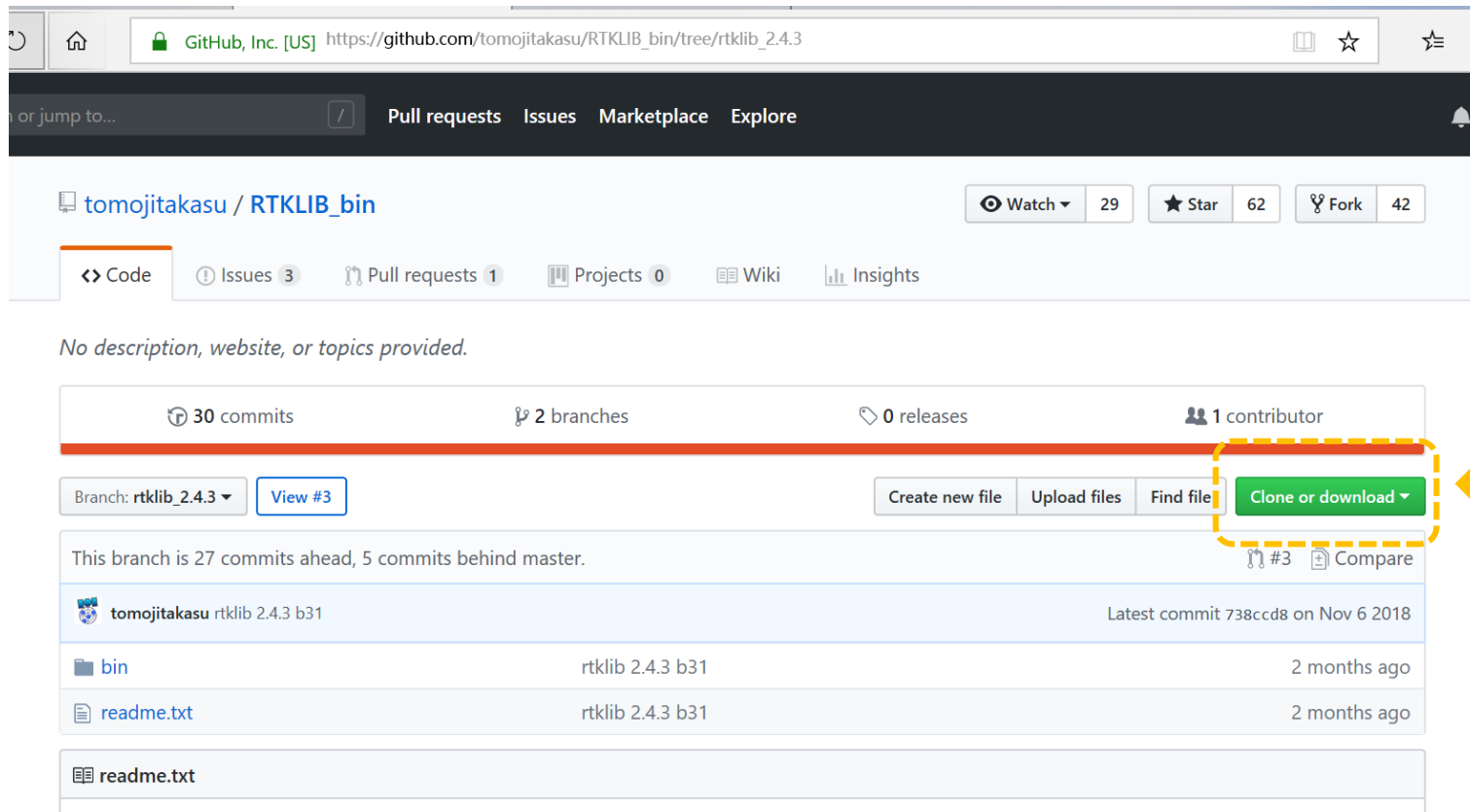
These are just old archives for recording. To download of the newest version, please visit the following GitHub links.

Version	Date	Binary APs for Windows	Source Programs and Data
2.4.2 p13	2018/01/29	GitHub	GitHub
2.4.3 b33	2019/08/19	GitHub	GitHub

<http://www.rtklib.com/>

<https://github.com/tomojitakasu/>

1 Download RTKLIB



GitHub, Inc. [US] https://github.com/tomojitakasu/RTKLIB_bin/tree/rtklib_2.4.3

tomojitakasu / RTKLIB_bin

Watch 29 Star 62 Fork 42




Code Issues 3 Pull requests 1 Projects 0 Wiki Insights

No description, website, or topics provided.

30 commits 2 branches 0 releases 1 contributor

Branch: rtklib_2.4.3 View #3 Create new file Upload files Find file Clone or download

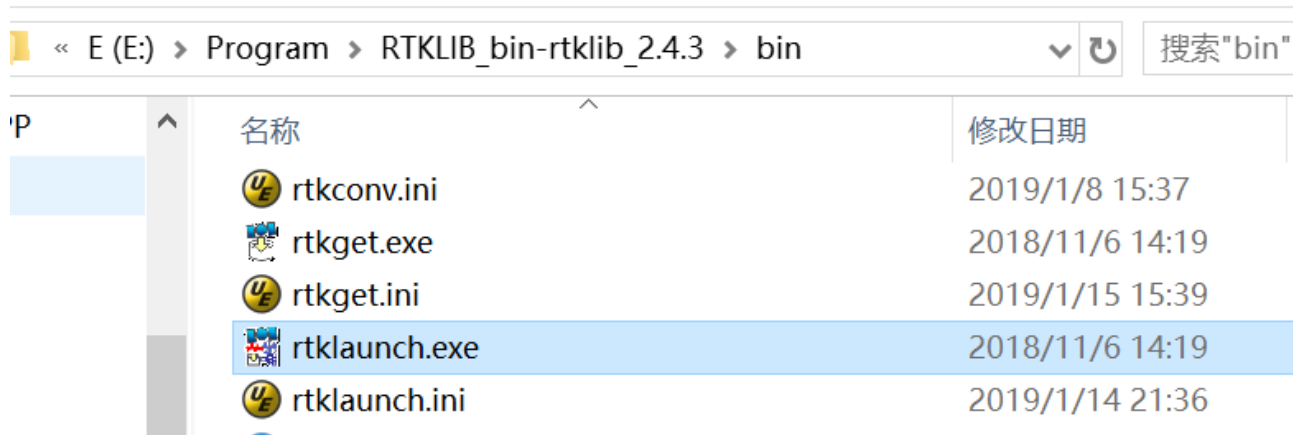
This branch is 27 commits ahead, 5 commits behind master. #3 Compare

 tomojitakasu	rtklib 2.4.3 b31	Latest commit 738ccd8 on Nov 6 2018
 bin	rtklib 2.4.3 b31	2 months ago
 readme.txt	rtklib 2.4.3 b31	2 months ago

readme.txt

https://github.com/tomojitakasu/RTKLIB_bin/tree/rtklib_2.4.3

1 Launch RTKLIB



1 RTKLIB GUIs

The image displays a collection of screenshots for various RTKLIB GUIs, arranged in a grid-like fashion. The GUIs shown are:

- RTKPLLOT**: A window showing a network of colored lines (representing baselines) connecting various station points on a map. The text "RTKPLLOT" is overlaid in red.
- RTKNAVI**: A window showing a 2D plot of a trajectory with a speed scale on the right. The text "RTKNAVI" is overlaid in red.
- RTKCONV**: A window showing a list of stations and their coordinates. The text "RTKCONV" is overlaid in red.
- RTKGET**: A window showing a list of stations and their coordinates, with a "Time Span (GPST)" field. The text "RTKGET" is overlaid in red.
- RTKPOST**: A window showing a list of stations and their coordinates, with a "Time Start (GPST)" and "Time End (GPST)" field. The text "RTKPOST" is overlaid in red.
- NTRIP BROWSER**: A window showing a list of stations and their coordinates, with a "Mountpoint ID" field. The text "NTRIP BROWSER" is overlaid in red.

Other visible windows include "RTKNAV1 ver.2.4.2" showing solution data (N: 35° 43' 08.2300", E: 138° 27' 02.1531", H: 367.442 m), "RTKGET v.2.4.2" showing station lists, and "RTKCONV v.2.4.2" showing station lists. The "RTKPOST" window shows a list of stations with columns for Station ID, Name, and RTK Version. The "NTRIP BROWSER" window shows a list of stations with columns for Mountpoint ID, Name, and RTK Version.

1 RTKLIB Manual

RTKLIB ver. 2.4.2 Manual



April 29, 2013

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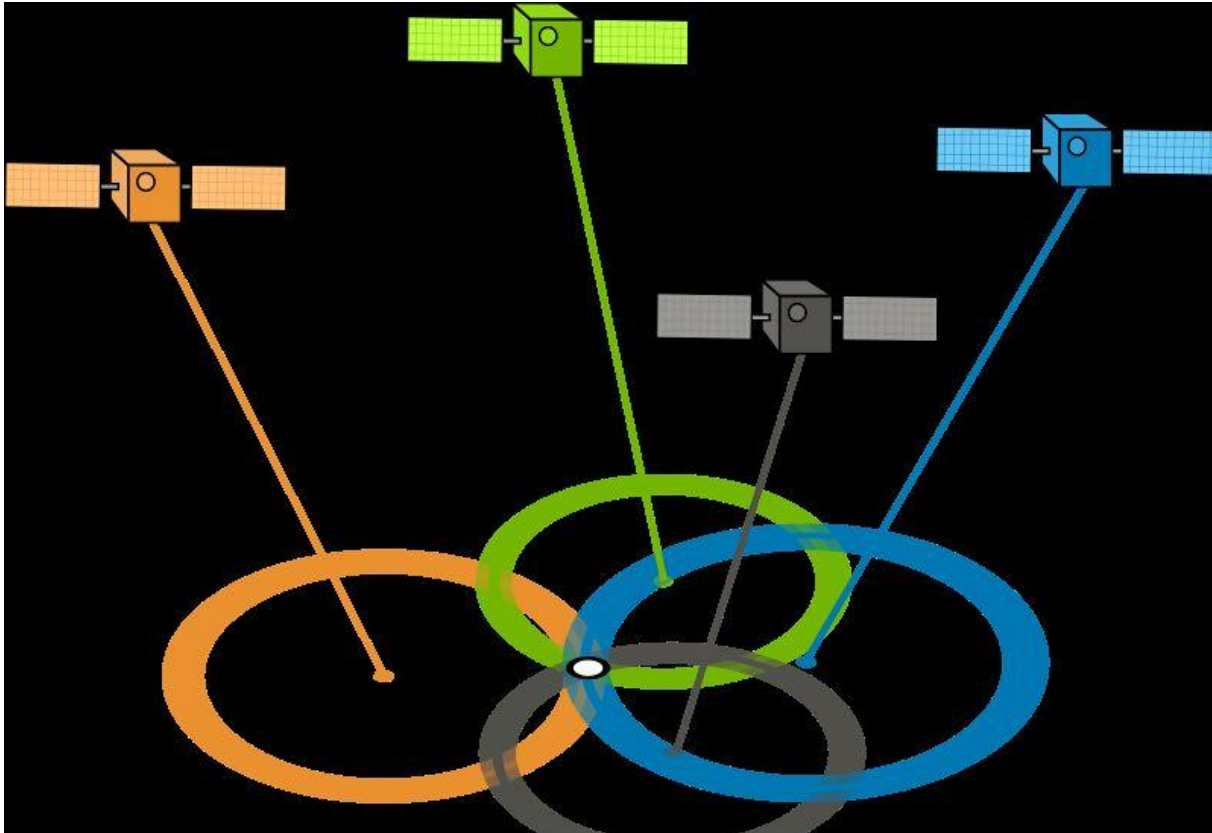
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• http://www.rtklib.com/prog/manual_2.4.2.pdf

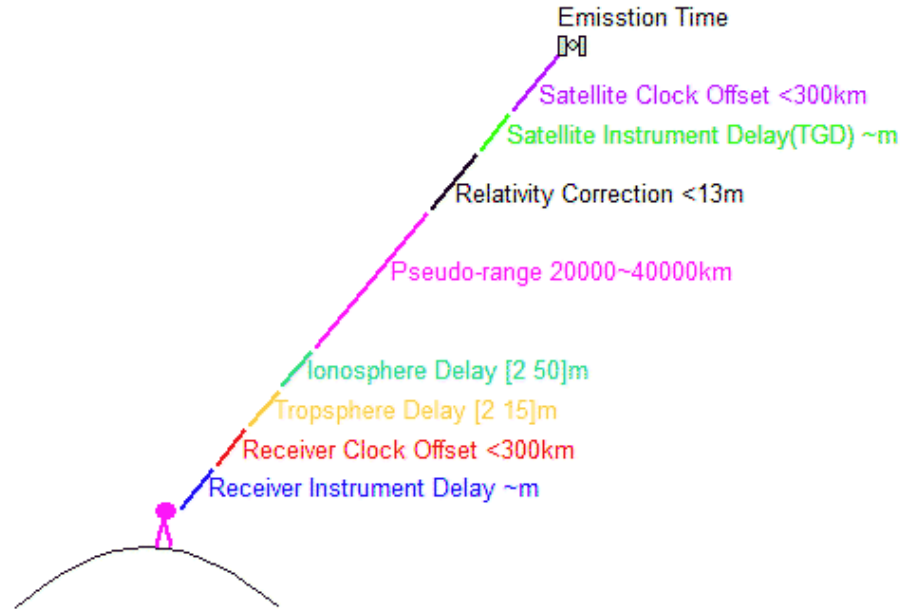
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 - RTK

2 GNSS Positioning



2 GNSS Observation and Errors

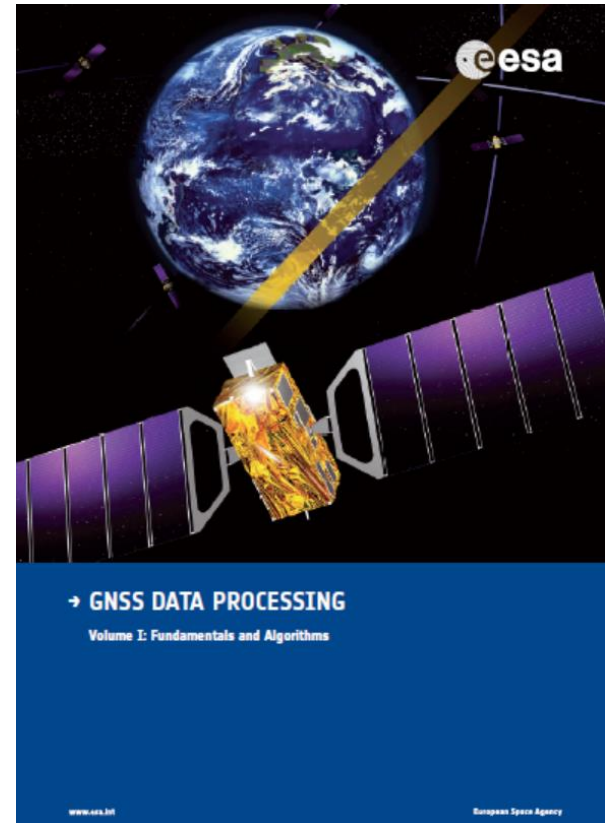


2 GNSS Positioning based on code and carrier phase

	Standard Positioning (code-based)	Precise Positioning (carrier-based)
Observables	Pseudorange (Code)	Carrier-Phase + Pseudorange
Receiver Noise	30 cm	3 mm
Multipath	30 cm - 30 m	1 - 3 cm
Sensitivity	High (<20dBHz)	Low (>35dBHz)
Discontinuity	No Slip	Cycle-Slip
Ambiguity	-	Estimated/Resolved
Receiver	Low-Cost (~\$100)	Expensive (~\$20,000)
Accuracy (RMS)	3 m (H), 5 m (V) (Single) 1 m (H), 2 m (V) (DGPS)	5 mm (H), 1 cm (V) (Static) 1 cm (H), 2 cm (V) (RTK)
Application	Navigation, Timing, SAR,...	Survey, Mapping, ...

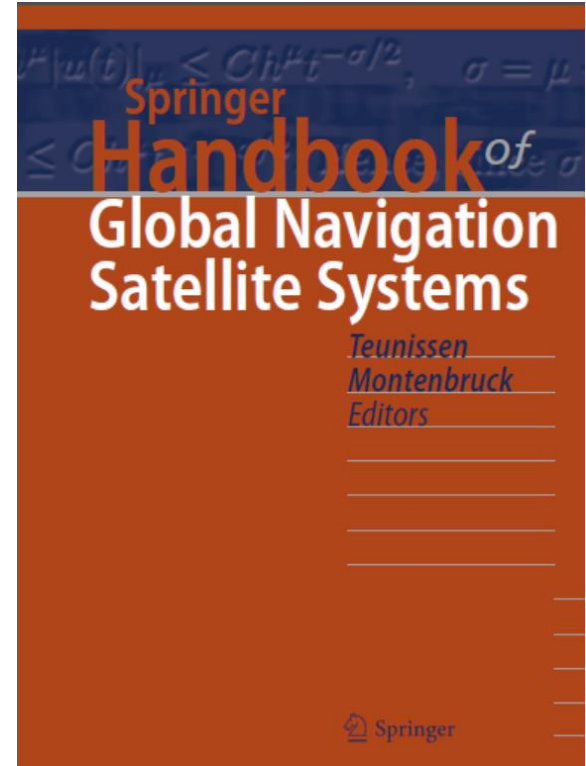
2 GNSS Observation and Errors

Subirana J. Sanz, Juan Zornoza J.M. and Hernández-Pajares M. GNSS Data Processing: Volume I: Fundamentals and Algorithms. ESA communications, Netherlands, 2013



2 GNSS Observation and Errors

Teunissen P J G , Montenbruck O . Springer Handbook of Global Navigation Satellite Systems [J]. 2017, 10.1007/978-3-319-42928-1.



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2.1.1 GNSS Pseudo-range Observation Equation

$$P_f^j = \rho^j + c \cdot \delta t_f - c \cdot \delta t_f^j - \Delta_{rela}^j + T^j - \frac{I^j}{f^2} + \varepsilon_{P_f}$$

The diagram illustrates the components of the GNSS pseudo-range observation equation. Each term in the equation is linked to a descriptive label by a colored arrow:

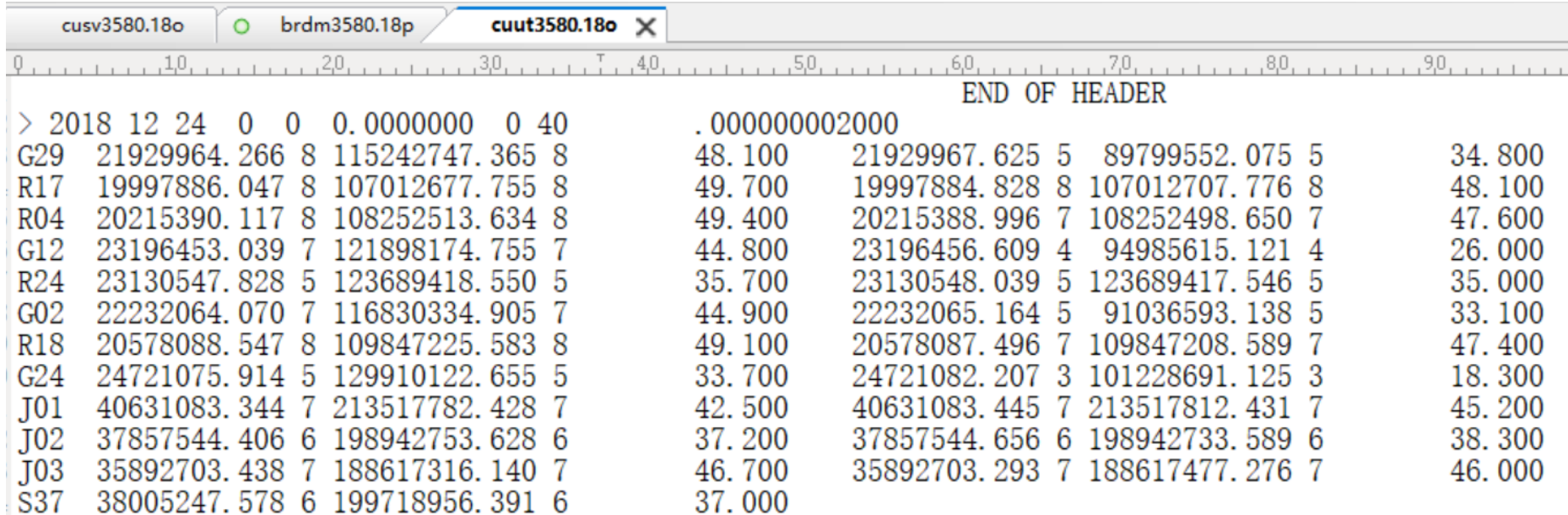
- Pseudo-range observation** (yellow arrow) points to P_f^j .
- Geometric distance from satellite to receiver (X, Y, Z)** (green arrow) points to ρ^j .
- Receiver clock** (blue arrow) points to $c \cdot \delta t_f$.
- Satellite clock** (light blue arrow) points to $-c \cdot \delta t_f^j$.
- Clock relativity correction** (red arrow) points to $-\Delta_{rela}^j$.
- Troposphere correction** (magenta arrow) points to T^j .
- Ionosphere correction** (purple arrow) points to $-\frac{I^j}{f^2}$.
- Noise and other modeled corrections** (black arrow) points to ε_{P_f} .

2.1.1 GNSS Observation Data (RINEX format)

cusv3580.18o										brdm3580.18p										cuut3580.18o																																																																					
0										10										20										30										40										50										60										70										80									
3.02																														OBSERVATION DATA										M (MIXED)										RINEX VERSION / TYPE																																							
NetR9 5.22										Receiver Operator										20181224 000001 UTC										COMMENT																																																											
NetR9 5.22										OA										20181224 000001 UTC										PGM / RUN BY / DATE																																																											
gfzrnrx-1.10-7329										HEADER EDIT										20181225 020444 UTC										COMMENT																																																											
CUUT																														MARKER NAME																																																											
21904S002																														MARKER NUMBER																																																											
GEODETTIC																														MARKER TYPE																																																											
AUTOMATIC										CU/SV										OBSERVER / AGENCY																																																																					
5427R49036										TRIMBLE NETR9 5.22										REC # / TYPE / VERS																																																																					
5000120293										TRM57971.00 NONE										ANT # / TYPE																																																																					
-1132915.8956										6092526.3508										1504641.4755										APPROX POSITION XYZ																																																											
0.0000										0.0000										0.0000										ANTENNA: DELTA_H/E/N																																																											
G 12 C1C L1C S1C C2W L2W S2W C2X L2X S2X C5X L5X S5X										SYS / # / OBS TYPES																																																																															
S 6 C1C L1C S1C C5I L5I S5I										SYS / # / OBS TYPES																																																																															
R 12 C1C L1C S1C C1P L1P S1P C2C L2C S2C C2P L2P S2P										SYS / # / OBS TYPES																																																																															
E 12 C1X L1X S1X C5X L5X S5X C7X L7X S7X C8X L8X S8X										SYS / # / OBS TYPES																																																																															
J 18 C1C L1C S1C C1X L1X S1X C1Z L1Z S1Z C2X L2X S2X C5X										SYS / # / OBS TYPES																																																																															
L5X S5X C6X L6X S6X										SYS / # / OBS TYPES																																																																															
C 6 C1I L1I S1I C7I L7I S7I										SYS / # / OBS TYPES																																																																															
30.000																														INTERVAL																																																											
2018 12 24										0 0										0.0000000										GPS										TIME OF FIRST OBS																																																	
G L2X -0.25000										SYS / PHASE SHIFT																																																																															
R L1P 0.25000										SYS / PHASE SHIFT																																																																															

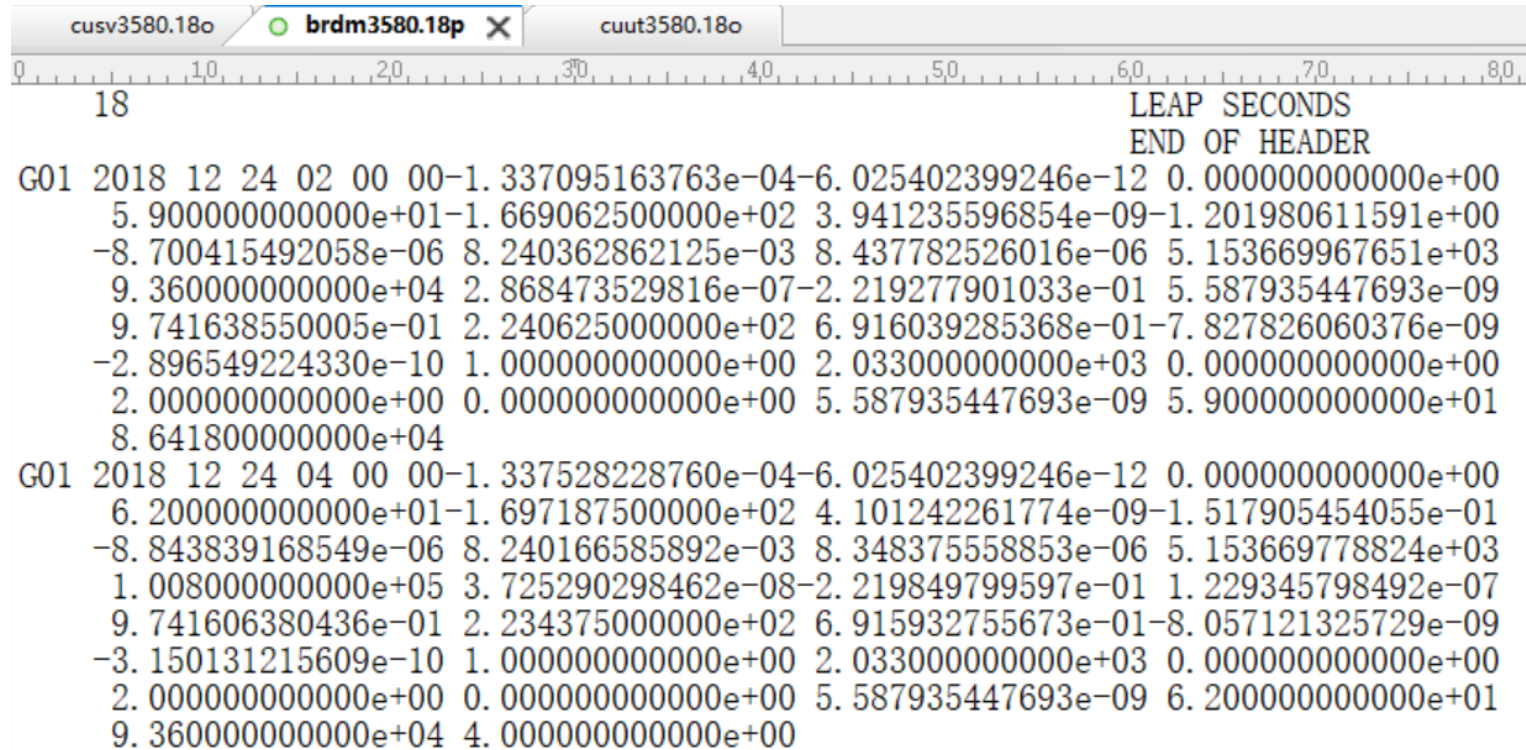
<ftp://igs.org/pub/data/format/rinex303.pdf>

2.1.1 GNSS Observation Data (RINEX format)



```
cusv3580.18o  brdm3580.18p  cuut3580.18o X
0 10 20 30 40 50 60 70 80 90
                                END OF HEADER
> 2018 12 24 0 0 0.000000 0 40 .000000002000
G29 21929964.266 8 115242747.365 8 48.100 21929967.625 5 89799552.075 5 34.800
R17 19997886.047 8 107012677.755 8 49.700 19997884.828 8 107012707.776 8 48.100
R04 20215390.117 8 108252513.634 8 49.400 20215388.996 7 108252498.650 7 47.600
G12 23196453.039 7 121898174.755 7 44.800 23196456.609 4 94985615.121 4 26.000
R24 23130547.828 5 123689418.550 5 35.700 23130548.039 5 123689417.546 5 35.000
G02 22232064.070 7 116830334.905 7 44.900 22232065.164 5 91036593.138 5 33.100
R18 20578088.547 8 109847225.583 8 49.100 20578087.496 7 109847208.589 7 47.400
G24 24721075.914 5 129910122.655 5 33.700 24721082.207 3 101228691.125 3 18.300
J01 40631083.344 7 213517782.428 7 42.500 40631083.445 7 213517812.431 7 45.200
J02 37857544.406 6 198942753.628 6 37.200 37857544.656 6 198942733.589 6 38.300
J03 35892703.438 7 188617316.140 7 46.700 35892703.293 7 188617477.276 7 46.000
S37 38005247.578 6 199718956.391 6 37.000
```

2.1.1 GNSS Navigation Data(RINEX format)



```
cusv3580.18o  brdm3580.18p  cuut3580.18o
0 10 20 30 40 50 60 70 80
18
LEAP SECONDS
END OF HEADER
G01 2018 12 24 02 00 00-1.337095163763e-04-6.025402399246e-12 0.000000000000e+00
5.900000000000e+01-1.669062500000e+02 3.941235596854e-09-1.201980611591e+00
-8.700415492058e-06 8.240362862125e-03 8.437782526016e-06 5.153669967651e+03
9.360000000000e+04 2.868473529816e-07-2.219277901033e-01 5.587935447693e-09
9.741638550005e-01 2.240625000000e+02 6.916039285368e-01-7.827826060376e-09
-2.896549224330e-10 1.000000000000e+00 2.033000000000e+03 0.000000000000e+00
2.000000000000e+00 0.000000000000e+00 5.587935447693e-09 5.900000000000e+01
8.641800000000e+04
G01 2018 12 24 04 00 00-1.337528228760e-04-6.025402399246e-12 0.000000000000e+00
6.200000000000e+01-1.697187500000e+02 4.101242261774e-09-1.517905454055e-01
-8.843839168549e-06 8.240166585892e-03 8.348375558853e-06 5.153669778824e+03
1.008000000000e+05 3.725290298462e-08-2.219849799597e-01 1.229345798492e-07
9.741606380436e-01 2.234375000000e+02 6.915932755673e-01-8.057121325729e-09
-3.150131215609e-10 1.000000000000e+00 2.033000000000e+03 0.000000000000e+00
2.000000000000e+00 0.000000000000e+00 5.587935447693e-09 6.200000000000e+01
9.360000000000e+04 4.000000000000e+00
```

2.1.1 SPP(Single Point Positioning)

Define:

$$\rho = \rho_0 + \frac{x_0 - x^{\text{sat}}}{\rho_0} dx + \frac{y_0 - y^{\text{sat}}}{\rho_0} dy + \frac{z_0 - z^{\text{sat}}}{\rho_0} dz$$

$$D = c \cdot \delta t^s + \Delta_{\text{rela}} - T + \frac{I}{f^2}$$

Then:

$$\begin{bmatrix} P_1 - \rho_1 - D_1 \\ \mathbf{y} \\ P_n - \rho_n - D_n \end{bmatrix} = \begin{bmatrix} \frac{x_0 - x^1}{\rho_0} & \frac{y_0 - y^1}{\rho_0} & \frac{z_0 - z^1}{\rho_0} & 1 \\ \vdots & \mathbf{G} & \vdots & \vdots \\ \frac{x_0 - x^n}{\rho_0} & \frac{y_0 - y^n}{\rho_0} & \frac{z_0 - z^n}{\rho_0} & 1 \end{bmatrix} \begin{bmatrix} dx \\ dy \\ dz \\ c \cdot \delta t \end{bmatrix}$$

2.1.1 Solving GNSS Equations

Then GNSS Equation can be simplified as:

$$\mathbf{y} = \mathbf{G}\mathbf{x} + \boldsymbol{\varepsilon}, \quad \mathbf{R} = E[\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}^T]$$

where \mathbf{y} is the OMC(observation minus correction), \mathbf{G} is the design matrix, \mathbf{x} is the estimated parameter, $\boldsymbol{\varepsilon}$ is observation noise, \mathbf{R} is observation covariance matrix.

2.1.1 Solving GNSS Equations: Least Square

Least square is to best-fit the condition of:

$$\min[\mathbf{V}^T \mathbf{W} \mathbf{V}] = \min \left[\sum_{i=1}^n (v_i w_i v_i)^2 \right] \quad \text{where } \mathbf{V} = \mathbf{G} \hat{\mathbf{x}} - \mathbf{y}$$

Following this condition, the Normal Equation of least square is:

$$(\mathbf{G}^T \mathbf{W} \mathbf{G}) \hat{\mathbf{x}} = \mathbf{G}^T \mathbf{W} \mathbf{y} \quad \text{or} \quad (\mathbf{G}^T \mathbf{R}^{-1} \mathbf{G}) \hat{\mathbf{x}} = \mathbf{G}^T \mathbf{R}^{-1} \mathbf{y}$$

So the least square solution is:

$$\hat{\mathbf{x}} = (\mathbf{G}^T \mathbf{R}^{-1} \mathbf{G})^{-1} \mathbf{G}^T \mathbf{R}^{-1} \mathbf{y}$$
$$\mathbf{P} = (\mathbf{G}^T \mathbf{R}^{-1} \mathbf{G})^{-1}$$

\mathbf{P} is the covariance matrix of the estimated parameter

2.1.1 Solving GNSS Equations: Kalman Filter

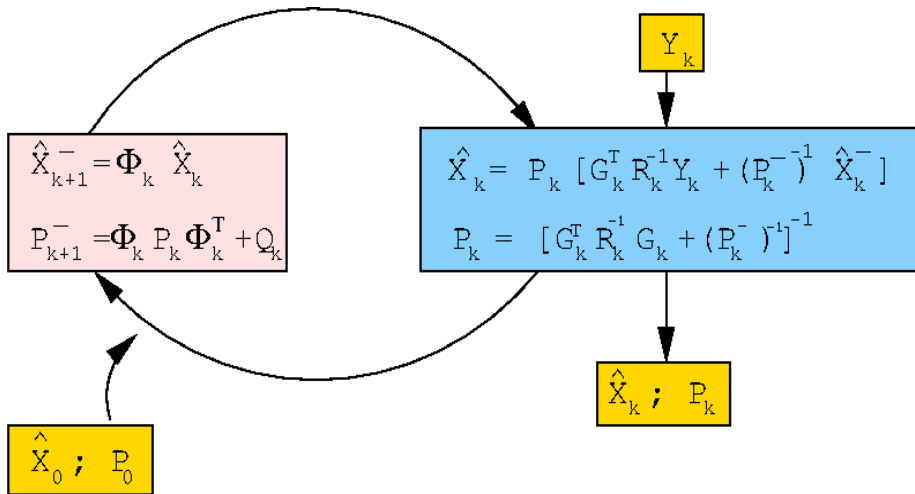
Predict:

$$\hat{\mathbf{x}}_k^- = \Phi_{k-1} \hat{\mathbf{x}}_{k-1}^-$$
$$\mathbf{P}_{\hat{\mathbf{x}}_k}^- = \Phi_{k-1} \mathbf{P}_{\hat{\mathbf{x}}_{k-1}}^- \Phi_{k-1}^T + \mathbf{Q}_{k-1}$$

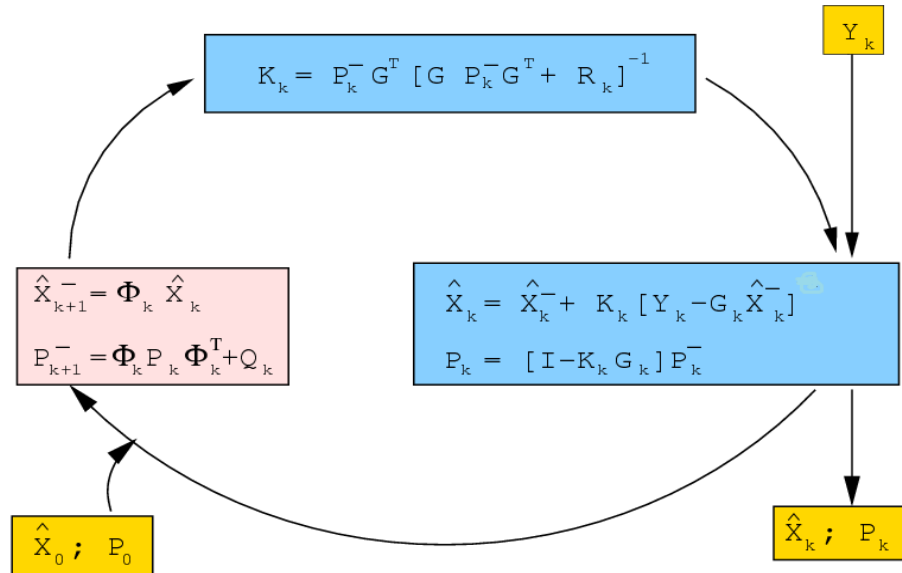
Estimate:

$$\mathbf{K}_k = \mathbf{P}_{\hat{\mathbf{x}}_k}^- \mathbf{G}_k^T \left[\mathbf{G}_k \mathbf{P}_{\hat{\mathbf{x}}_k}^- \mathbf{G}_k^T + \mathbf{R}_k \right]^{-1}$$
$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}_k^- + \mathbf{K}_k \left[\mathbf{y}_k - \mathbf{G}_k \hat{\mathbf{x}}_k^- \right]$$
$$\mathbf{P}_{\hat{\mathbf{x}}_k} = \left[\mathbf{I} - \mathbf{K}_k \mathbf{G}_k \right] \mathbf{P}_{\hat{\mathbf{x}}_k}^-$$

2.1.1 Solving GNSS Equations: LS vs. KF



Least Square



Kalman Filter

2.1.1 DOP

Covariance matrix of SPP is:

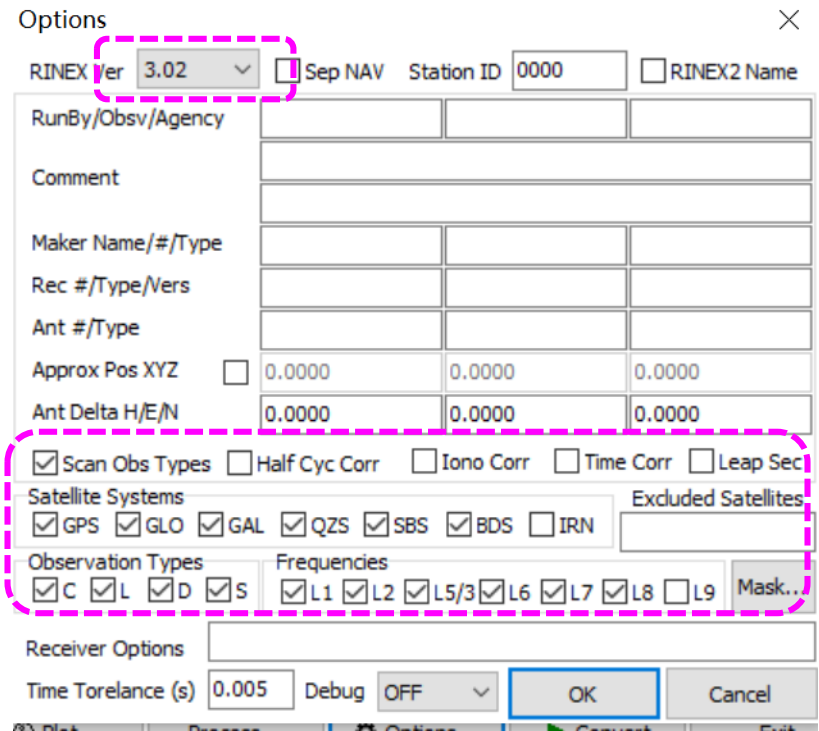
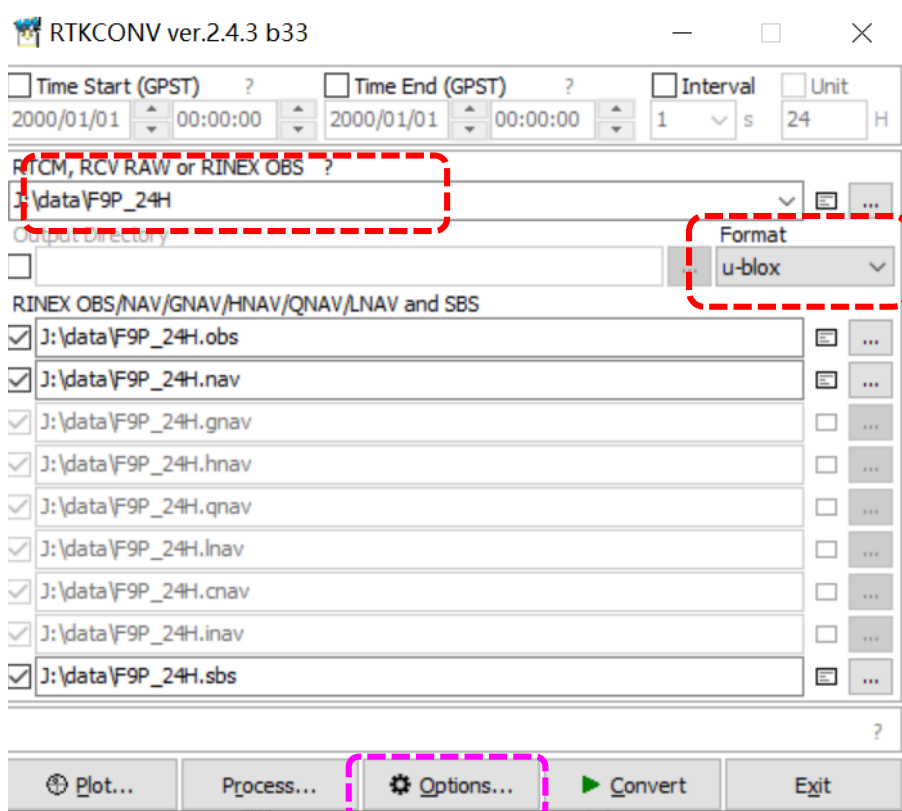
$$\mathbf{P} = (\mathbf{G}^T \mathbf{R}^{-1} \mathbf{G})^{-1}$$

$$\mathbf{P} = \begin{bmatrix} p_{11} & \cdots & p_{14} \\ \vdots & \ddots & \vdots \\ p_{41} & \cdots & p_{44} \end{bmatrix}$$

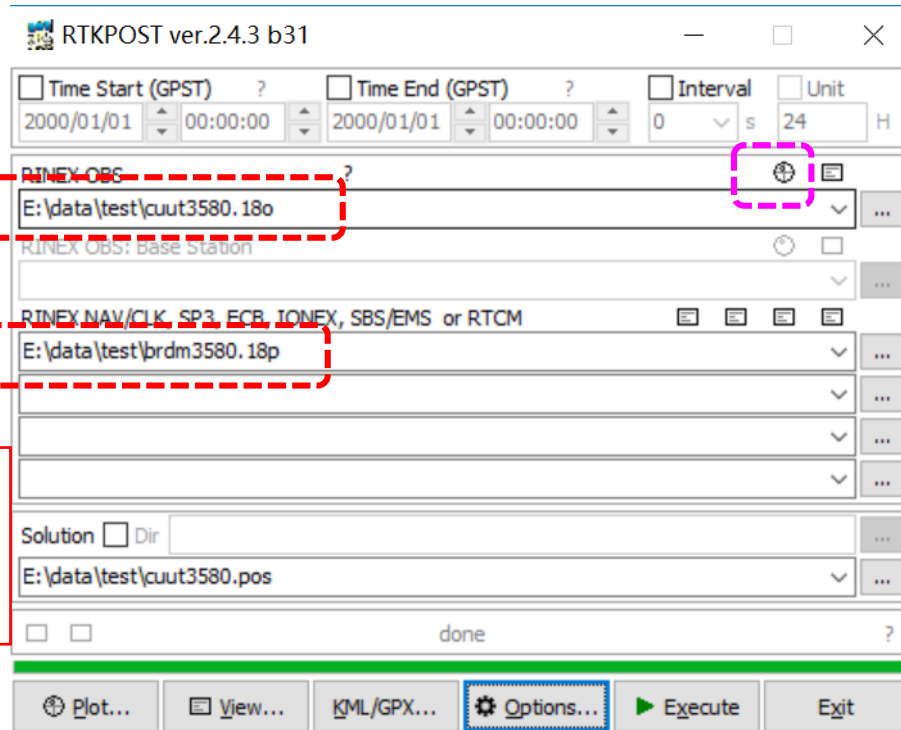
Define:

$$\begin{aligned} PDOP &= \sqrt{p_{11} + p_{22} + p_{33}} \\ HDOP &= \sqrt{p_{11} + p_{22}} \\ VDOP &= \sqrt{p_{33}} \\ GDOP &= \sqrt{p_{11} + p_{22} + p_{33} + p_{44}} \end{aligned}$$

2.1.2 Convert data to RINEX using RTKCONV

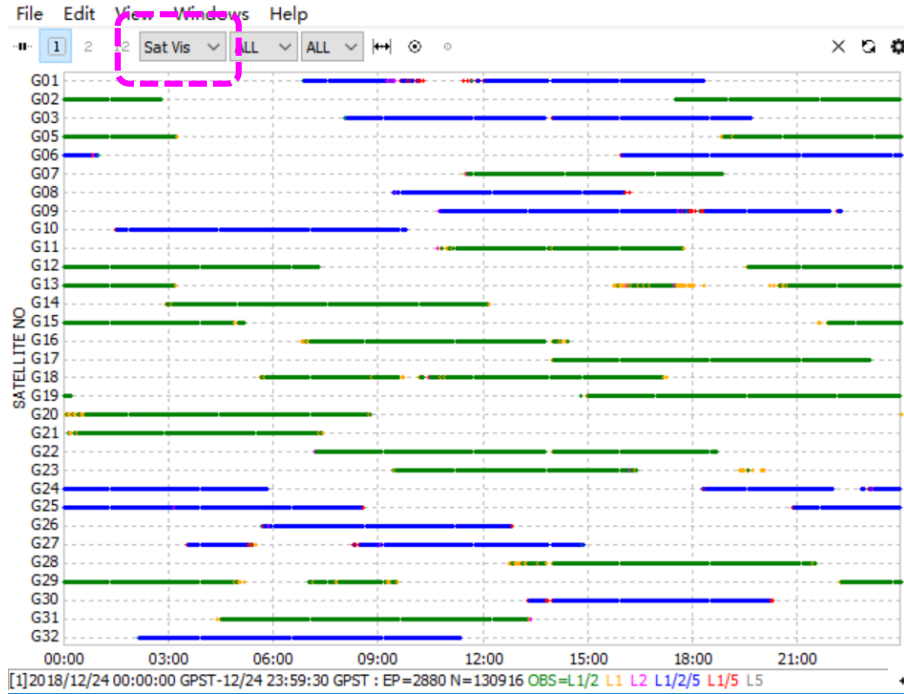


2.1.2 Data quality check using RTKLIB

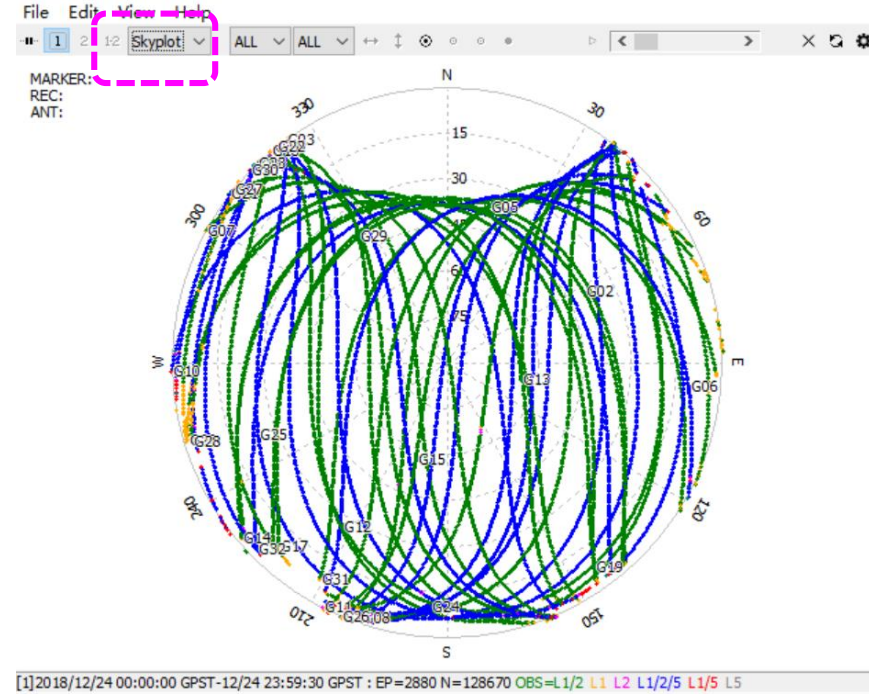


You can input all the other types of navigation files (*.p; *.nav; *.n;*.c;*.g)

2.1.2 Data quality check using RTKLIB

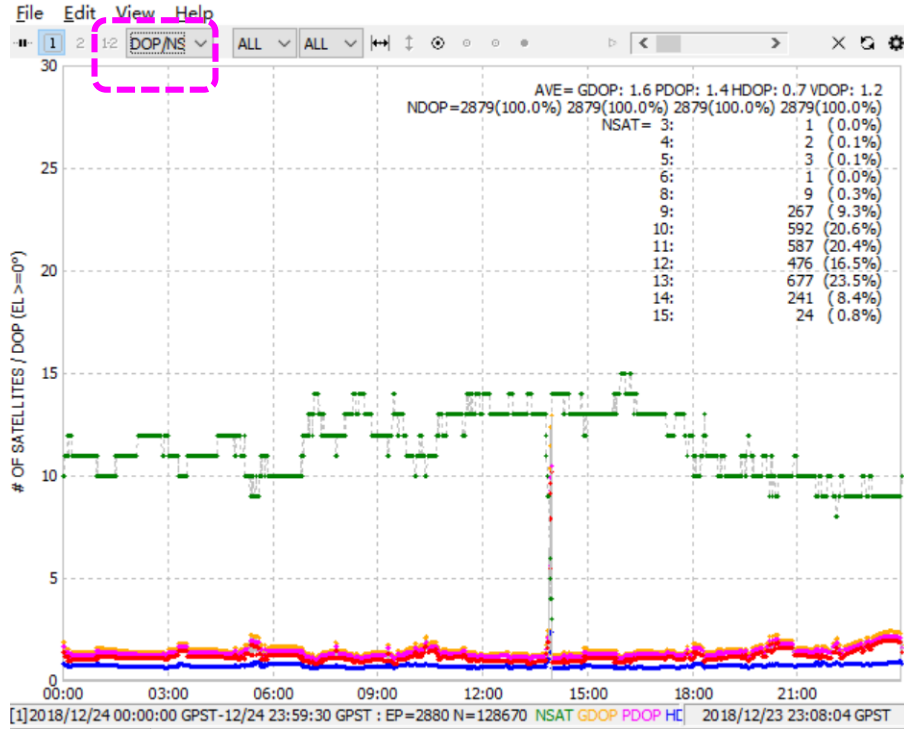


Sat Visibility

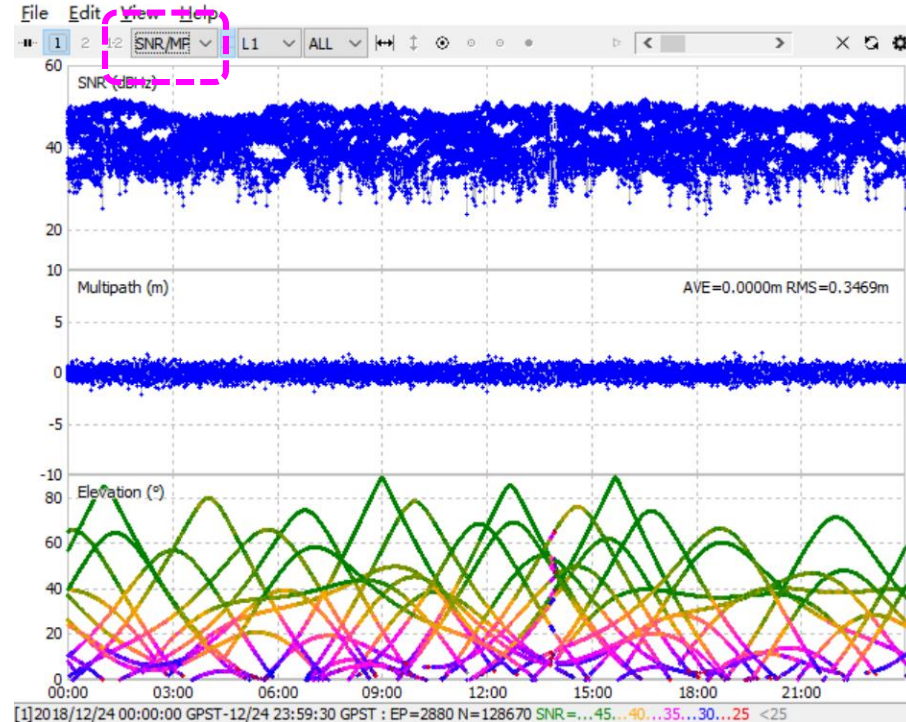


SkyPlot

2.1.2 Data quality check using RTKLIB

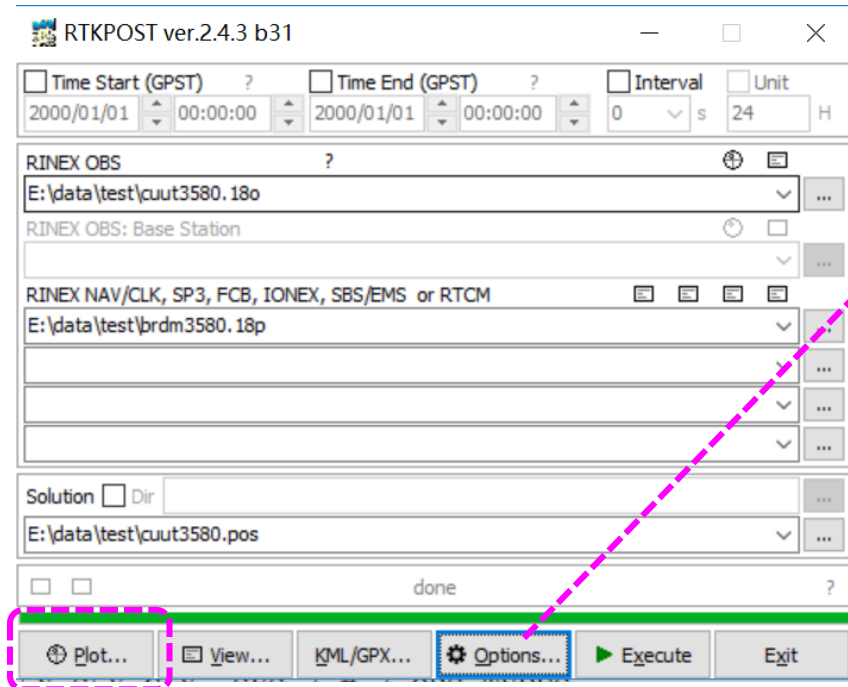


DOP/SatNum

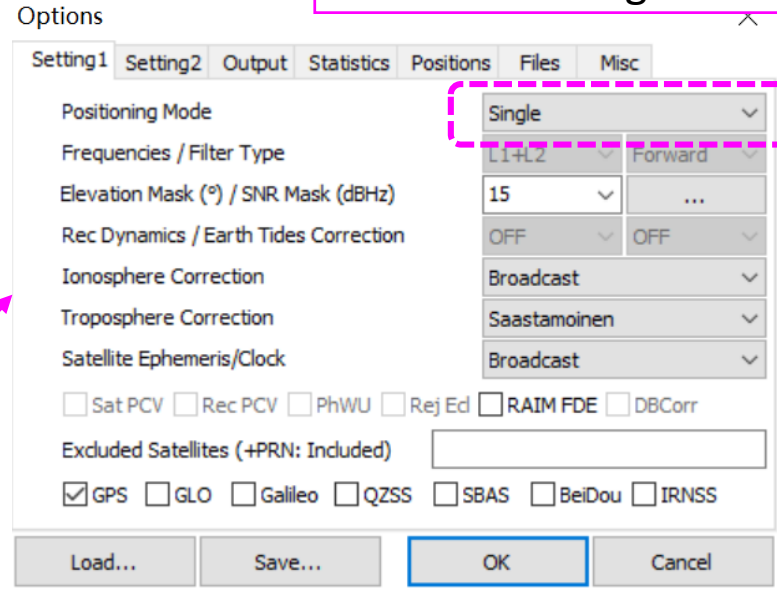


SNR/MP/Ele

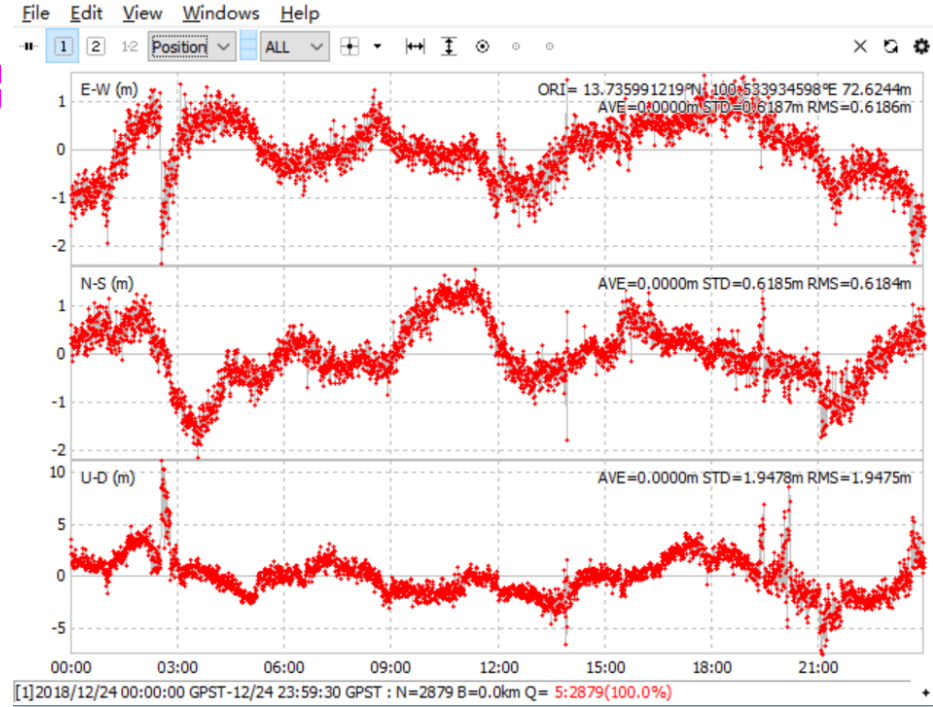
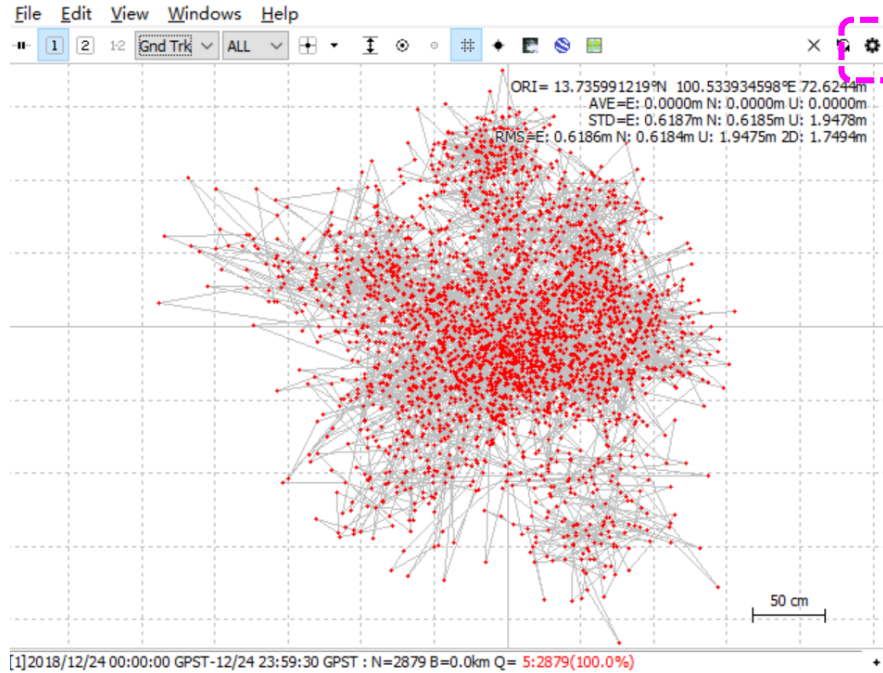
2.1.3 Example of SPP using RTKLIB



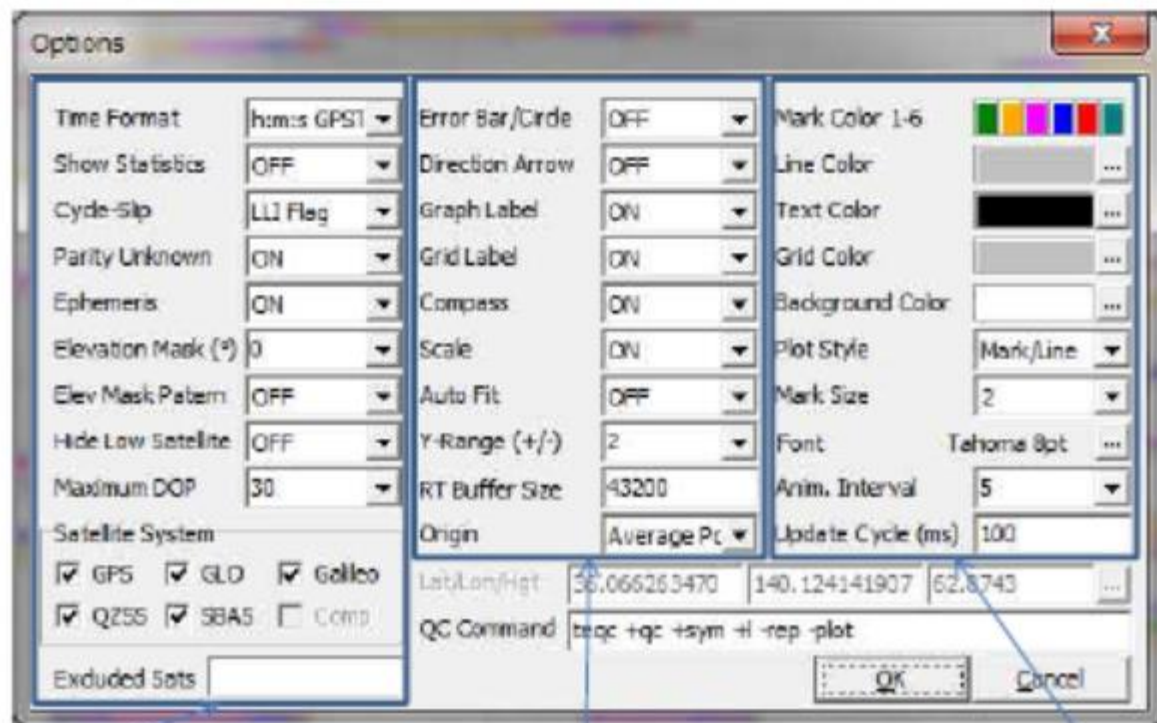
Default setting of RTKLIB



2.1.3 RTK PLOT of SPP



2.1.3 RTKPLOT OPTIONS



OBS Data Options

Solution Data Options

Common Options

2.1.3 Example of SPP using RTKLIB: GPS+Galileo

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode: Single

Frequencies / Filter Type: L1+L2 Forward

Elevation Mask (°) / SNR Mask (dBHz): 15

Rec Dynamics / Earth Tides Correction: OFF OFF

Ionosphere Correction: Broadcast

Troposphere Correction: Saastamoinen

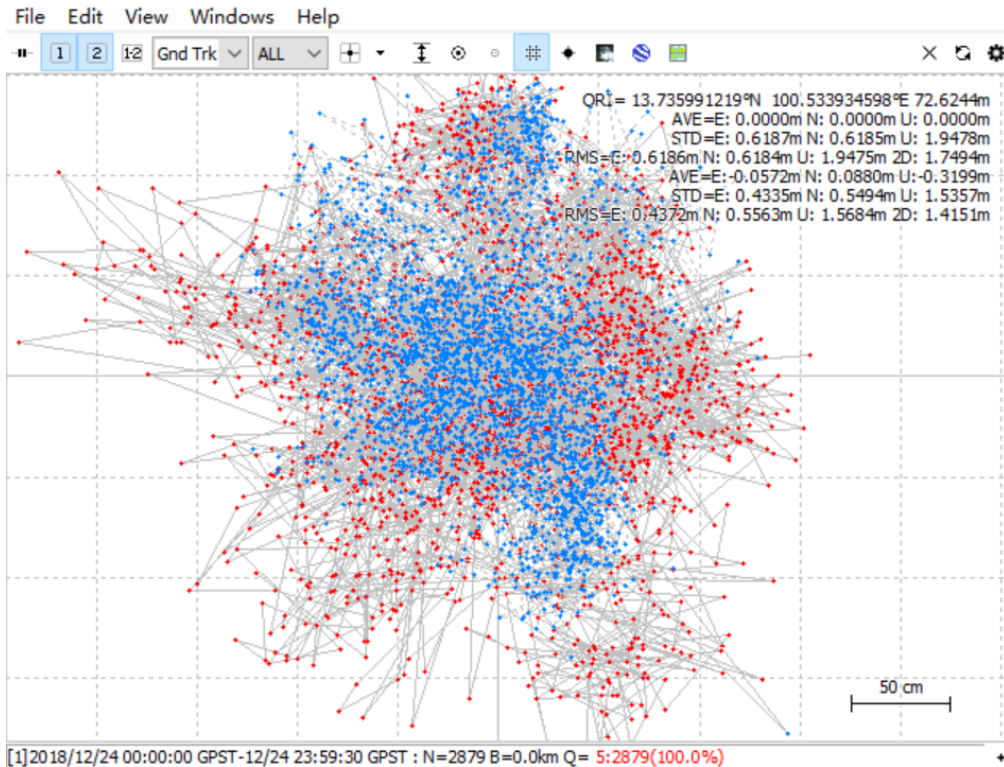
Satellite Ephemeris/Clock: Broadcast

Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr

Excluded Satellites (+PRN: Included):

GPS GLO Galileo QZSS SBAS BeiDou IRNSS

Load... Save... OK Cancel



Contents

1. Introduction of RTKLIB	SPP
2. GNSS Positioning Theory & Example of using RTKLIB	DGNSS
	PPP
	RTK

2.2.1 DGNSS(Differential GNSS)

For one common satellite observed by base station and rover station at frequency f :

$$P_b = \rho_b + c \cdot \delta t_b - c \cdot \delta t^s - rel_r + T - \frac{I}{f^2} + \varepsilon_b$$

$$P_r = \rho_r + c \cdot \delta t_r - c \cdot \delta t^s - rel_r + T - \frac{I}{f^2} + \varepsilon_r$$

After station differencing:

$$P_{br} = \rho_r - \rho_b + c \cdot \delta t_{br} + \varepsilon_{br}$$

By Least Square or Kalman Filter, we can get the **coordinate difference** of these two stations. If the coordinate of base station is known, then the position of rover station can be get:

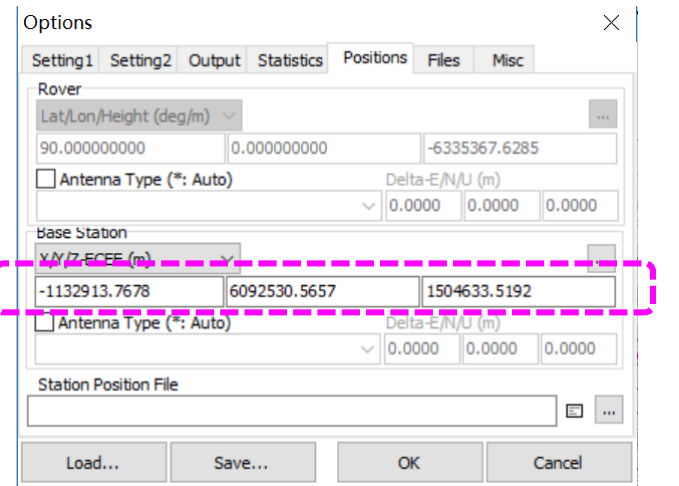
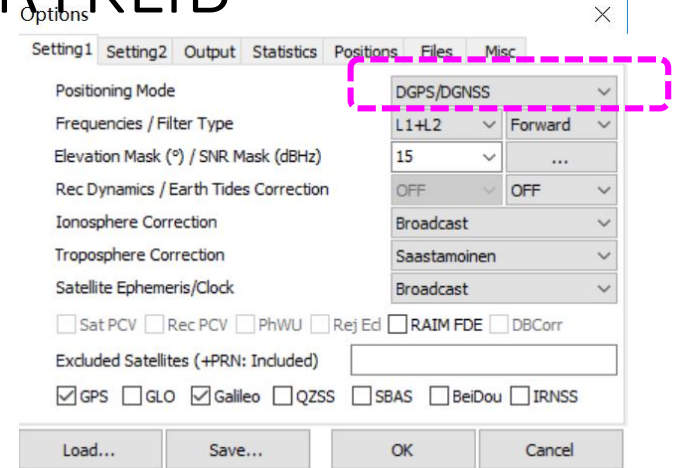
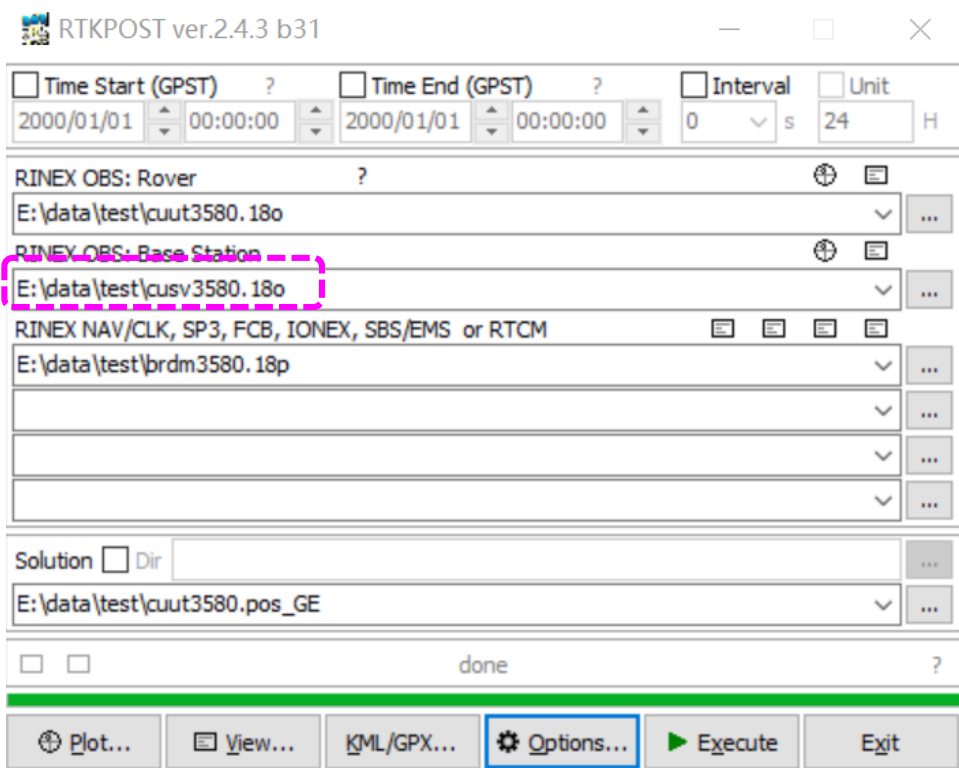
$$Pos_r = Pos_b + dPos_{br}$$

2.2.1 Benefit of DGNSS

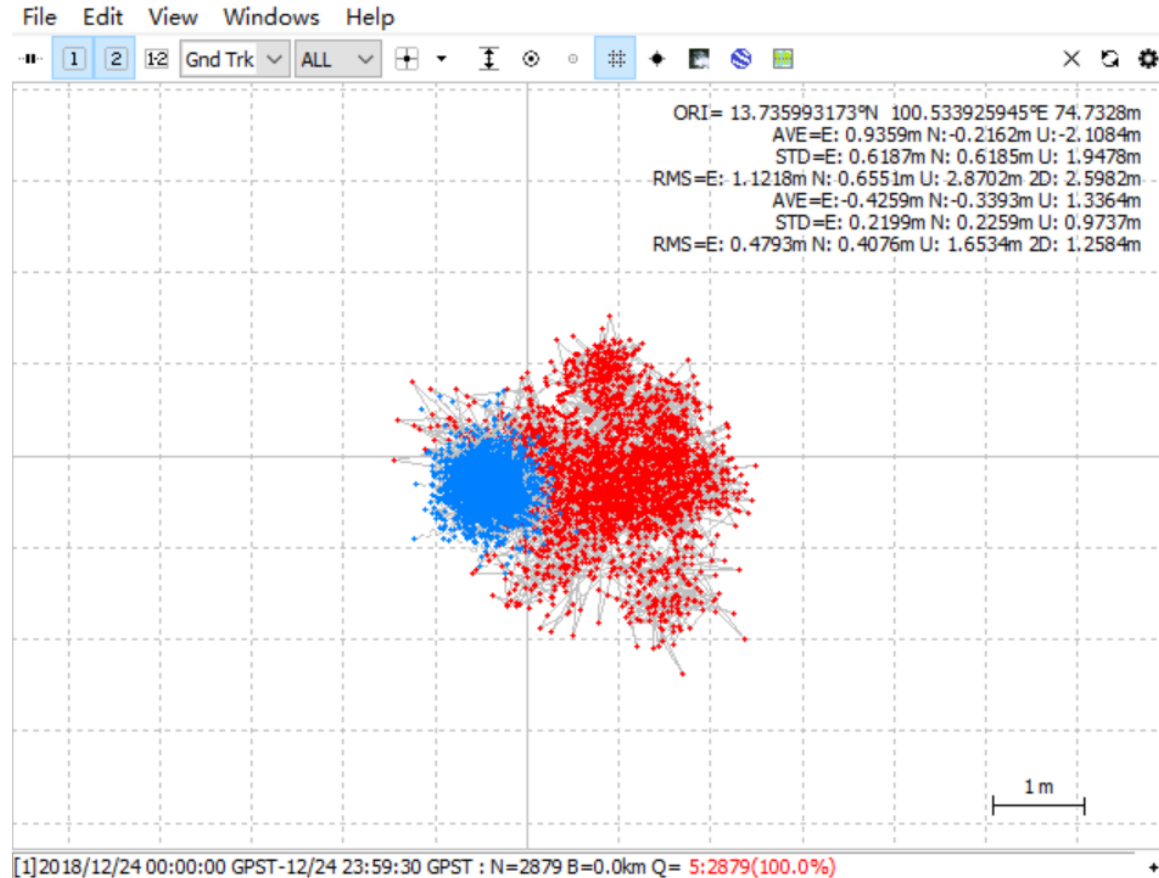
For short baseline, DGNSS would remove errors from **satellite** and **atmosphere**, including satellite orbit, clock, relativity, ionosphere, troposphere error.

However, DGNSS can't remove errors from receivers, will enlarge pseudo-range **observation noise** by $\sqrt{2}$ times.

2.2.2 Example of DGNSS using RTKLIB



2.2.2 Example of DGNSS using RTKLIB



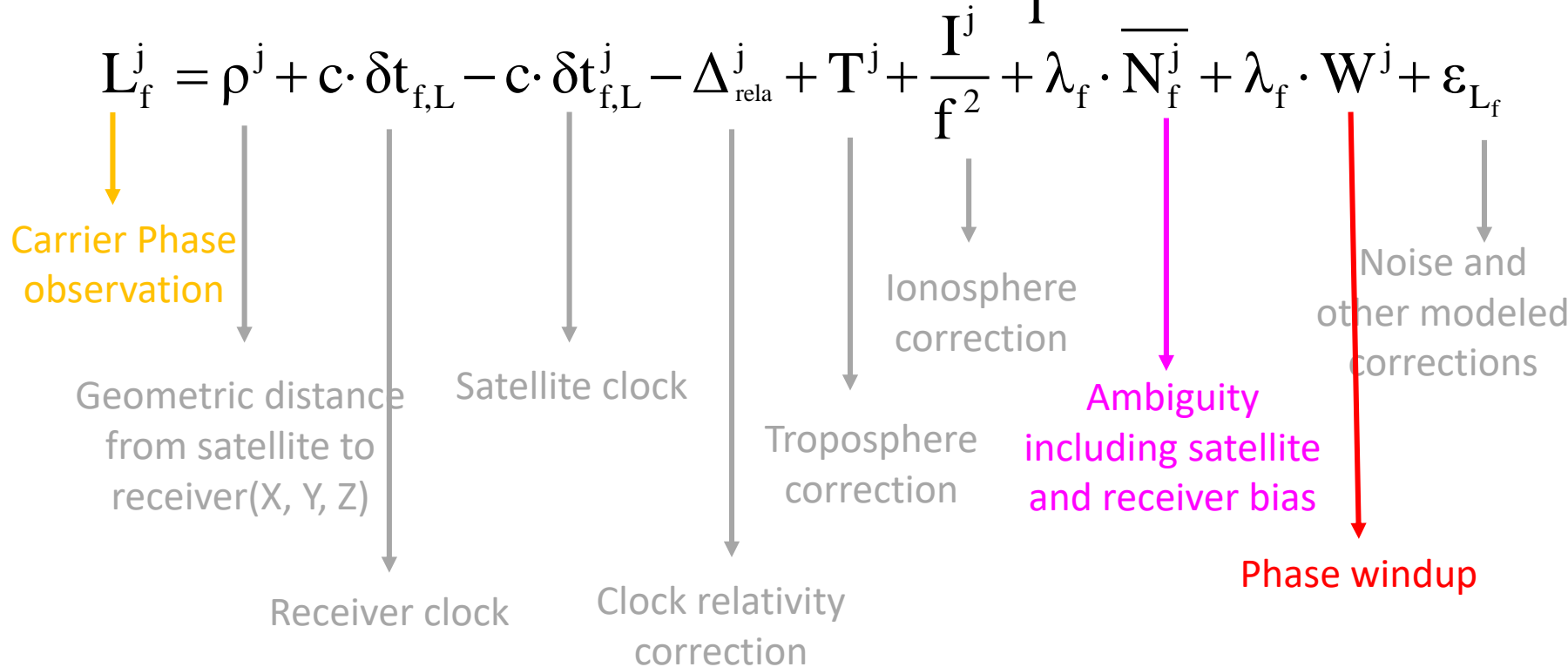
STD improve from [0.62, 0.62, 1.95]m to [0.22, 0.23, 0.97]m

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- 1. Introduction of RTKLIB
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2.3.1 GNSS Carrier Phase Observation Equation

$$P_f^j = \rho^j + c \cdot \delta t_f - c \cdot \delta t_f^j - \Delta_{rela}^j + T^j - \frac{I^j}{f^2} + \epsilon_{P_f}$$



2.3.1 PPP(Precise Point Positioning)

Similar as SPP, we can establish PPP model by combining pseudo-range and carrier phase observation:

$$\begin{bmatrix} P_1 - \rho_1 - D_{P1} \\ L_1 - \rho_1 - D_{L1} \\ \vdots \\ P_n - \rho_n - D_{Pn} \\ L_n - \rho_n - D_{Ln} \end{bmatrix} = \begin{bmatrix} \frac{x_0 - x^1}{\rho_0} & \frac{y_0 - y^1}{\rho_0} & \frac{z_0 - z^1}{\rho_0} & 1 & M_{wet}^1 & 0 & \dots & 0 \\ \frac{x_0 - x^1}{\rho_0} & \frac{y_0 - y^1}{\rho_0} & \frac{z_0 - z^1}{\rho_0} & 1 & M_{wet}^1 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{x_0 - x^n}{\rho_0} & \frac{y_0 - y^n}{\rho_0} & \frac{z_0 - z^n}{\rho_0} & 1 & M_{wet}^n & 0 & \dots & 0 \\ \frac{x_0 - x^n}{\rho_0} & \frac{y_0 - y^n}{\rho_0} & \frac{z_0 - z^n}{\rho_0} & 1 & M_{wet}^n & 0 & \dots & 1 \end{bmatrix} \begin{bmatrix} dx \\ dy \\ dz \\ c \cdot \delta t \\ dZTD_w \\ B_1 \\ \vdots \\ B_n \end{bmatrix}$$

Troposphere residual after model correction and carrier phase ambiguity is estimated together with receiver coordinate and receiver clock.

2.3.1 PPP(Precise Point Positioning)

Each errors must be corrected carefully.

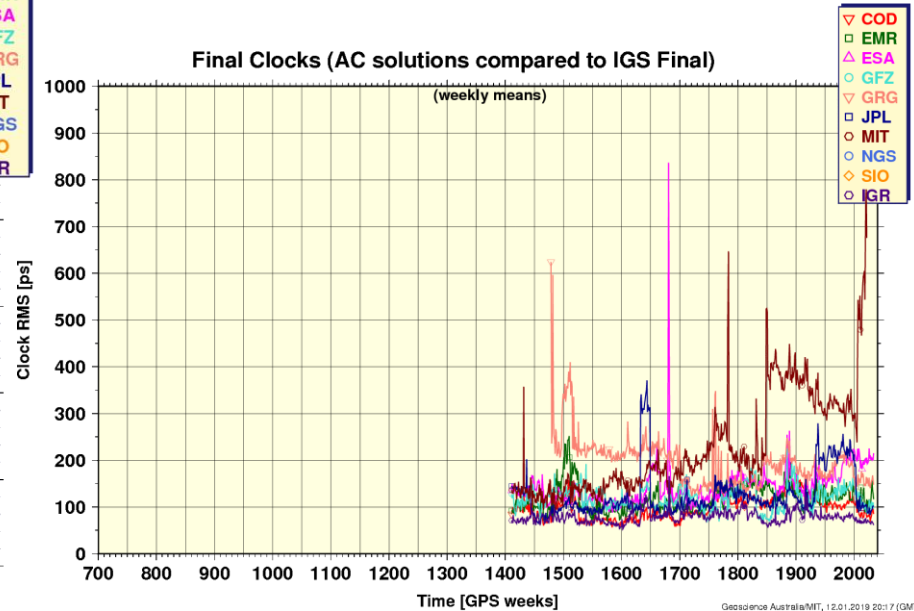
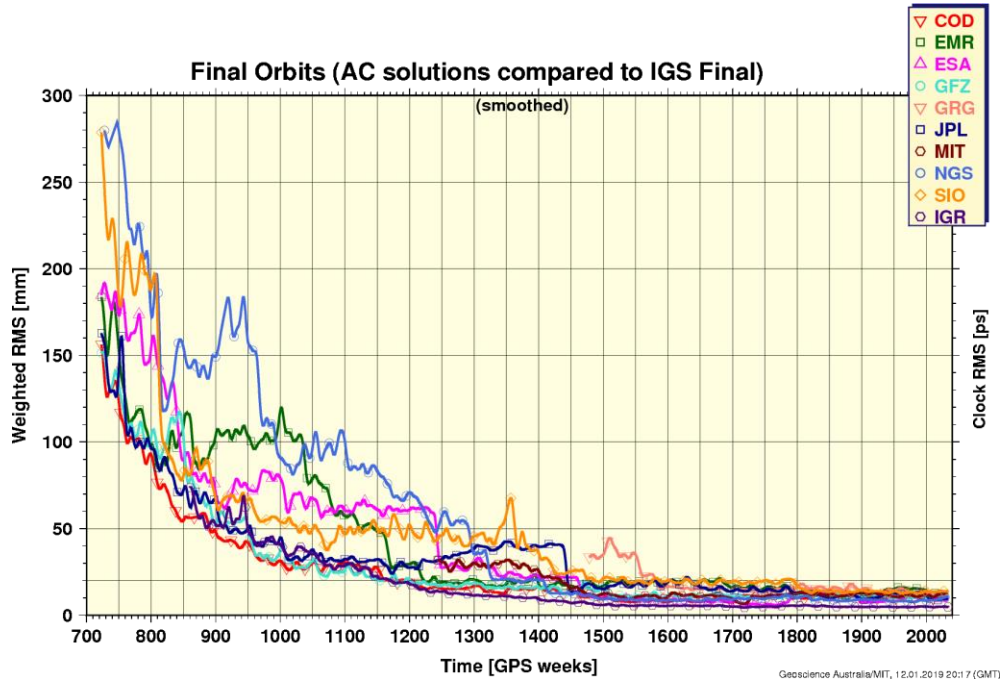
- (1) Satellite clock and coordinate are from IGS final products(.sp3, .clk);
- (2) Satellite and receiver Phase Center Offset(PCO) and Phase Center Variation(PCV) should be corrected by IGS antenna model(.atx);
- (3) Ionosphere error usually removed after Ionosphere-Free combination, or estimated as a random walk parameter;
- (4) Troposphere residual after model correction and carrier phase ambiguity should be estimated together with coordinate and receiver clock.
- (5) Earth solid tide and ocean tide error must be corrected.

2.3.1 PPP: IGS products

Type		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~100 cm	real time	--	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 - 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 - 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 - 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min






<http://www.igs.org/products>

2.3.1 PPP: IGS products



<http://acc.igs.org/>

2.3.1 PPP: IGS products

-  igs14_2035.atx
-  igs18P2033.erp
-  igs20331.clk
-  igs20331.sp3
-  P1C11812.DCB

http://kb.igs.org/hc/en-us/article_attachments/203088448/UsingIGSProductsVer21_cor.pdf

<https://kb.igs.org/hc/en-us/articles/201096516-IGS-Formats>

A GUIDE TO USING INTERNATIONAL GNSS SERVICE (IGS) PRODUCTS

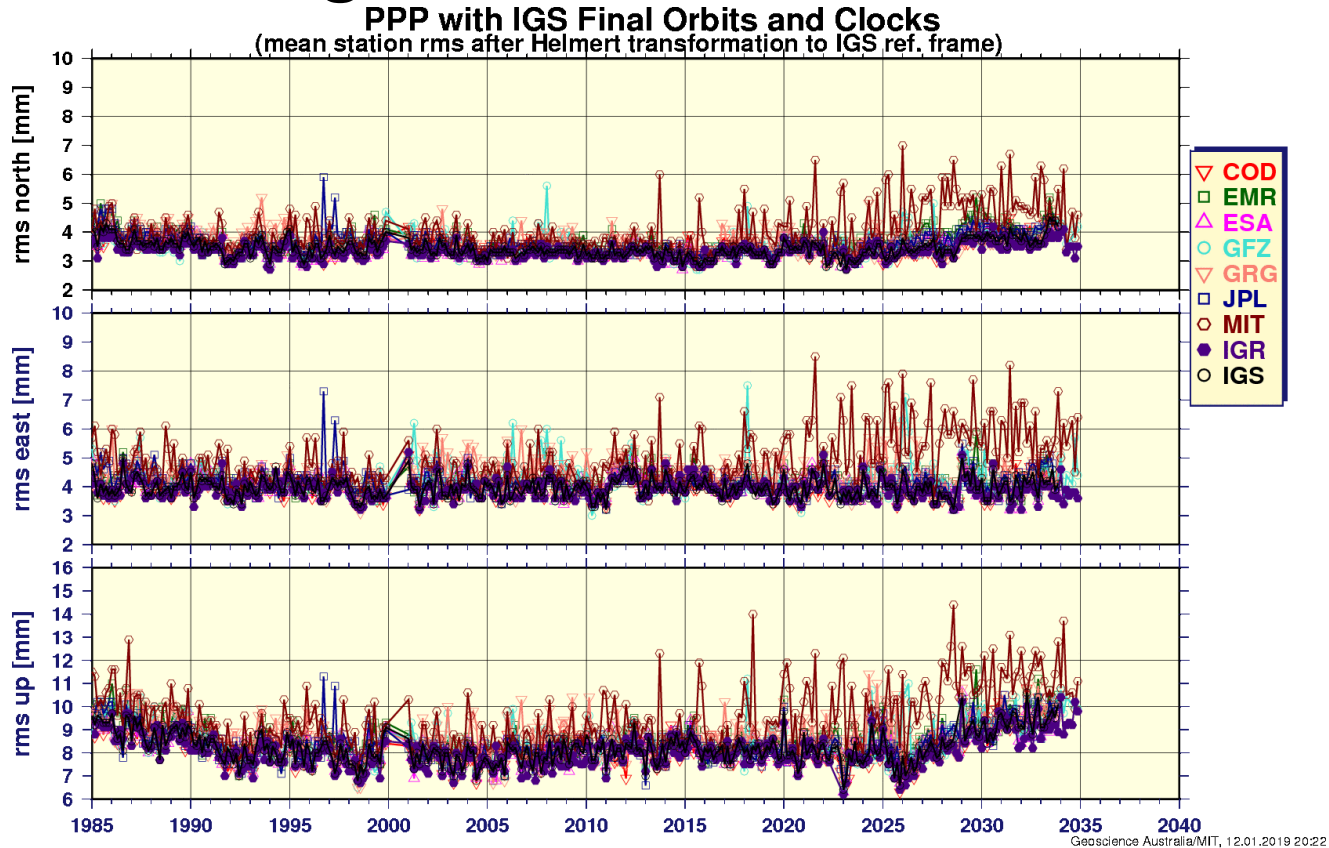
Jan Kouba
Geodetic Survey Division
Natural Resources Canada
615 Booth Street, Ottawa, Ontario K1A 0E9
Email: kouba@geod.nrcan.gc.ca

Updated September 2015

Abstract

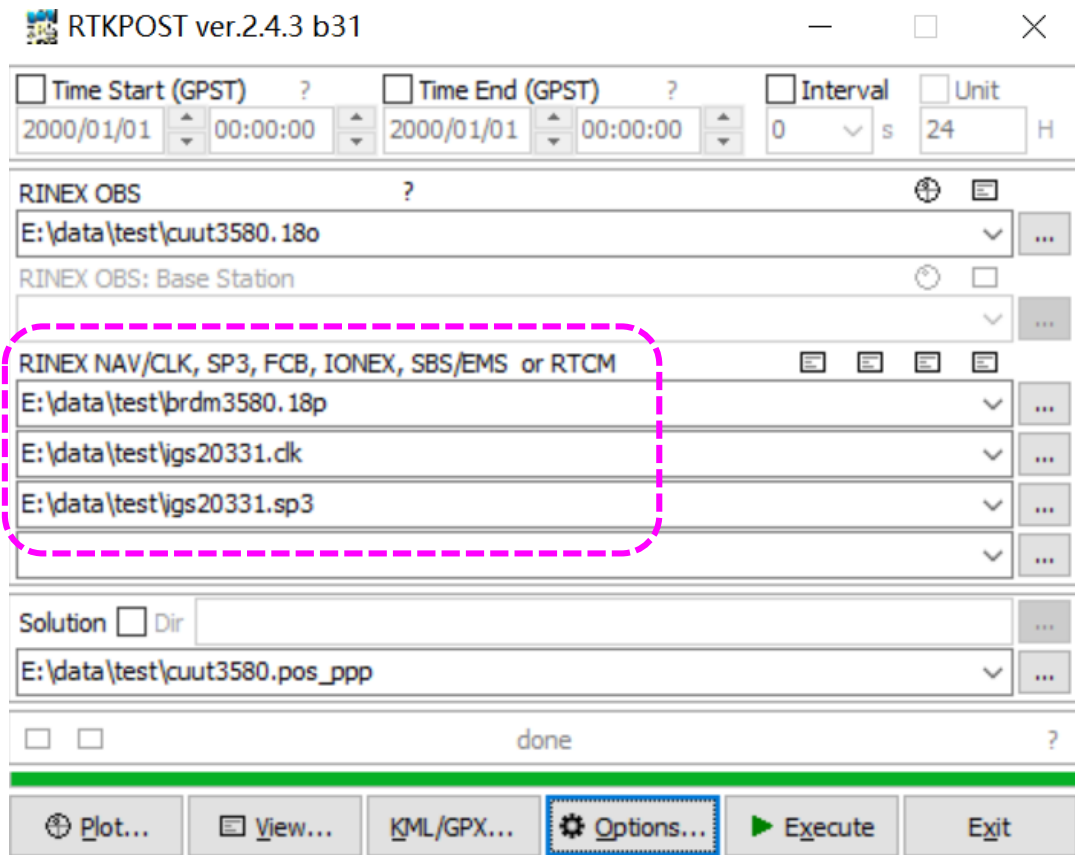
Since 1994, the International GNSS Service (IGS) has provided precise GPS orbit products to the scientific community with increased precision and timeliness. Many national geodetic agencies and GNSS (Global Navigation Satellite System) users interested in geodetic positioning have adopted the IGS precise orbits to achieve centimeter level accuracy and ensure long-term reference frame stability. Relative positioning approaches that require the combination of observations from a minimum of two GNSS receivers, with at least one occupying a station with known coordinates are commonly used. The user position can then be estimated relative to one or multiple reference stations, using differenced carrier phase observations and a baseline or network estimation approach. Differencing observations is a popular way to eliminate common GNSS satellite and receiver clock errors. Baseline or network processing is effective in connecting the user position to the coordinates of the reference stations while the precise orbit virtually eliminates the errors introduced by the GNSS space segment. One drawback is the practical constraint imposed by the requirement that simultaneous observations be made at reference stations. An alternative post-processing approach uses un-differenced dual-frequency pseudorange and carrier phase observations along with IGS precise orbit products, for stand-alone precise geodetic point positioning (static or kinematic) with centimeter precision. This is possible if one takes advantage of the satellite clock estimates available with the satellite coordinates in the IGS precise orbit/clock products and models systematic effects that cause centimeter variations in the satellite to user range. Furthermore, station tropospheric zenith path delays with mm precision and GNSS receiver clock estimates precise to 0.03 nanosecond are also obtained. To achieve the highest accuracy and consistency, users must also implement the GNSS-specific conventions and models adopted by the IGS. This paper describes both post-processing approaches, summarizes the adjustment procedure and specifies the Earth and space based models and conventions that must be implemented to achieve mm-cm level positioning, tropospheric zenith path delay and clock solutions.

2.3.1 PPP using Final Orbits and Clocks



<http://acc.igs.org/>

2.3.2 Example of PPP using RTKLIB



2.3.2 Example of Static PPP using RTKLIB

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode PPP Static

Frequencies / Filter Type L1+L2 Forward

Elevation Mask (°) / SNR Mask (dBHz) 15

Rec Dynamics / Earth Tides Correction OFF Solid/OTL

Ionosphere Correction Iono-Free LC

Troposphere Correction Estimate ZTD

Satellite Ephemeris/Clock Precise

Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr

Excluded Satellites (+PRN: Included)

GPS GLO Galileo QZSS SBAS BeiDou IRNSS

Load... Save... OK Cancel

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Satellite/Receiver Antenna PCV File ANTEX/NGS PCV

E:\data\test\jgs14_2035.atx

E:\data\test\jgs14_2035.atx

Geoid Data File

DCB Data File

E:\data\test\IP1C11812.DCB

EOP Data File

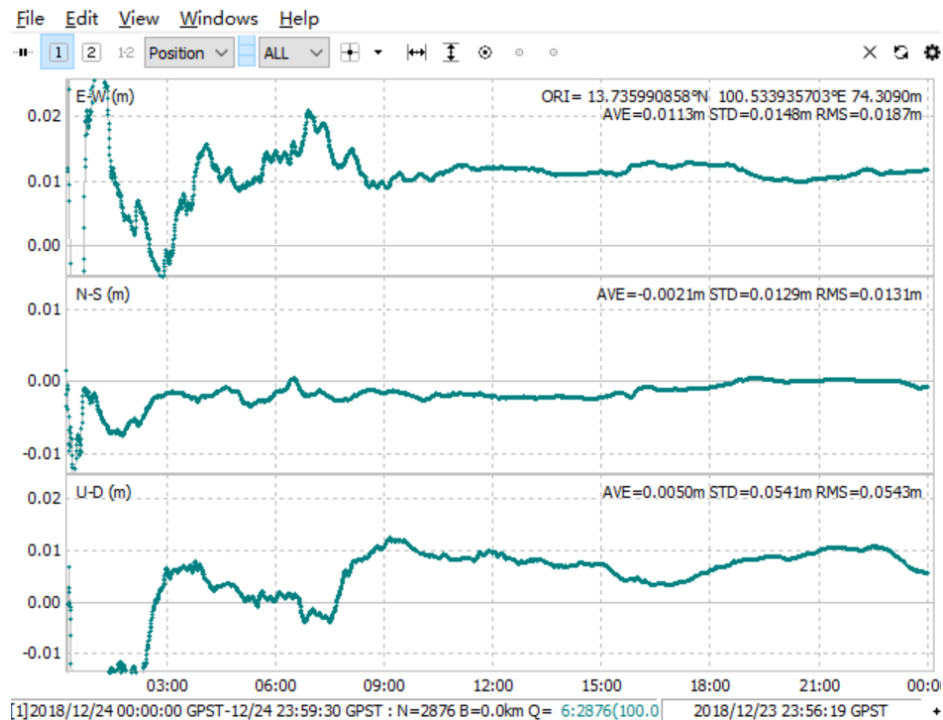
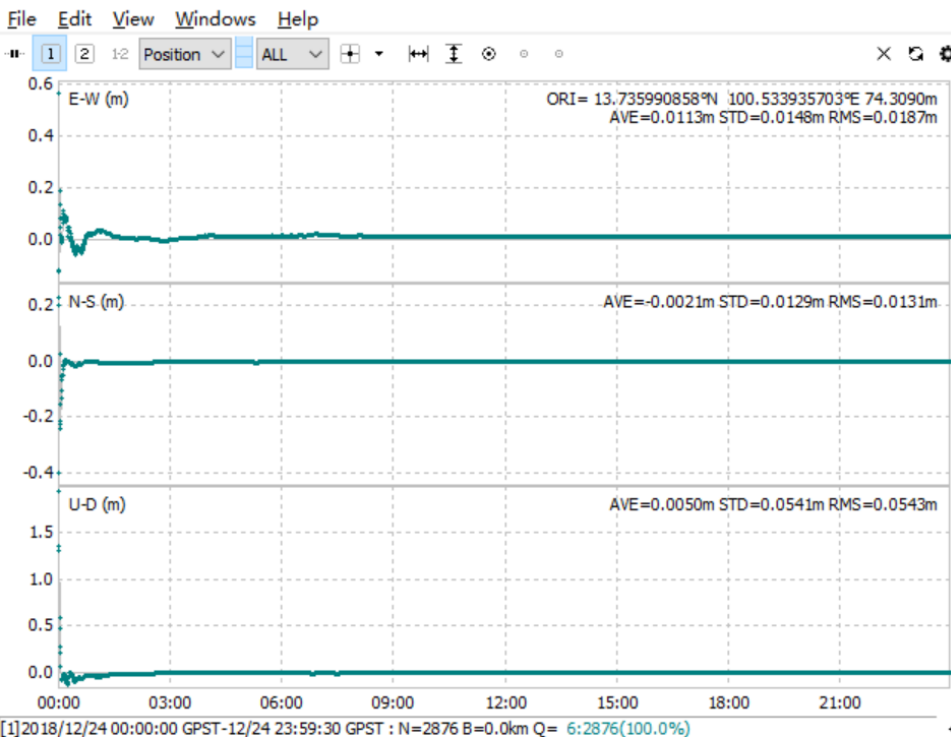
E:\data\test\jgs18P2033.erp

OTL BLQ File

Ionosphere Data File

Load... Save... OK Cancel

2.3.2 Example of Static PPP using RTKLIB



2.3.2 Example of Kinematic PPP using RTKLIB

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode: PPP Kinematic

Frequencies / Filter Type: L1+L2 Forward

Elevation Mask (°) / SNR Mask (dBHz): 15 ...

Rec Dynamics / Earth Tides Correction: OFF Solid/OTL

Ionosphere Correction: Iono-Free LC

Troposphere Correction: Estimate ZTD+Grad

Satellite Ephemeris/Clock: Precise

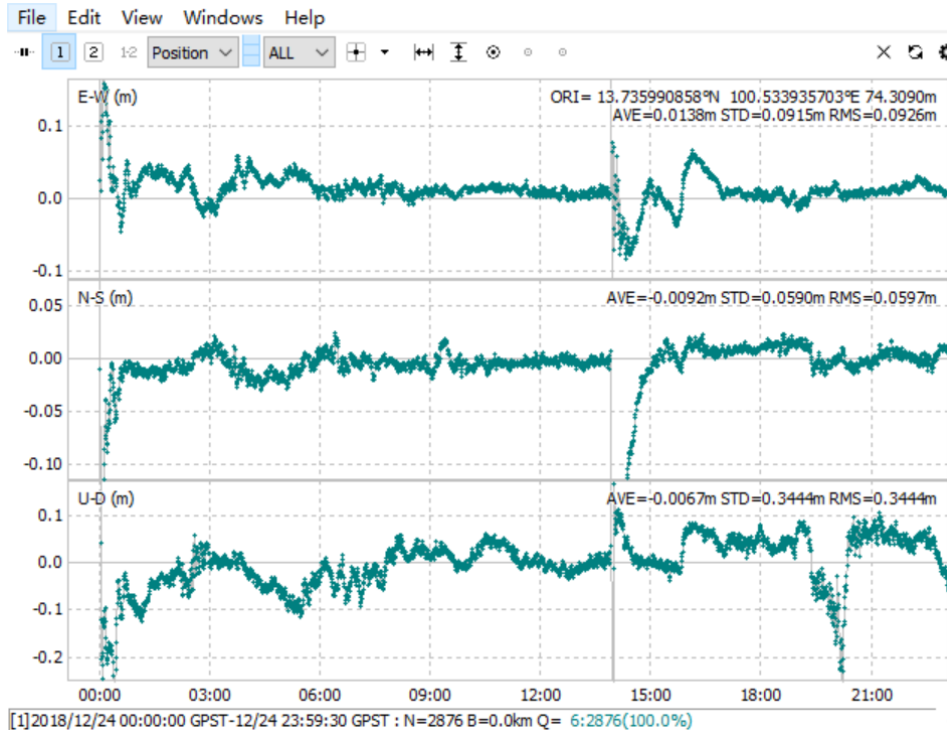
Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr

Excluded Satellites (+PRN: Included):

GPS GLO Galileo QZSS SBAS BeiDou IRNSS

Load... Save... OK Cancel

×



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- 1. Introduction of RTKLIB
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2.4.1 RTK(Real Time Kinematic)

For one common satellite observed by base station and rover station at frequency f :

$$L_b = \rho_b + c \cdot \delta t_b - c \cdot \delta t^s - rel_r + T + \frac{I}{f^2} + \lambda_f \cdot N_b + \lambda_f \cdot B_b - \lambda_f \cdot B^s + \lambda_f \cdot W + \varepsilon_b$$

$$L_r = \rho_r + c \cdot \delta t_r - c \cdot \delta t^s - rel_r + T + \frac{I}{f^2} + \lambda_f \cdot N_r + \lambda_f \cdot B_r - \lambda_f \cdot B^s + \lambda_f \cdot W + \varepsilon_r$$

After station differencing:

$$L_{br} = \rho_r - \rho_b + c \cdot \delta t_{br} + \lambda_f \cdot N_{br} + \lambda_f \cdot B_{br} + \varepsilon_{br}$$

After satellite differencing:

$$L_{br}^{ij} = \rho_r^{ij} - \rho_b^{ij} + \lambda_f \cdot N_{br}^{ij} + \varepsilon_{br}^{ij}$$

2.4.1 Integer Least Square(ILS)

By Least Square or Kalman Filter, we can get the **float solution** of coordinate difference and float ambiguity.

$$\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = \begin{bmatrix} Q_{\hat{a}\hat{a}} & Q_{\hat{a}\hat{b}} \\ Q_{\hat{b}\hat{a}} & Q_{\hat{b}\hat{b}} \end{bmatrix}$$

The float solution of ambiguity can be fixed to integer using **LAMBDA**(Least-squares AMBiguity Decorrelation Adjustment).

$$\begin{aligned} \hat{\mathbf{z}} &= \mathbf{Z}^T \hat{\mathbf{a}}, \mathbf{Q}_z = \mathbf{Z}^T \mathbf{Q}_a \mathbf{Z} \\ \tilde{\mathbf{z}} &= \arg \min_{\mathbf{z} \in \mathbf{Z}^n} (\hat{\mathbf{z}} - \mathbf{z})^T \mathbf{Q}_z^{-1} (\hat{\mathbf{z}} - \mathbf{z}) \\ \tilde{\mathbf{a}} &= \mathbf{Z}^{-T} \tilde{\mathbf{z}} \end{aligned}$$

2.4.1 Integer Least Square(ILS)

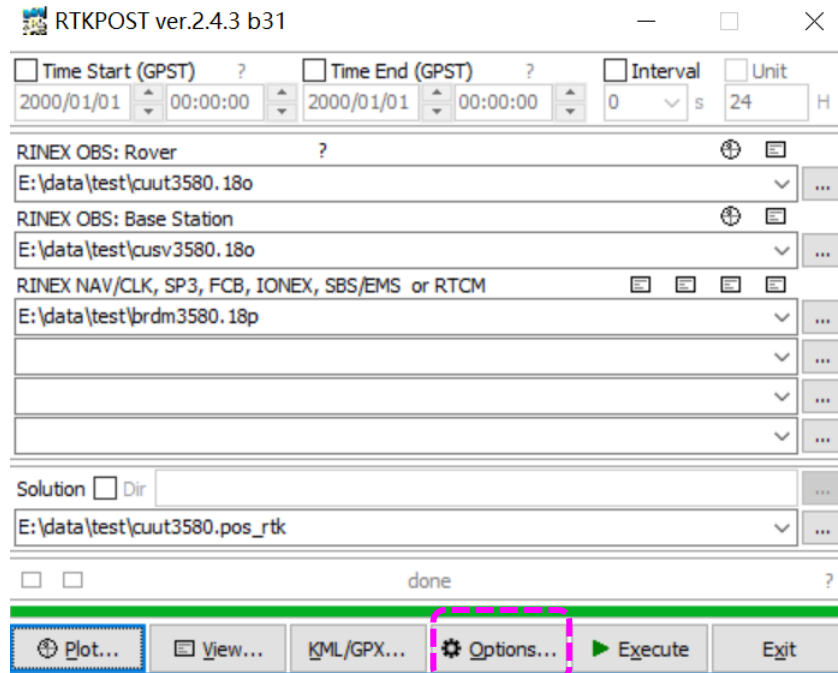
After ambiguity is fixed, the float coordinate solution will updated as:

$$\tilde{\mathbf{b}} = \hat{\mathbf{b}} - Q_{\hat{\mathbf{b}}\hat{\mathbf{a}}} Q_{\hat{\mathbf{a}}\hat{\mathbf{a}}}^{-1} (\hat{\mathbf{a}} - \check{\mathbf{a}})$$

The covariance an also updated as:

$$Q_{\tilde{\mathbf{b}}\tilde{\mathbf{b}}} = Q_{\hat{\mathbf{b}}\hat{\mathbf{b}}} - Q_{\hat{\mathbf{b}}\hat{\mathbf{a}}} Q_{\hat{\mathbf{a}}\hat{\mathbf{a}}}^{-1} Q_{\hat{\mathbf{a}}\hat{\mathbf{b}}}$$

2.4.2 Example of RTK using RTKLIB



2.4.2 Example of RTK using RTKLIB

The image displays four screenshots of the RTKLIB software configuration interface, illustrating the setup for Real Time Kinematic (RTK) using RTKLIB. The windows are arranged in a 2x2 grid, with pink dashed boxes highlighting specific configuration elements.

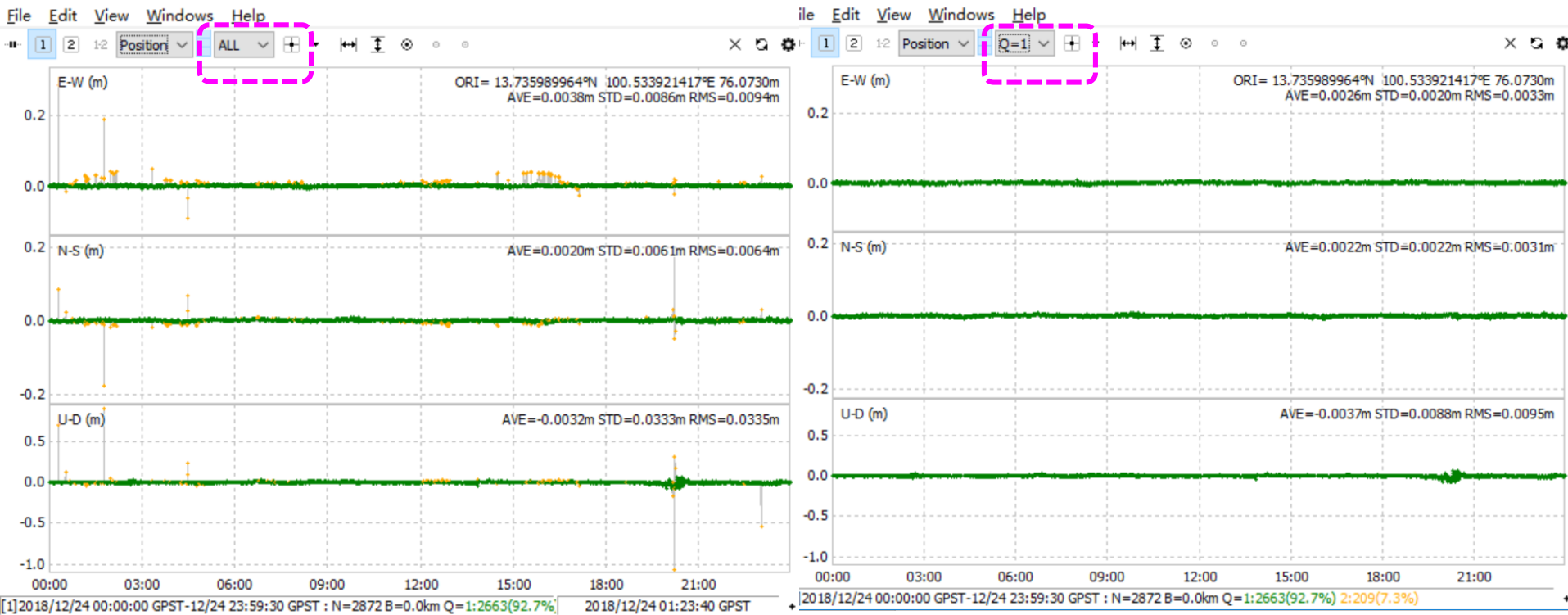
Top-Left Window (Options): Shows the 'Positioning Mode' set to 'Kinematic' (highlighted with a pink dashed box). Other settings include 'Frequencies / Filter Type' (L1+L2), 'Elevation Mask' (15), and 'Rec Dynamics / Earth Tides Correction' (OFF).

Top-Right Window (Options): Shows the 'Integer Ambiguity Res (GPS/GLO/BDS)' set to 'Continue' (highlighted with a pink dashed box). Other settings include 'Min Ratio to Fix Ambiguity' (3), 'Min Confidence / Max FCB to Fix Amb' (0.9999 / 0.25), and 'Min Lock / Elevation' (0 / 0).

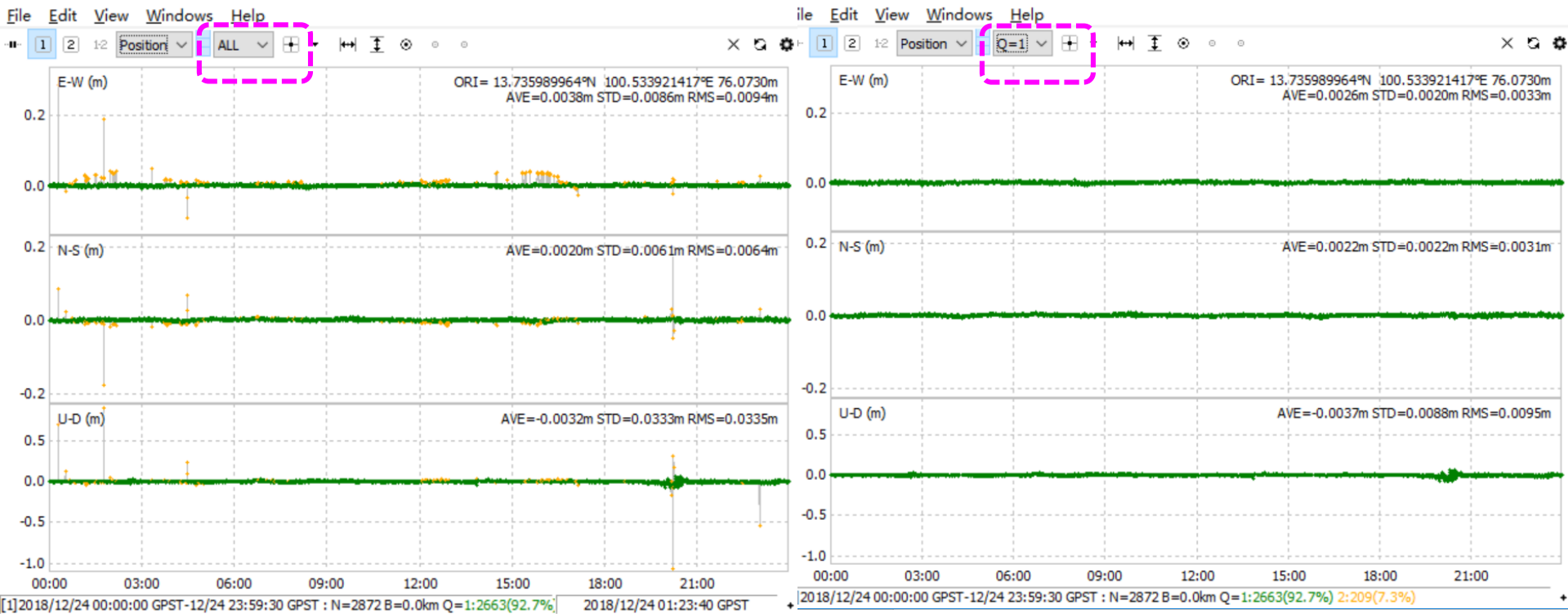
Bottom-Left Window (Options): Shows the 'Measurement Errors (1-sigma)' section with values: Code/Carrier-Phase Error Ratio L1/L2 (100.0 / 100.0), Carrier-Phase Error a+b/sinE (0.003 / 0.003), Carrier-Phase Error/Baseline (m/10km) (0.000), Doppler Frequency (Hz) (10.000). The 'Process Noises (1-sigma/sqrt(s))' section includes Receiver Accel Horiz/Vertical (m/s²) (1.00E+01 / 1.00E+01), Carrier-Phase Bias (cycle) (1.00E-04), Vertical Ionospheric Delay (m/10km) (1.00E-03), Zenith Tropospheric Delay (m) (1.00E-04), and Satellite Clock Stability (s/s) (5.00E-12).

Bottom-Right Window (Options): Shows the 'Rover' section with 'Lat/Lon/Height (deg/m)' set to 90.000000000, 0.000000000, -6335367.6285. The 'Base Station' section has 'X/Y/Z-ECEF (m)' set to -1132913.7678, 6092530.5657, 1504633.5192 (highlighted with a pink dashed box). Both sections have 'Antenna Type (*: Auto)' set to Delta-E/N/U (m).

2.4.2 Example of RTK using RTKLIB



2.4.2 Example of RTK using RTKLIB



2.4.2 If we set SNR Mask

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode: Kinematic

Frequencies / Filter Type: L1+L2 Forward

Elevation Mask (°) / SNR Mask (dBHz): 15 ...

Rec Dynamics / Earth Tides Correction: OFF OFF

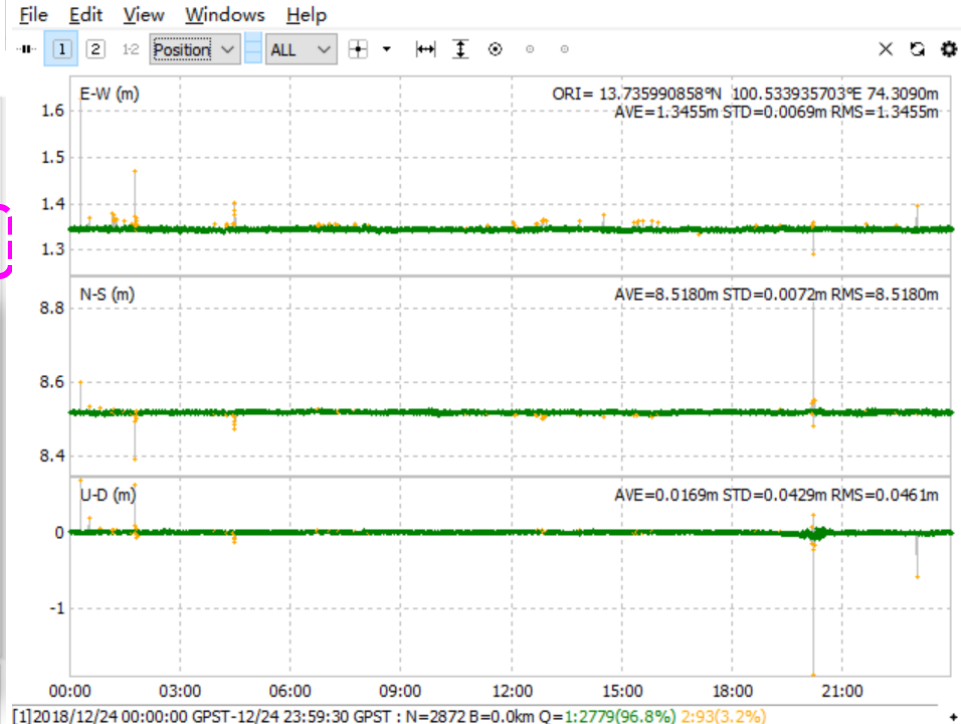
SNR Mask

Rover Base Station

	Elevation (deg)								(dBHz)
	<5	15	25	35	45	55	65	75	>85
L1	30	30	30	30	30	30	30	30	30
L2	30	30	30	30	30	30	30	30	30
L5	0	0	0	0	0	0	0	0	0

OK Cancel

×



Fix rate will improve from 92.7% to 96.8%

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DGNSS

PPP

RTK

RTKNAVI

2.5 RTKNAVI

- RTKPOST is for post processing of GNSS data
- For real-time users, RTKNAVI is usually used.



2.5 RTKNAVI

RTKNAVI ver.2.4.3 b31

2000/01/01 00:00:00.0 GPST

Lat/Lon/Height

Rover:Base SNR (dBHz)

Solution: ----

N: 0° 00' 00.0000"

E: 0° 00' 00.0000"

He: 0.000 m

N: 0.000 E: 0.000 U: 0.000 m

Age: 0.0 s Ratio: 0.0 #Sat: 0

Start Mark... Plot Options... Exit

Input Streams

Input Stream	Type	Opt	Cmd	Format	Opt
<input checked="" type="checkbox"/> (1) Rover	NTRIP Client	BINEX	...
<input checked="" type="checkbox"/> (2) Base Station	NTRIP Client	BINEX	...
<input type="checkbox"/> (3) Correction	Serial	RTCM 2	...

NTRIP Client Options

NTRIP Caster Host: 153.121.59.53 Port: 2101

Mountpoint: ECJ22 User-ID: gspase Password:

String:

Ntrip... OK Cancel

2.5 RTKNAVI

RTKNAVI ver.2.4.3 b31

2000/01/01 00:00:00.0 GPST I [Icons] O L

Lat/Lon/Height

Rover:Base SNR (dBHz)

Solution:

N: 0° 00' 00.0000"

E: 0° 00' 00.0000"

He: 0.000 m

N: 0.000 E: 0.000 U: 0.000 m

Age: 0.0 s Ratio: 0.0 #Sat: 0

Start Mark... Plot Options... Exit

Output Streams

Output Stream	Type	Option	Format
<input checked="" type="checkbox"/> (4) Solution 1	File	...	Lat/Lon/Height
<input type="checkbox"/> (5) Solution 2	Serial	...	Lat/Lon/Height

Output File Paths

C:\Users\yize\Desktop\11

Time-Tag Swap Intv [Dropdown] H ?

OK Cancel

2.5 RTKNAVI

RTKNAVI ver.2.4.3 b31

The screenshot shows the RTKNAVI main interface. At the top, it displays the date and time '2000/01/01 00:00:00.0' and the mode 'GPST'. Below this, there are several data fields: 'Lat/Lon/Height', 'Rover:Base SNR (dBHz)', and 'Solution:'. The solution data shows coordinates N: 0° 00' 00.0000", E: 0° 00' 00.0000", and Height: 0.000 m. At the bottom, there is a control bar with buttons for 'Start', 'Mark...', 'Plot', 'Options...', and 'Exit'. The 'Options...' button is highlighted with a dashed blue box.

Options

The screenshot shows the 'Options' dialog box. It has several tabs: 'Setting1', 'Setting2', 'Output', 'Statistics', 'Positions', 'Files', and 'Misc'. The 'Setting1' tab is active. The settings are as follows:

- Positioning Mode: Kinematic
- Frequencies / Filter Type: L1+L2
- Elevation Mask (°) / SNR Mask (dBHz): 15
- Rec Dynamics / Earth Tides Correction: OFF
- Ionosphere Correction: Broadcast
- Troposphere Correction: Saastamoinen
- Satellite Ephemeris/Clock: Broadcast
- Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr
- Excluded Satellites (+PRN: Included):
- GPS GLO Galileo QZSS SBAS BeiDou IRNSS

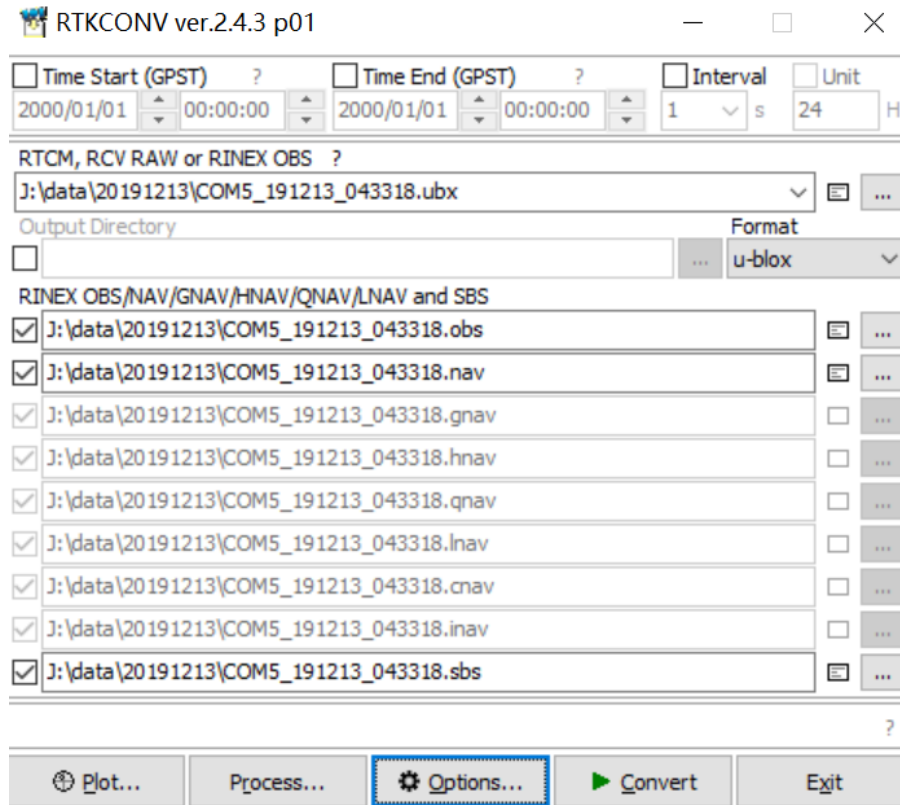
At the bottom, there are buttons for 'Load...', 'Save...', 'OK', and 'Cancel'. The 'Options...' button in the main interface is highlighted with a dashed blue box, and a pink arrow points from it to the 'Options' dialog box.

Same as RTKPOST

2.5 RTKNAVI



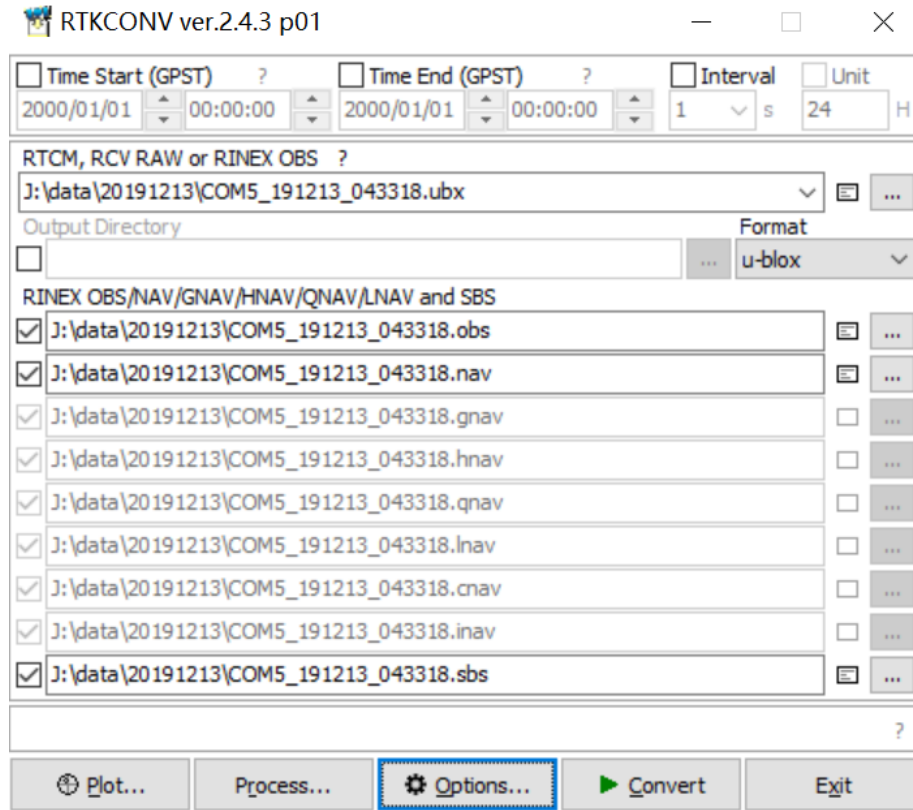
3 Other software: Modified RTKCONV v2.4.3 p01



3 Other software

<https://onedrive.live.com/?authkey=%21AJqI2JkZaRwVhAM&id=CA40E2337C7D7327%2112977&cid=CA40E2337C7D7327>

3 Modified RTKCONV v2.4.3 p01



3 Modified RTKPOST v2.4.3 p01

RTKPOST ver.2.4.3 p01

Time Start (GPST) ? Time End (GPST) ? Interval Unit

2018/09/06 03:09:18 2018/09/06 04:13:39 1 s 24 H

RINEX OBS: Rover ?

E:\TUMSAT\2017200\rov2000.17o

RINEX OBS: Base Station ?

E:\TUMSAT\2017200\ref_net9_1hz.17o

RINEX NAV/CLK, SP3, FCB, IONEX, SBS/EMS or RTCM

E:\TUMSAT\2017200\ref_net9.nav

Solution Dir

E:\TUMSAT\2017200\rov2000_inst.pos

Plot... View... KML/GPX... Options... Execute Exit

Options

Setting1 Setting2 Output Statistics Positions Files Misc INS

Integer Ambiguity Res (GPS/GLO/BDS) Instanta OFF ON

Min AR Ratio/Min Success Rate/Partial AR 3 0.68 ON

Min Confidence / Max FCB to Fix Amb 0.9999 0.25

Min Lock / Elevation (°) to Fix Amb 5 20

Min Fix / Elevation (°) to Hold Amb 10 0

Options

Setting1 Setting2 Output Statistics Positions Files Misc INS

Positioning Mode Kinematic

Frequencies / Filter Type L1+L2(E5b) Forward

Elevation Mask (°) / SNR Mask (dBHz) 10 ...

Rec Dynamics / Earth Tides Correction OFF OFF

Ionosphere Correction Broadcast

Troposphere Correction UNB3m

Satellite Ephemeris/Clock Broadcast

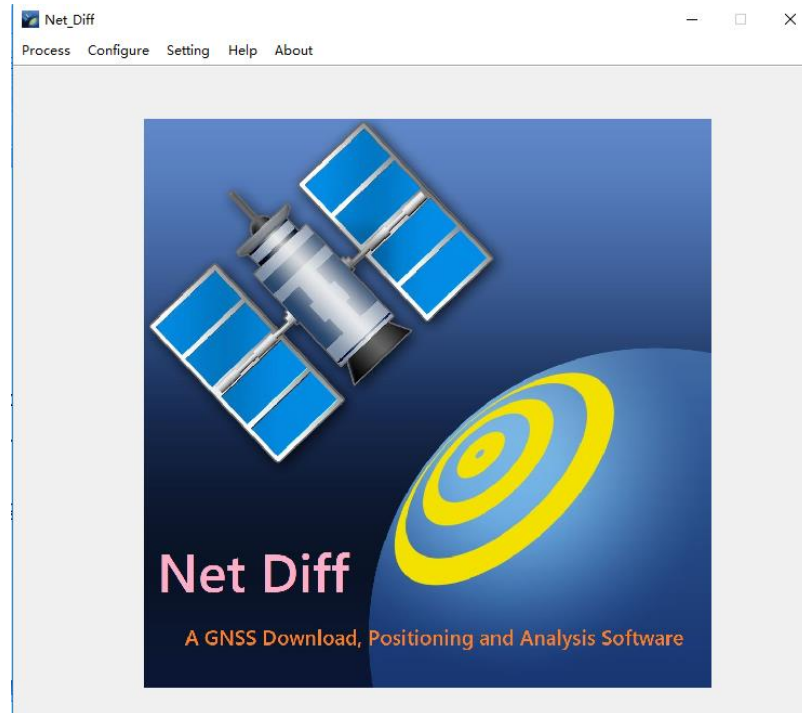
Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr 2nd Pri

Excluded Satellites (+PRN: Included)

3 Net_Diff

● Functions:

- ✓ 1. SPP/PPP/RTK/DGNSS/PPP-AR/PPP-RTK
 - ✓ 2 GPS/Glonass/Galileo/BeiDou/QZSS/IRNSS
 - ✓ 3 Single, dual, triple-frequency
 - ✓ 4 Data download
 - ✓ 5 Observation and positioning analysis
 - ✓ 6 Ntrip receiving, data conversion
 - ✓ 7 Orbit simulation
- https://github.com/YizeZhang/Net_Diff



Thank you!