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) APs:

	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)	Downloder 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         RTKRCV        (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 genration 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

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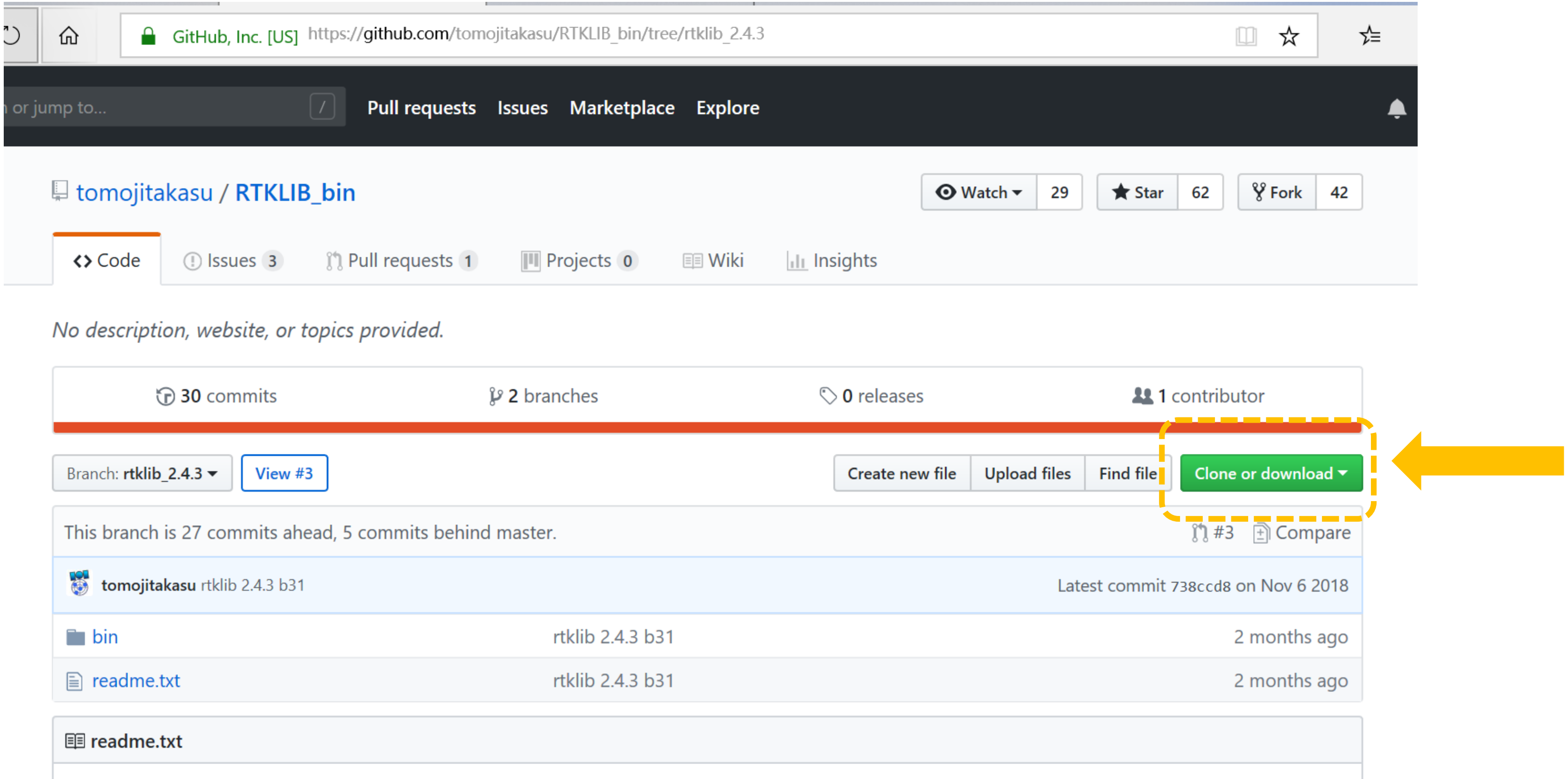
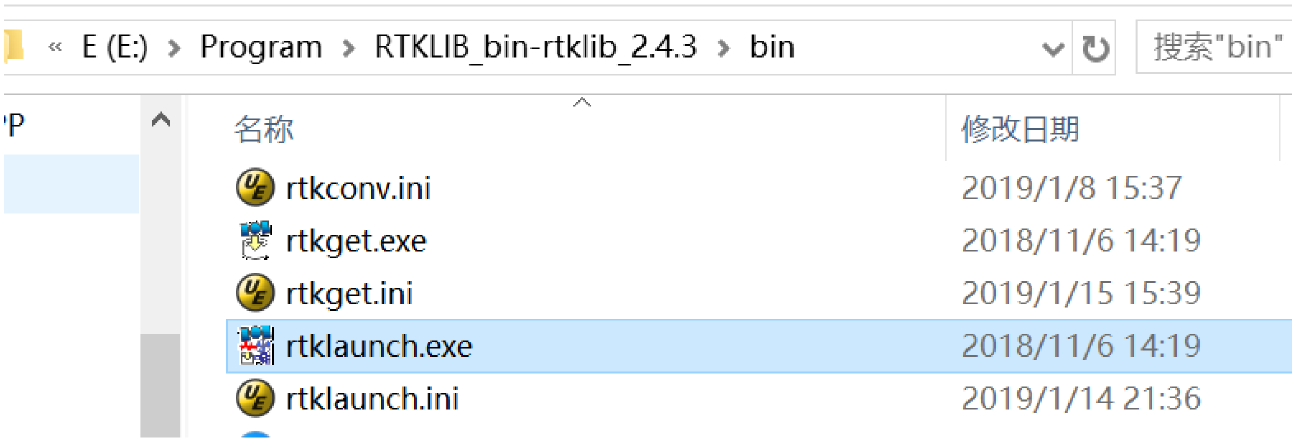
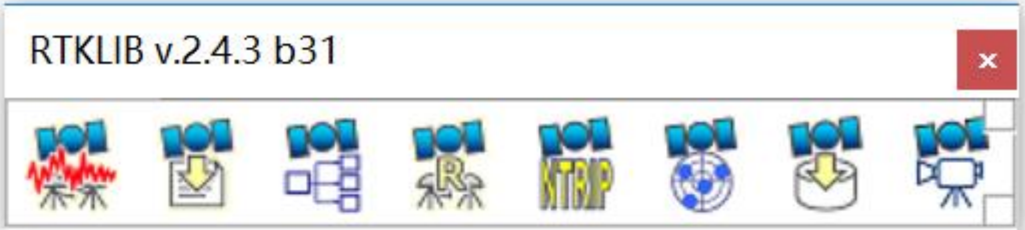
Tokyo University of Marine Science and Technology



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

1 Launch RTKLIB





1 RTKLIB GUIs

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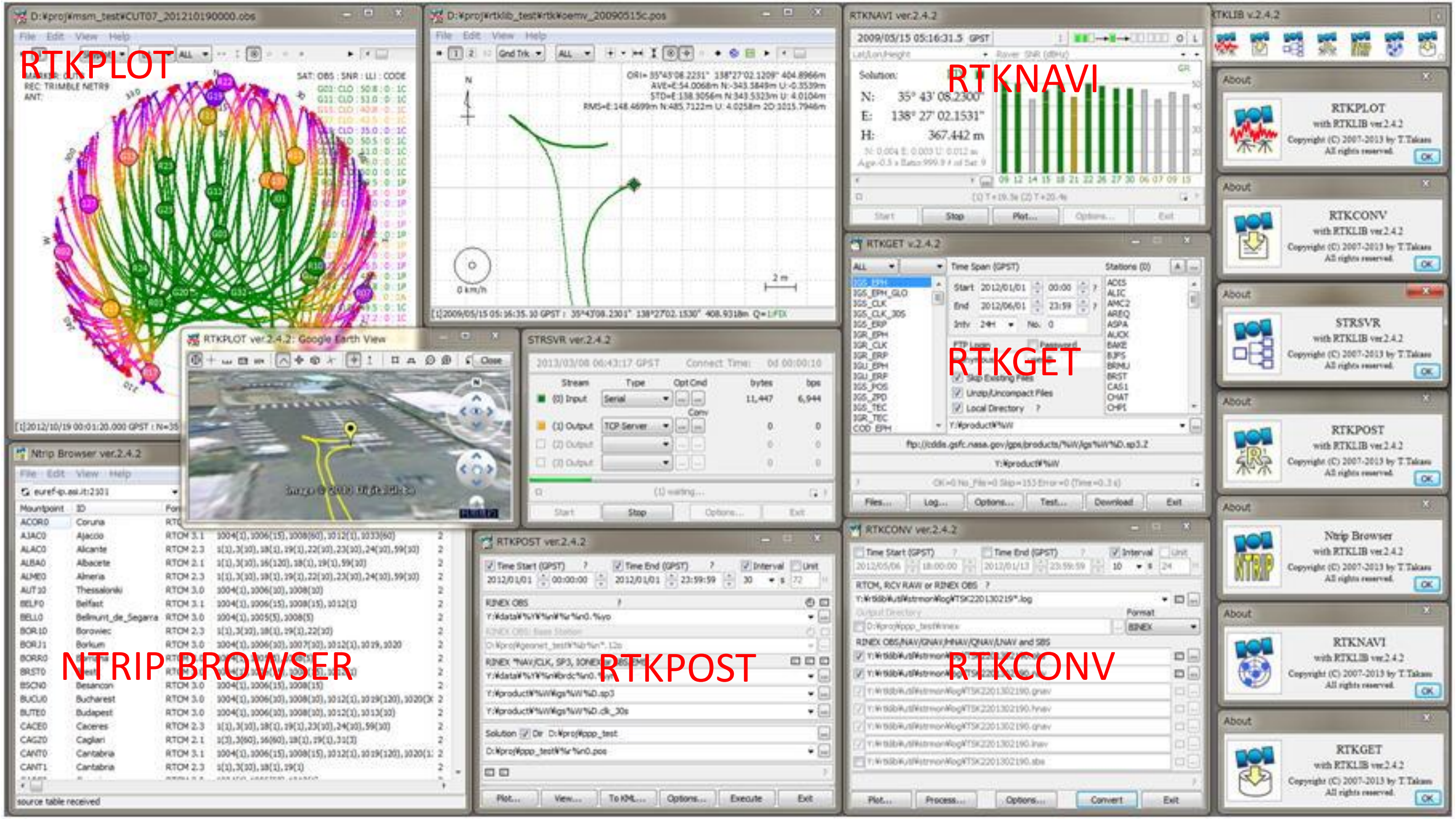

1 RTKLIB Manual

RTKLIB ver. 2.4.2 Manual

April 29, 2013

Contents

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

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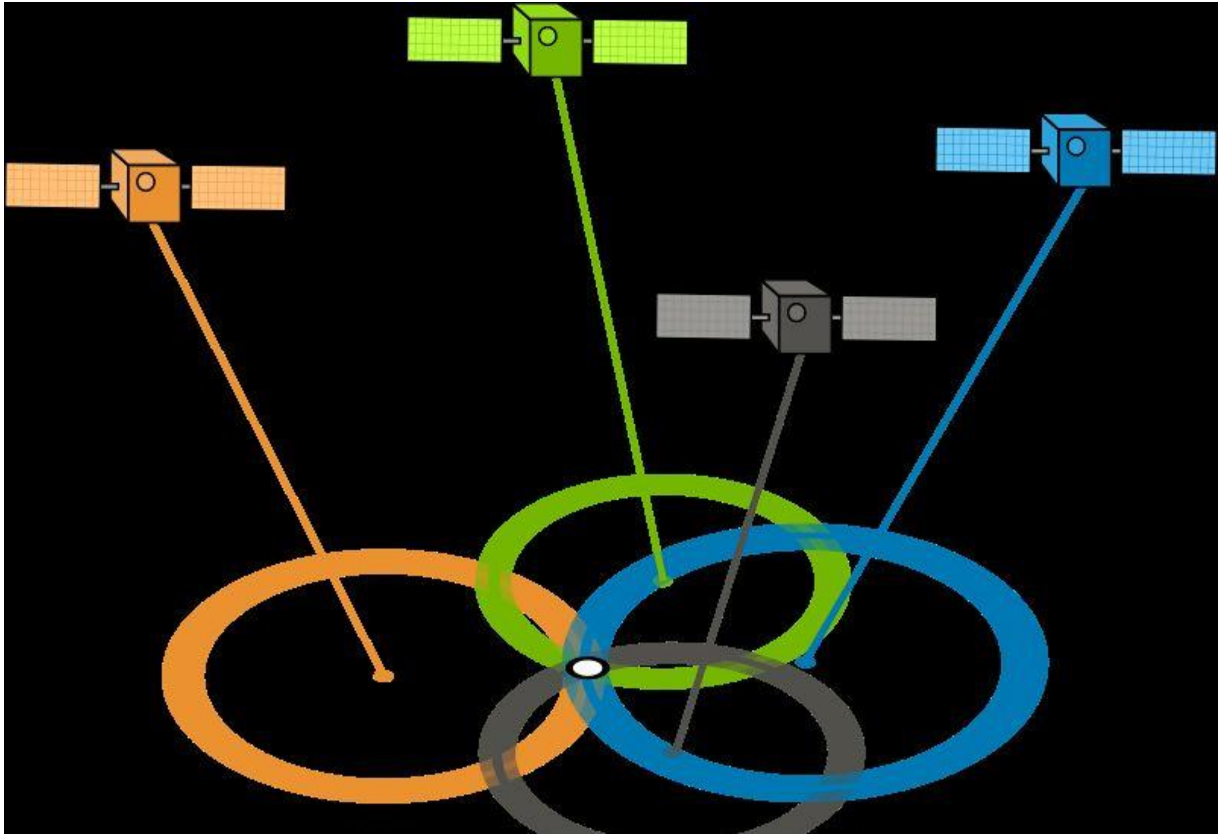
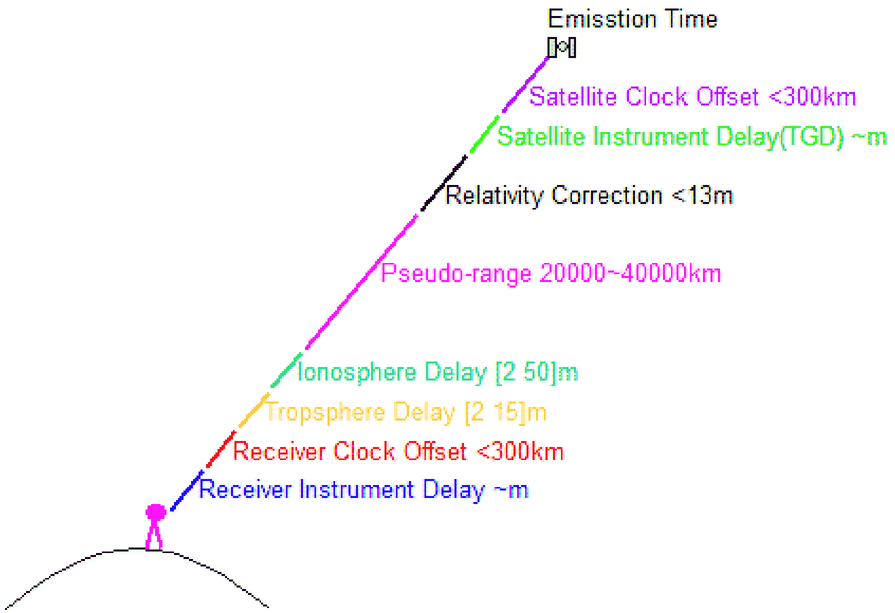
- DGNSS
- PPP
- RTK

2 GNSS Positioning



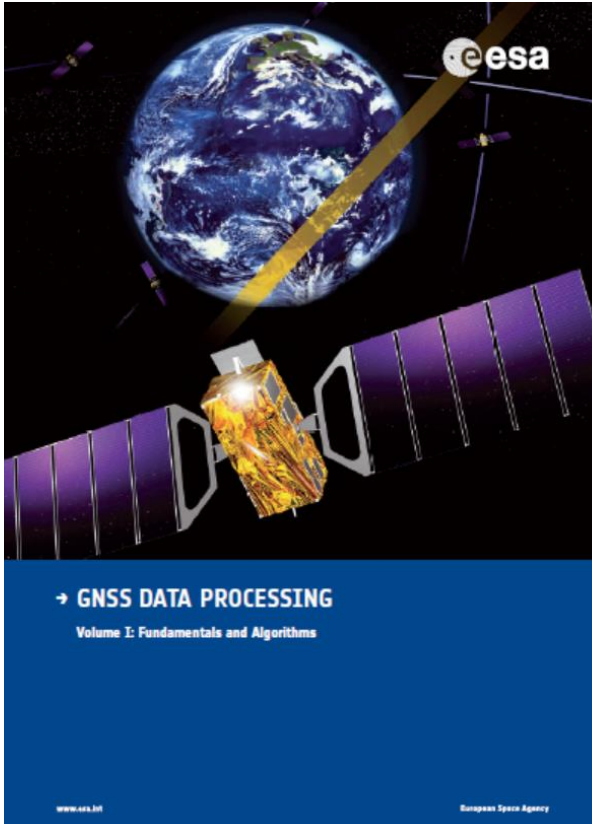
2 GNSS Observation and Errors



2 GNSS Positioning based on code and carrier phase

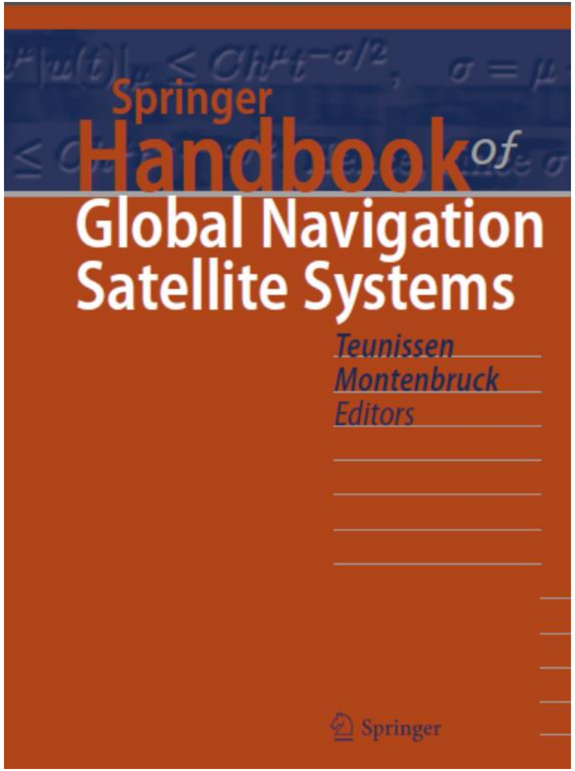
	Standard Positioning (code-based)	Precise Positioning (carrier-based)
Observables	Pseudorange (Code)	**Carrier-Phase** + Pseudorange
Receiver Noise	30 cm	3 mm
Multipath	30 cm - 30 m	1 - 3 cm
Sensitivity	High (<20dBHz)	Low (>35dBHz)
Discontinuity	No Slip	Cycle-Slip
Ambiguity	-	Estimated/Resolved
Receiver	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: Volumn 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

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

Pseudo-range observation

Geometric distance from satellite to receiver(X, Y, Z)

Receiver clock

Satellite clock

Clock relativity correction

Troposphere correction

Ionosphere correction

Noise and other modeled corrections

2.1.1 GNSS Observation Data (RINEX format)

cusv3580.18o　brdm3580.18p　cuut3580.18o

```
     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
gfzrnx-1.10-7329    HEADER EDIT         20181225 020444 UTC COMMENT
CUUT                                                        MARKER NAME
21904S002                                                   MARKER NUMBER
GEODETIC                                                    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

```
                                                            END OF HEADER
> 2018 12 24  0  0  0.0000000  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
```

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

2.1.1 GNSS Navigation Data(RINEX format)

cusv3580.18o | brdm3580.18p | cuut3580.18o

```
    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
```

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

2.1.1 SPP(Single Point Positioning)

Define:

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

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

Then:

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

2.1.1 Solving GNSS Equations

Then GNSS Equation can be simplified as:

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

where **y** is the OMC(observation minus correction),**G** is the design matrix, **x** is the estimated parameter, **ε** is observation noise, **R** is observation covariance matrix.

2.1.1 Solving GNSS Equations: Least Square

Least square is to best-fit the condition of:

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

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

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

So the least square solution is:

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

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

P is the covariance matrix of the estimated parameter

2.1.1 Solving GNSS Equations: Kalman Filter

Predict:

$$\hat{\mathbf{x}}^{-}{}_{\mathrm{k}} = \mathbf{\Phi}_{k-1}\hat{\mathbf{x}}^{-}{}_{k-1}$$

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

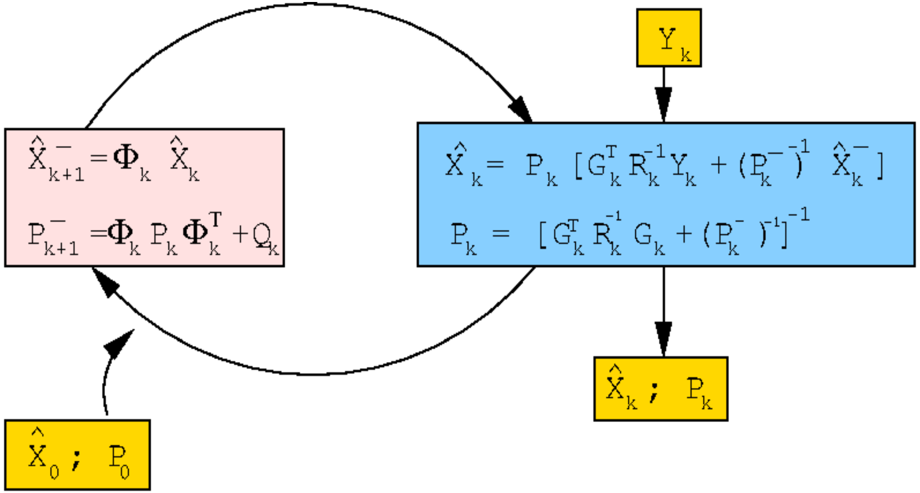
Estimate:

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

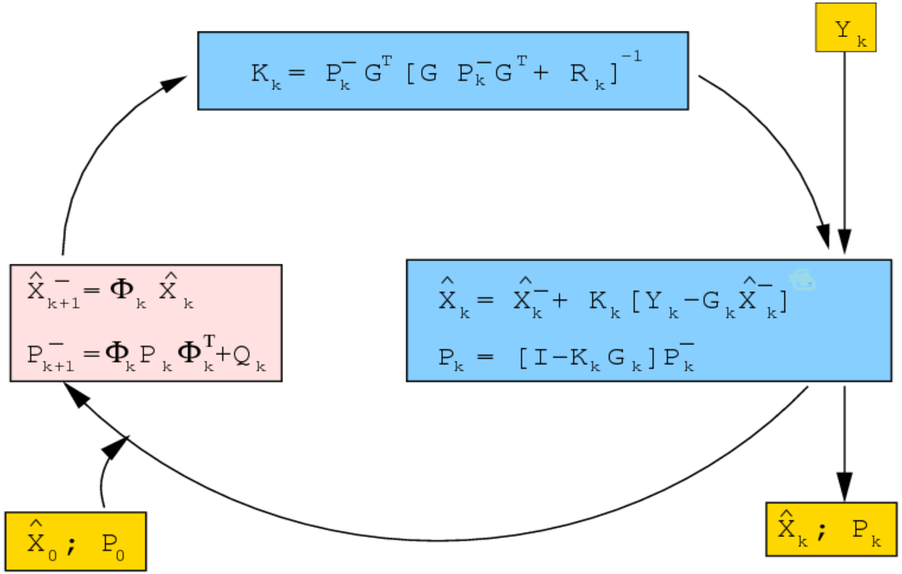
$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}^{-}{}_k + \mathbf{K}_k\left[\mathbf{y}_k - \mathbf{G}_k\hat{\mathbf{x}}^{-}{}_k\right]$$

$$\mathbf{P}_{\hat{\mathbf{x}}_{\mathrm{k}}} = \left[\mathbf{I} - \mathbf{K}_k\mathbf{G}_k\right]\mathbf{P}^{-}_{\hat{\mathbf{x}}_k}$$

2.1.1 Solving GNSS Equations: LS vs. KF



Least Square



Kalman Filter

2.1.1 DOP

Covariance matrix of SPP is:

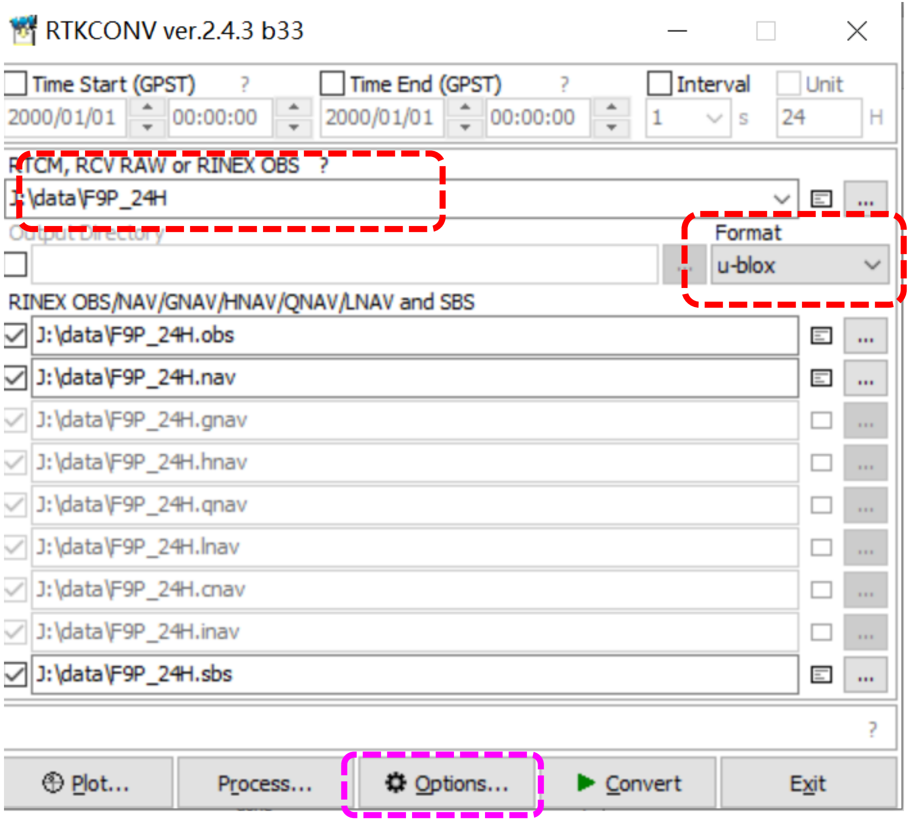
$$\boldsymbol{P} = (\boldsymbol{G}^T \boldsymbol{R}^{-1} \boldsymbol{G})^{-1}$$

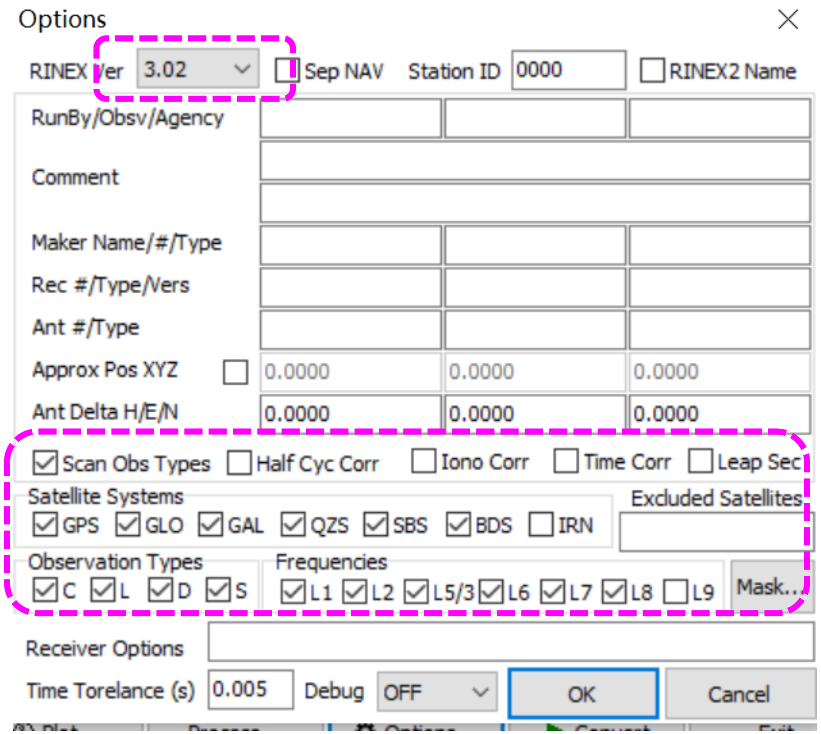
$$\boldsymbol{P} = \begin{bmatrix} \boldsymbol{p_{11}} & \cdots & \boldsymbol{p_{14}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{p_{41}} & \cdots & \boldsymbol{p_{44}} \end{bmatrix}$$

Define:

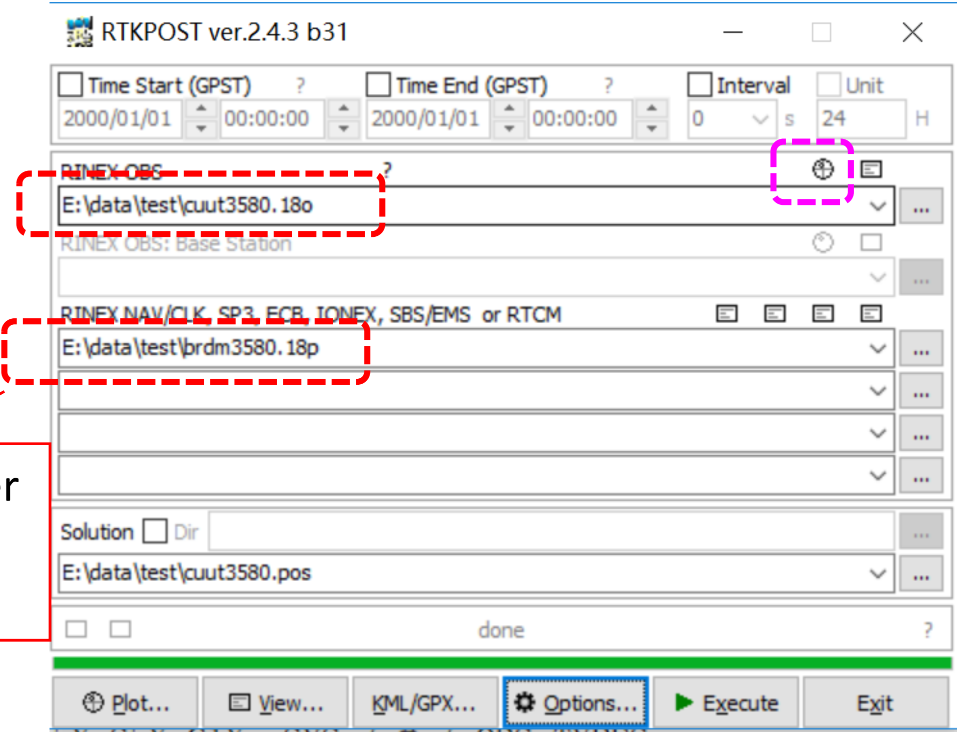
$$PDOP = \sqrt{p_{11} + p_{22} + p_{33}}$$
$$HDOP = \sqrt{p_{11} + p_{22}}$$
$$\mathrm{V}DOP = \sqrt{p_{33}}$$
$$GDOP = \sqrt{p_{11} + p_{22} + p_{33} + p_{44}}$$

2.1.2 Convert data to RINEX using RTKCONV



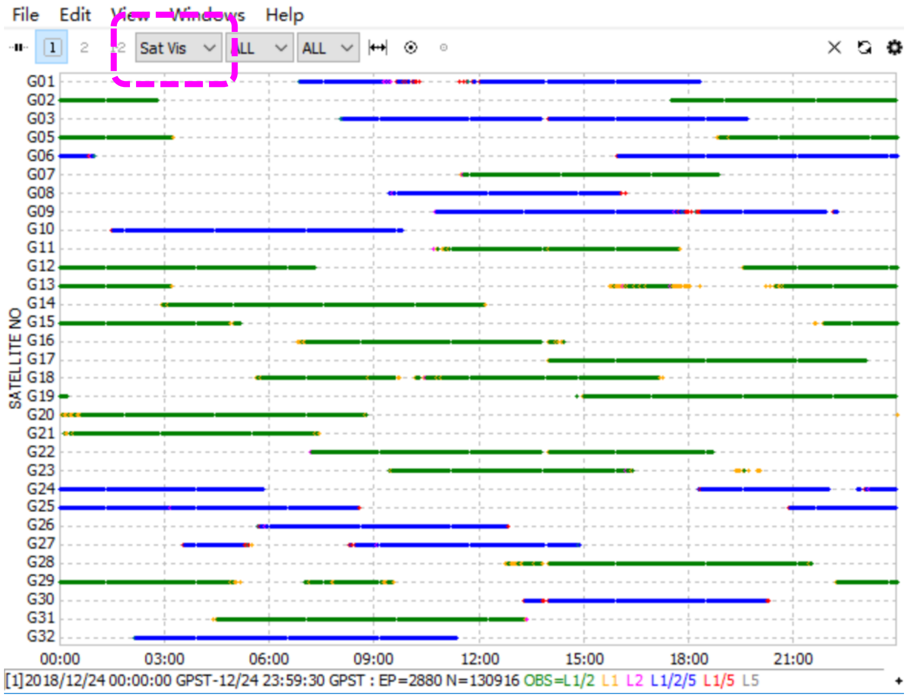


2.1.2 Data quality check using RTKLIB

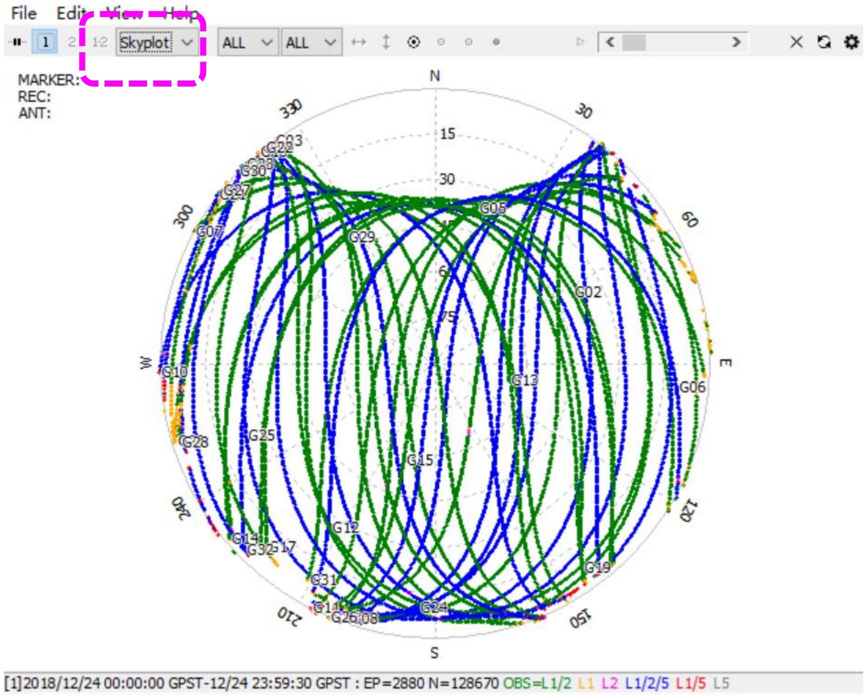


You can input all the other types of navigation files (*.p; *.nav; *.n;*.c;*.g)

2.1.2 Data quality check using RTKLIB

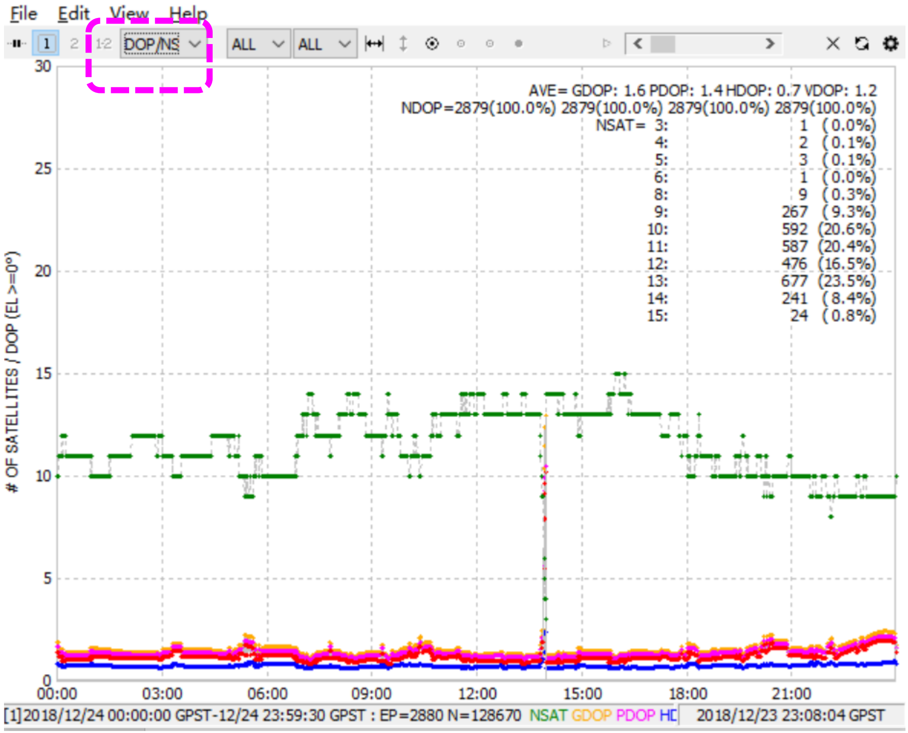


Sat Visibility

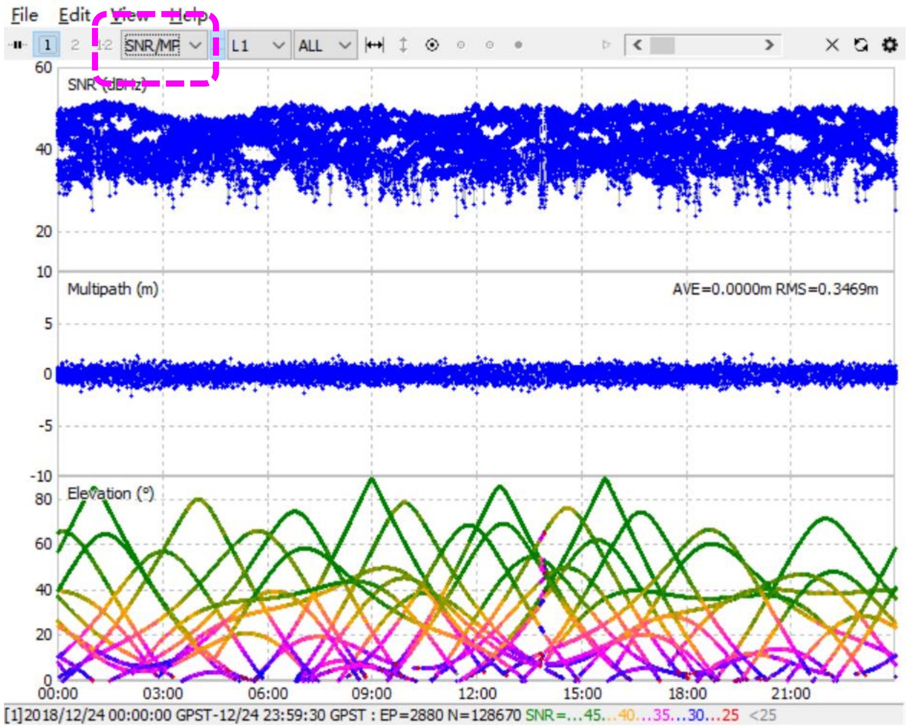


SkyPlot

2.1.2 Data quality check using RTKLIB

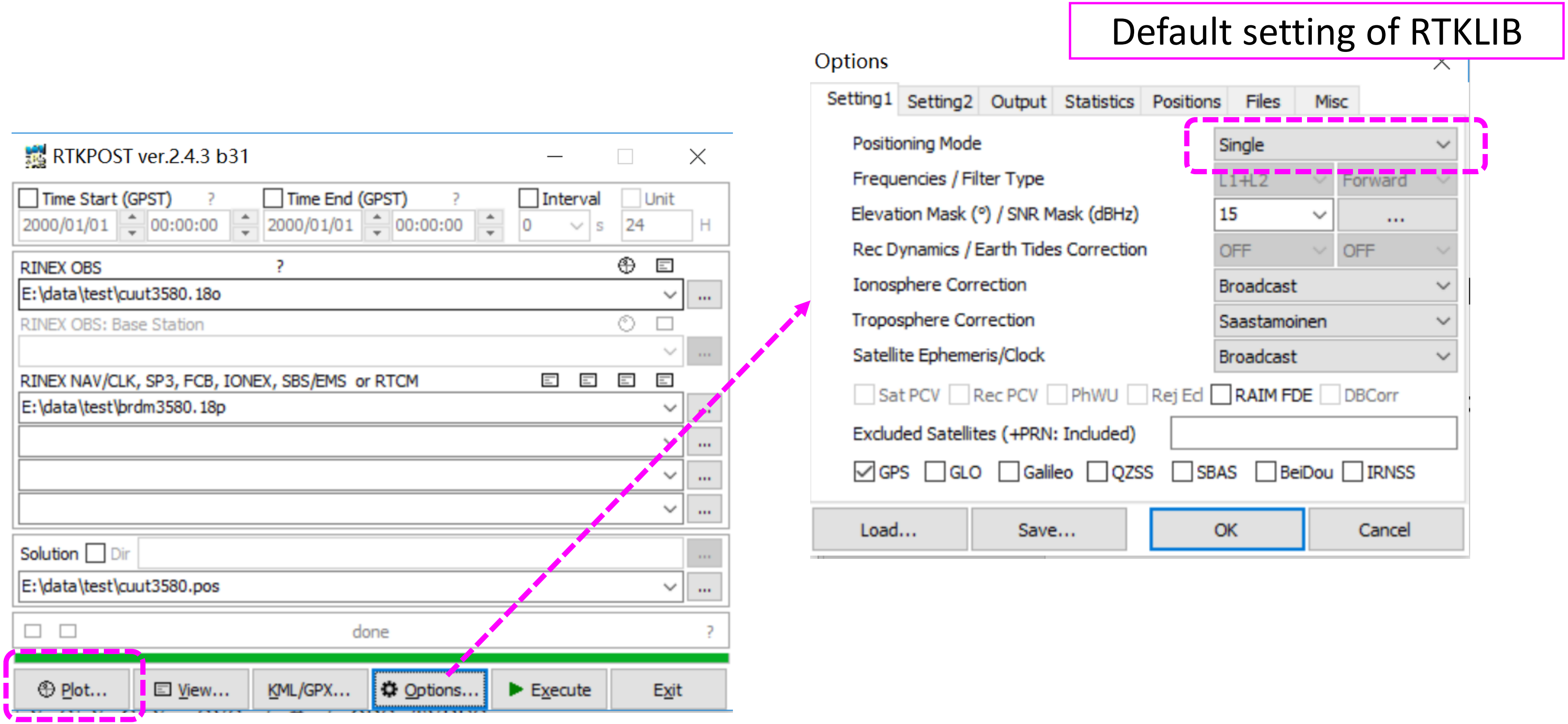


DOP/SatNum

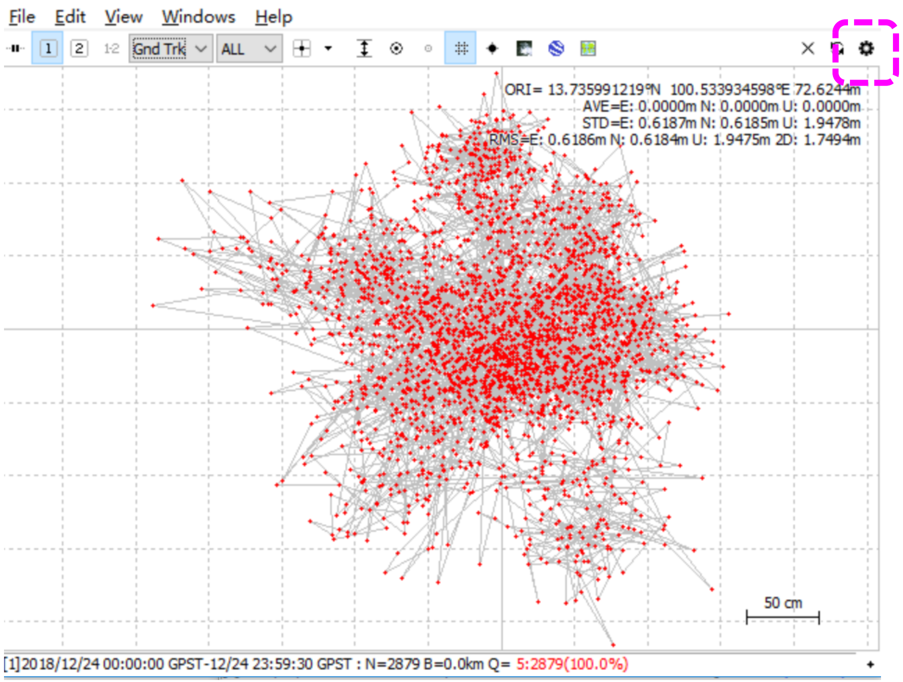


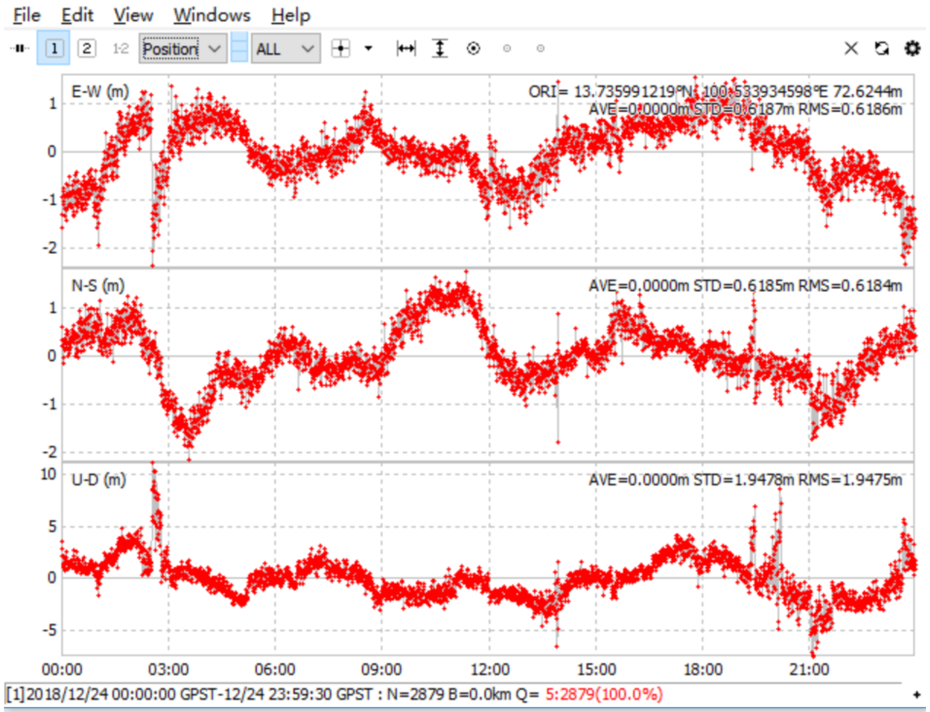
SNR/MP/Ele

2.1.3 Example of SPP using RTKLIB

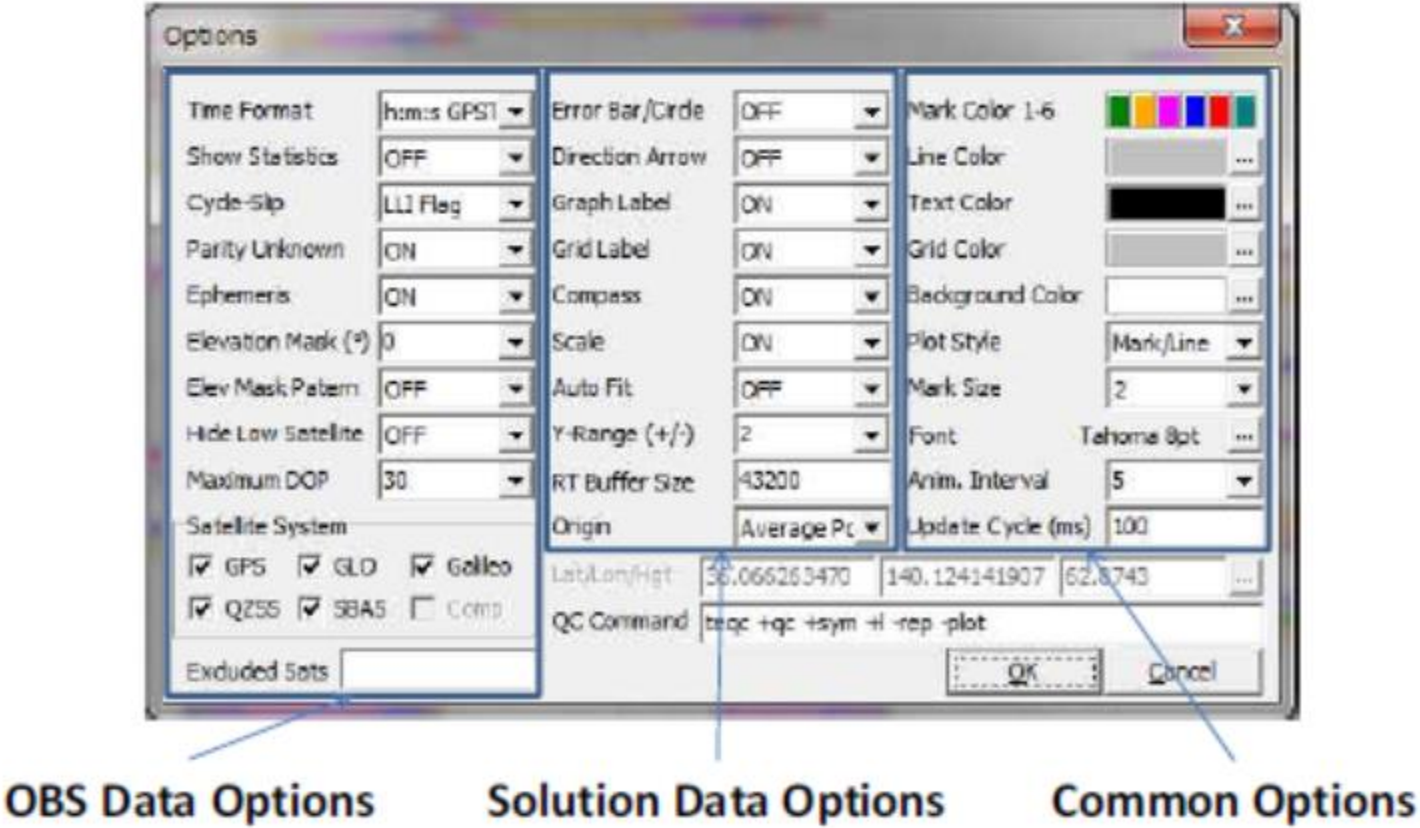


2.1.3 RTKPLOT of SPP

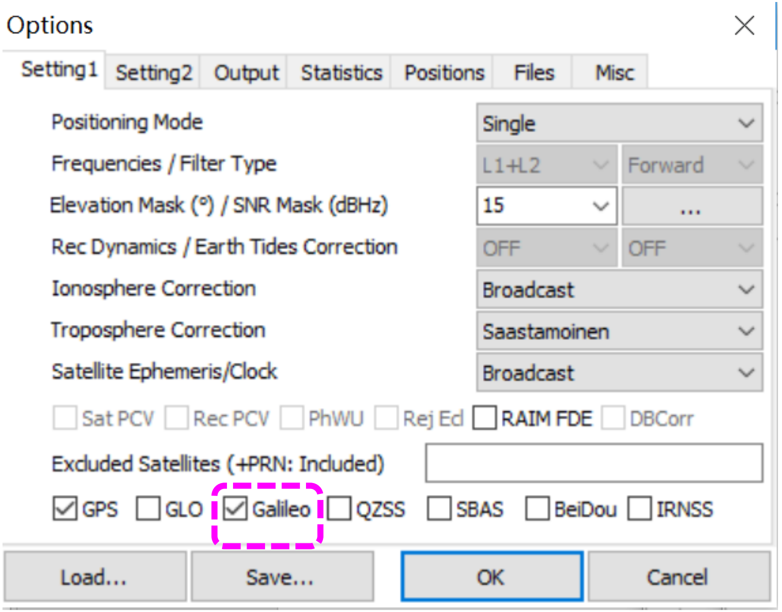


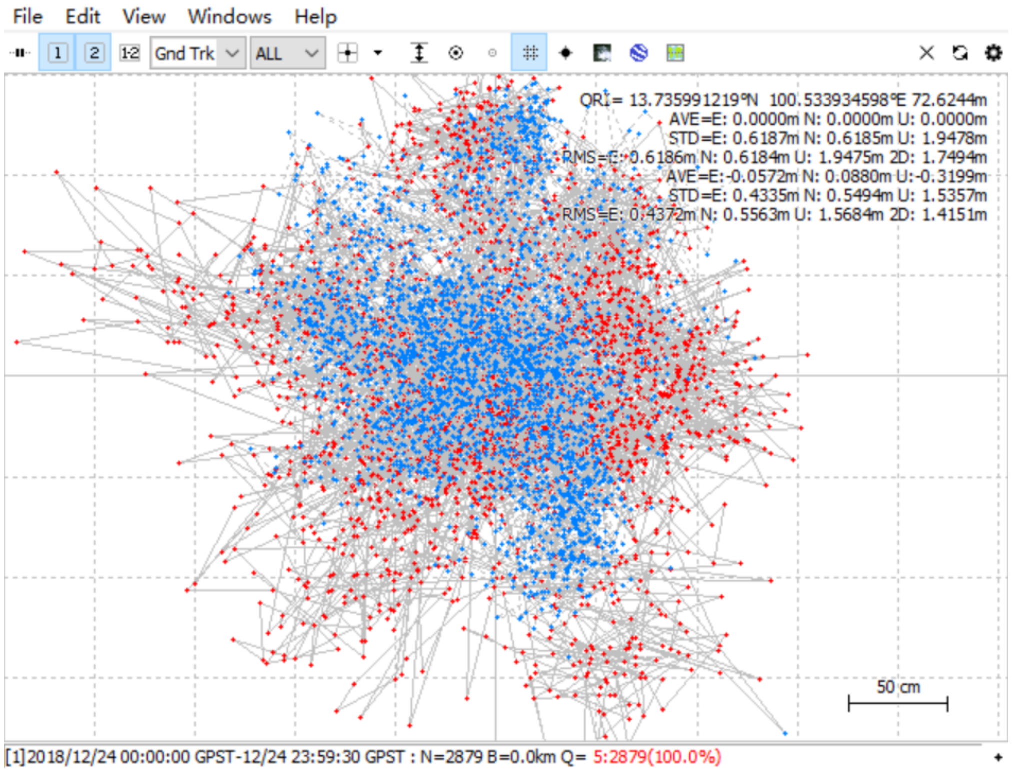


2.1.3 RTKPLOT OPTIONS



2.1.3 Example of SPP using RTKLIB: GPS+Galileo





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   - 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:

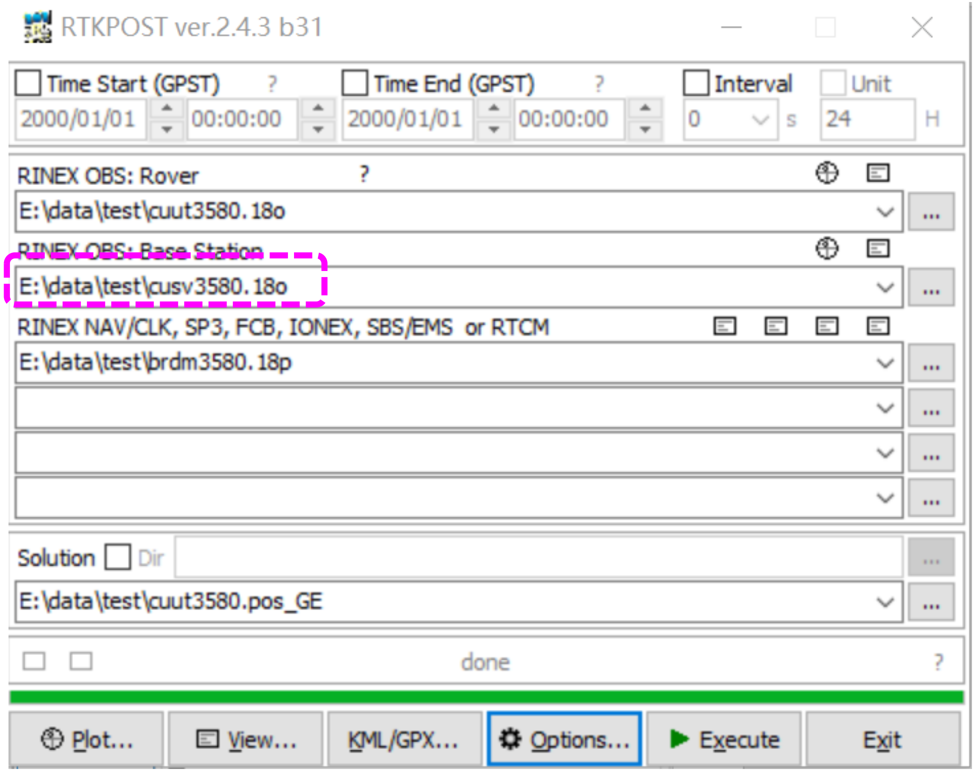
$$Pos_r = Pos_b + dPos_{br}$$

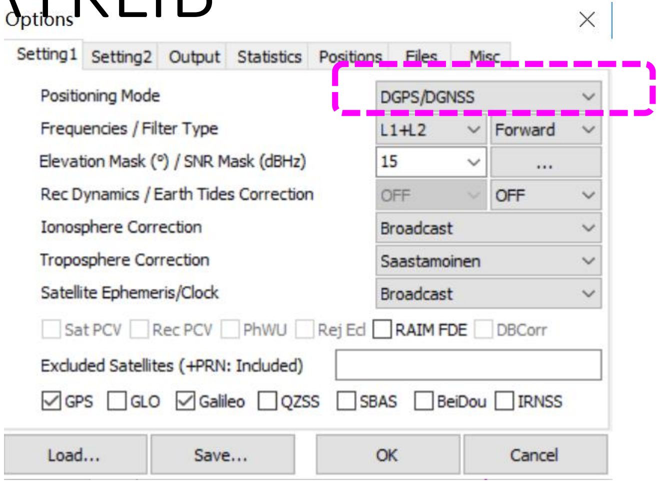
2.2.1 Benefit of DGNSS

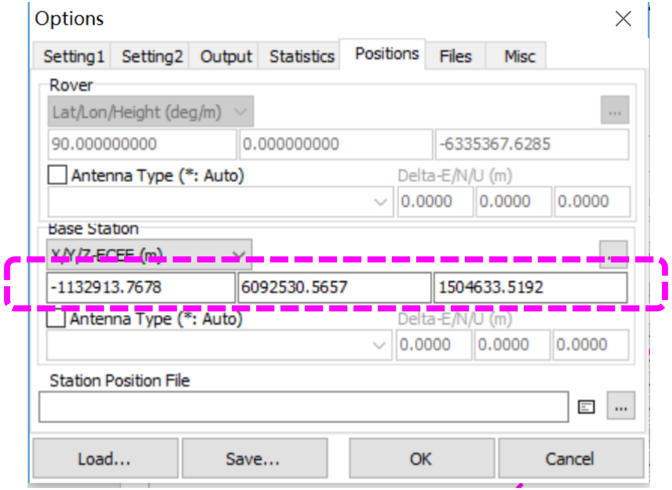
For short baseline, DGNSS would remove errors from satellite and atmosphere, including satellite orbit, clock, relativity, ionosphere, troposphere error.

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

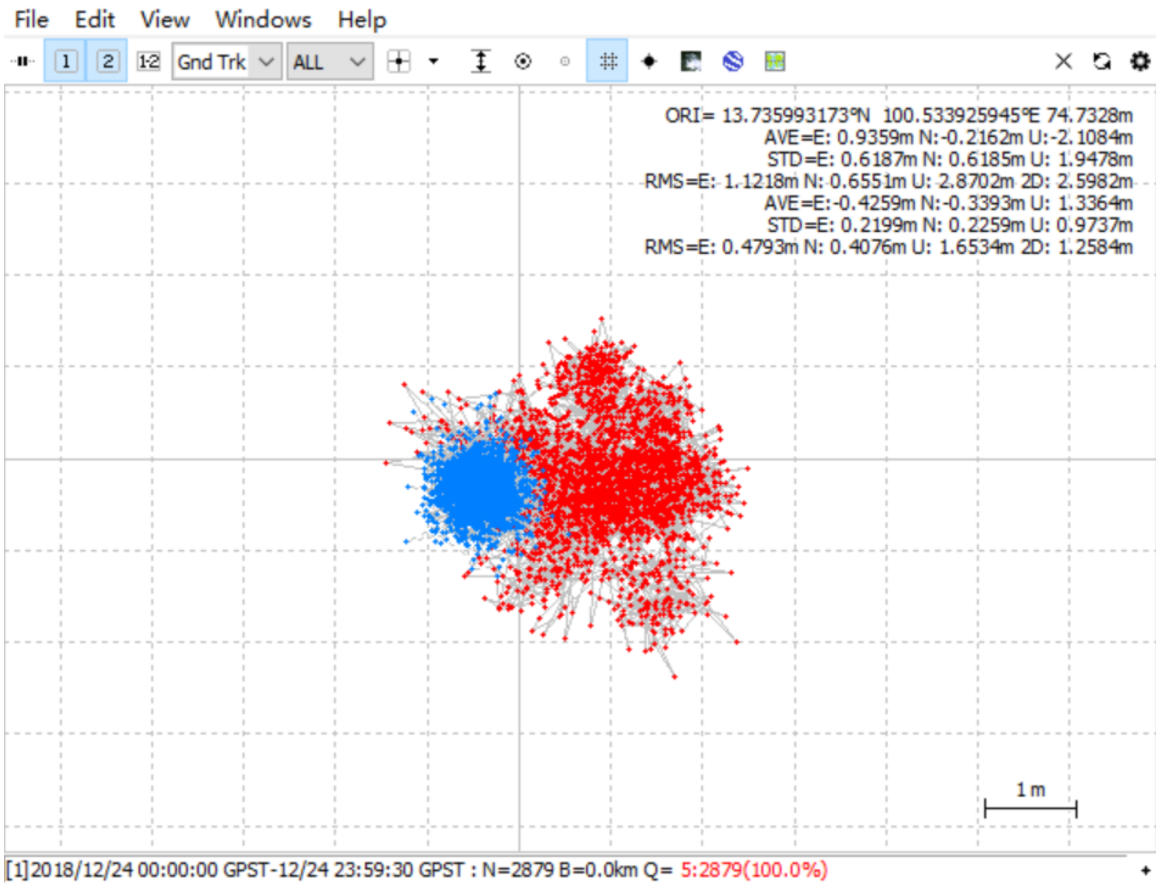
2.2.2 Example of DGNSS using RTKLIB







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

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

$$L_f^j = \rho^j + c\cdot\delta t_{f,L} - c\cdot\delta t_{f,L}^j - \Delta_{rela}^j + T^j + \frac{I^j}{f^2} + \lambda_f\cdot\overline{N_f^j} + \lambda_f\cdot W^j + \varepsilon_{L_f}$$

- L_f^j: Carrier Phase observation
- ρ^j: Geometric distance from satellite to receiver(X, Y, Z)
- $c\cdot\delta t_{f,L}$: Receiver clock
- $c\cdot\delta t_{f,L}^j$: Satellite clock
- Δ_{rela}^j: Clock relativity correction
- T^j: Troposphere correction
- $\frac{I^j}{f^2}$: Ionosphere correction
- $\overline{N_f^j}$: Ambiguity including satellite and receiver bias
- W^j: Phase windup
- ε_{L_f}: Noise and other modeled corrections

2.3.1 PPP(Precise Point Positioning)

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

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

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.

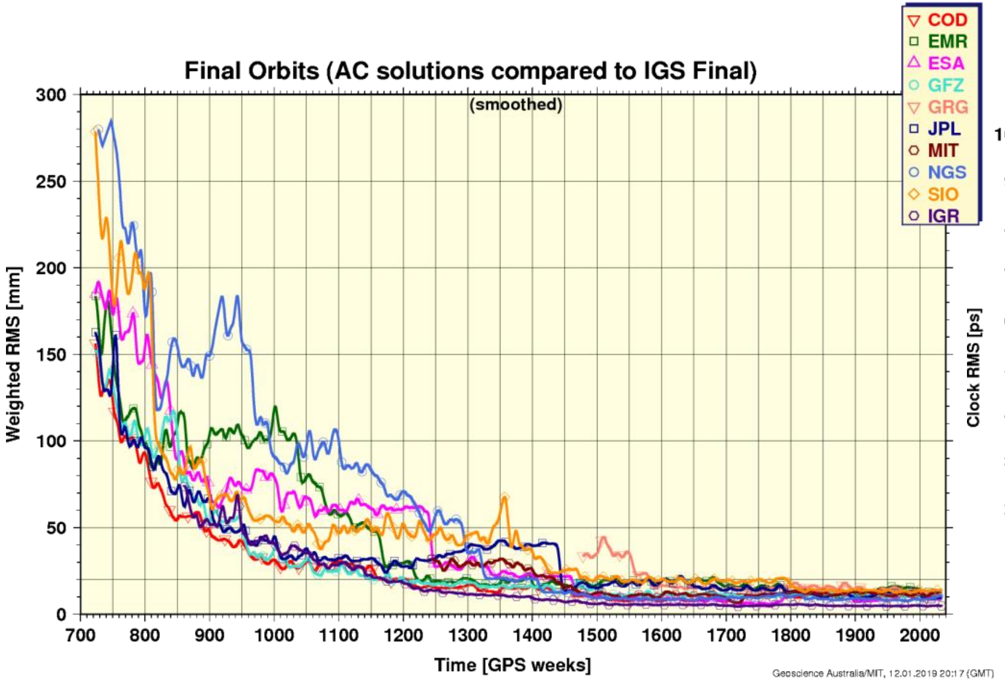
(5) Earth solid tide and ocean tide error must be corrected.

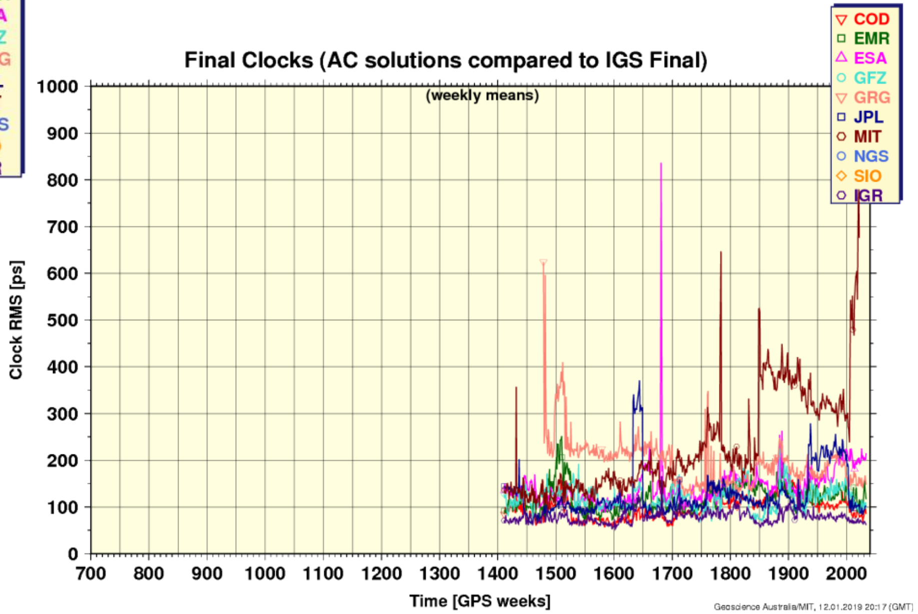
2.3.1 PPP: IGS products

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

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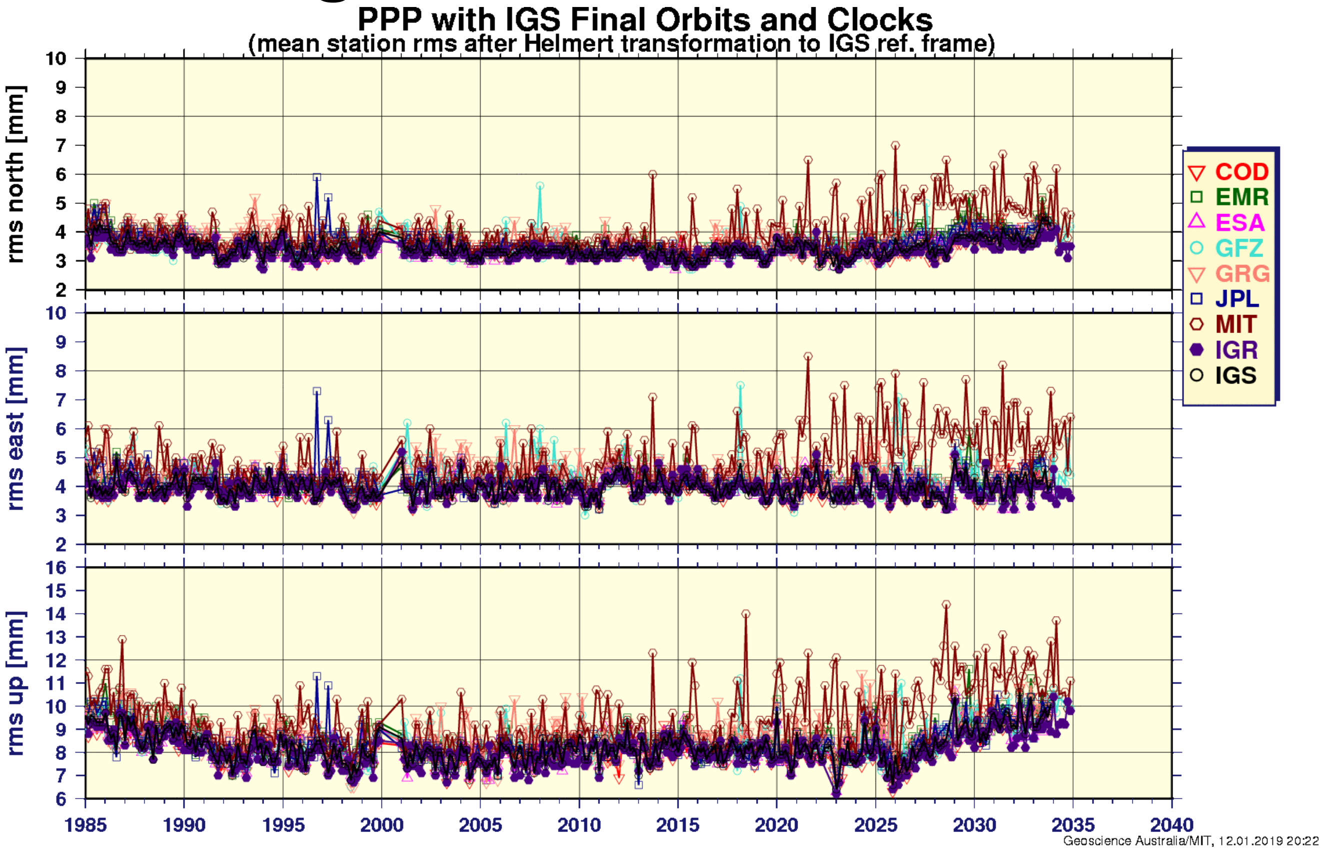
Updated September 2015

Abstract

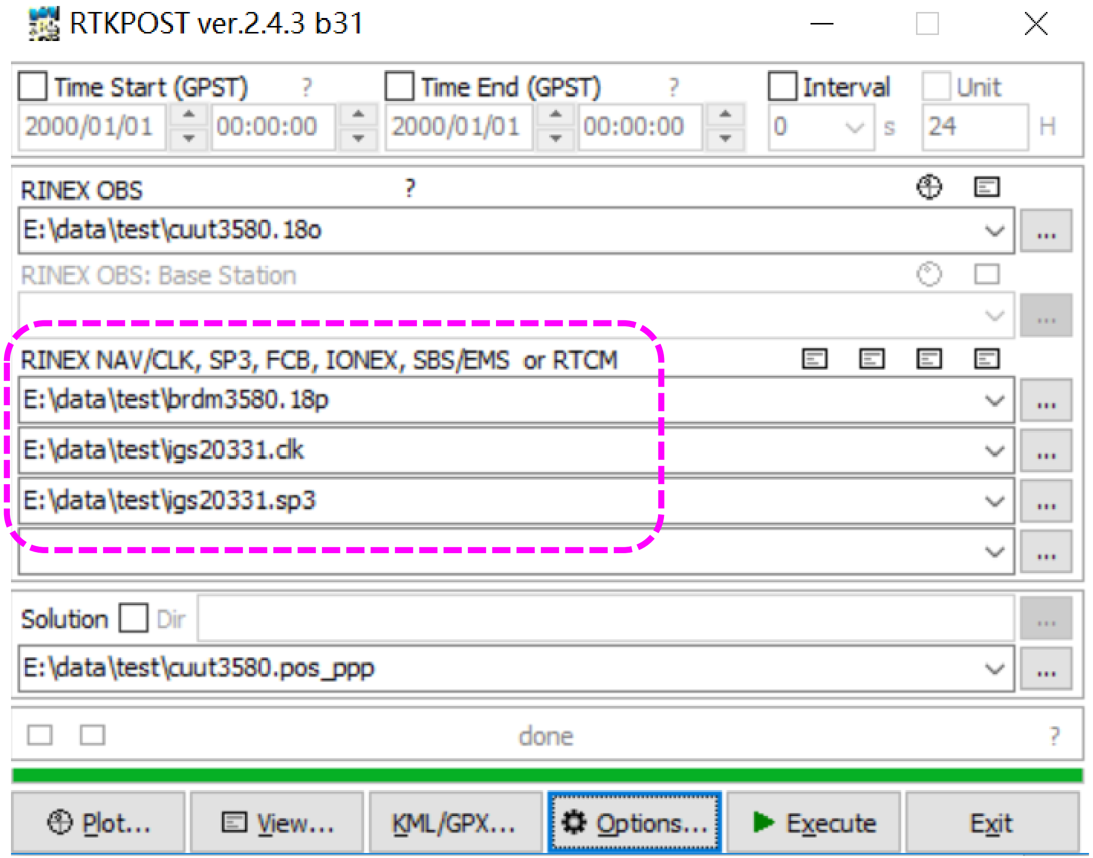
Since 1994, the International GNSS Service (IGS) has provided precise GPS orbit products to the scientific community with increased precision and timeliness. Many national geodetic agencies and GNSS (Global Navigation Satellite System) users interested in geodetic positioning have adopted the IGS precise 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

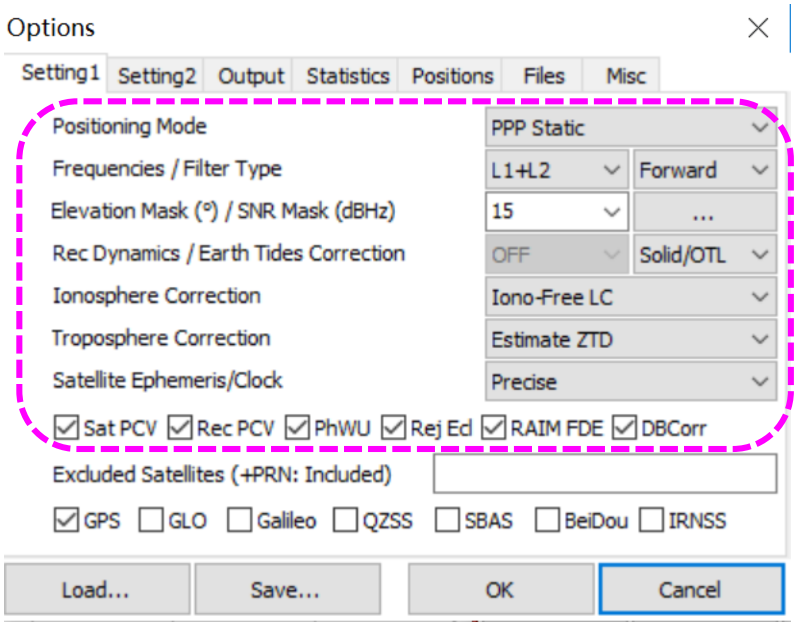


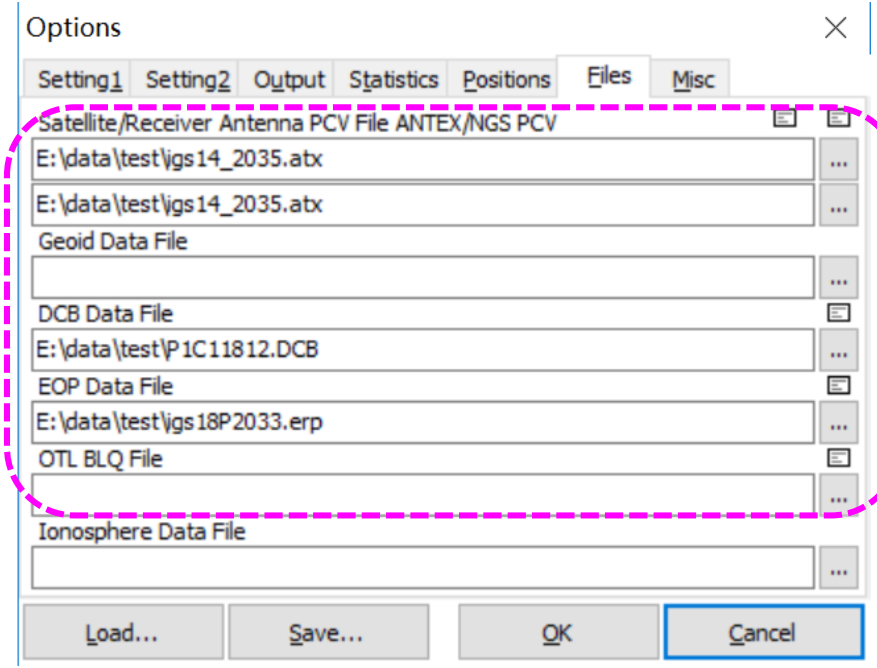
http://acc.igs.org/

2.3.2 Example of PPP using RTKLIB

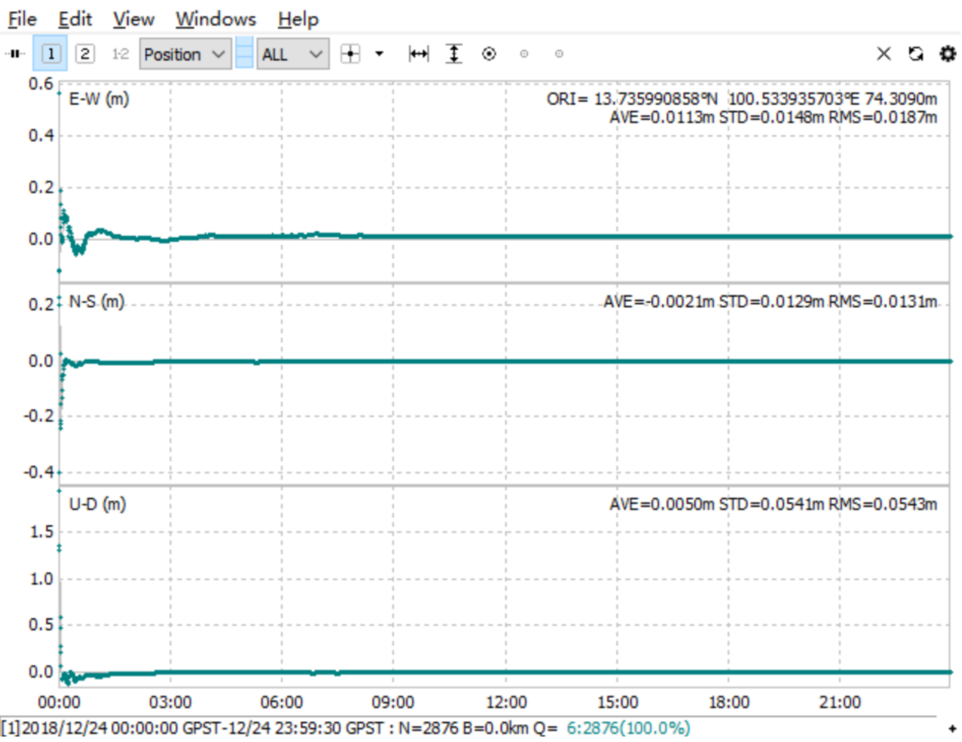


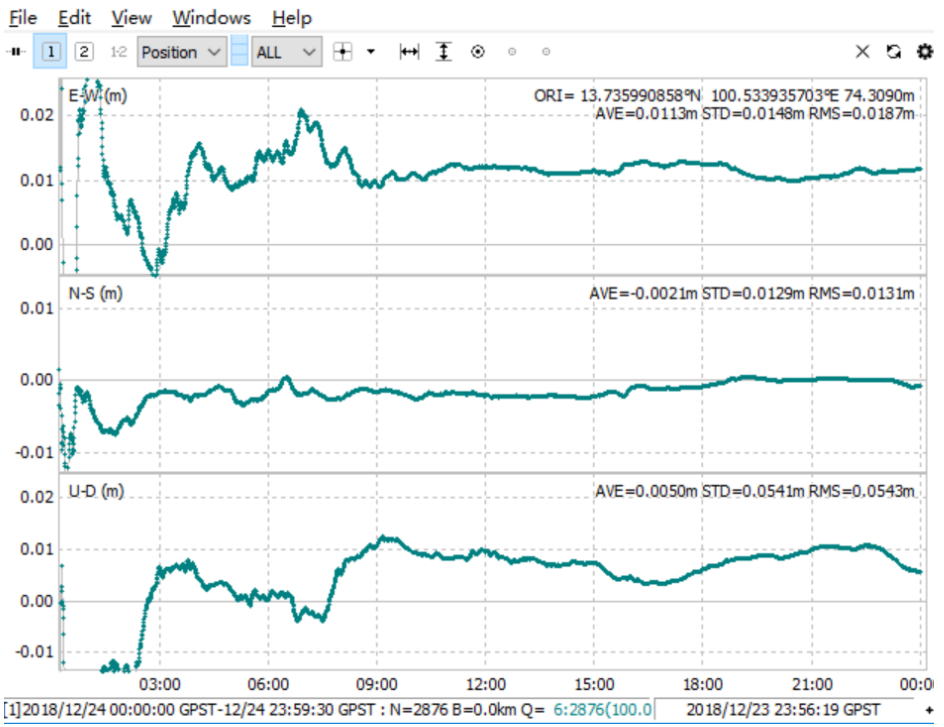
2.3.2 Example of Static PPP using RTKLIB



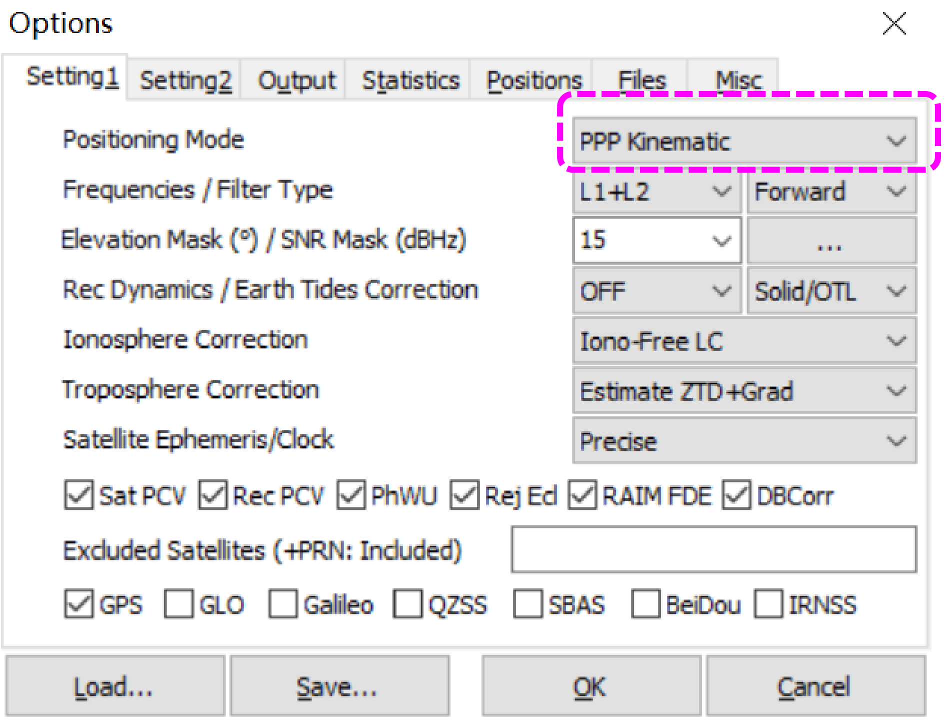


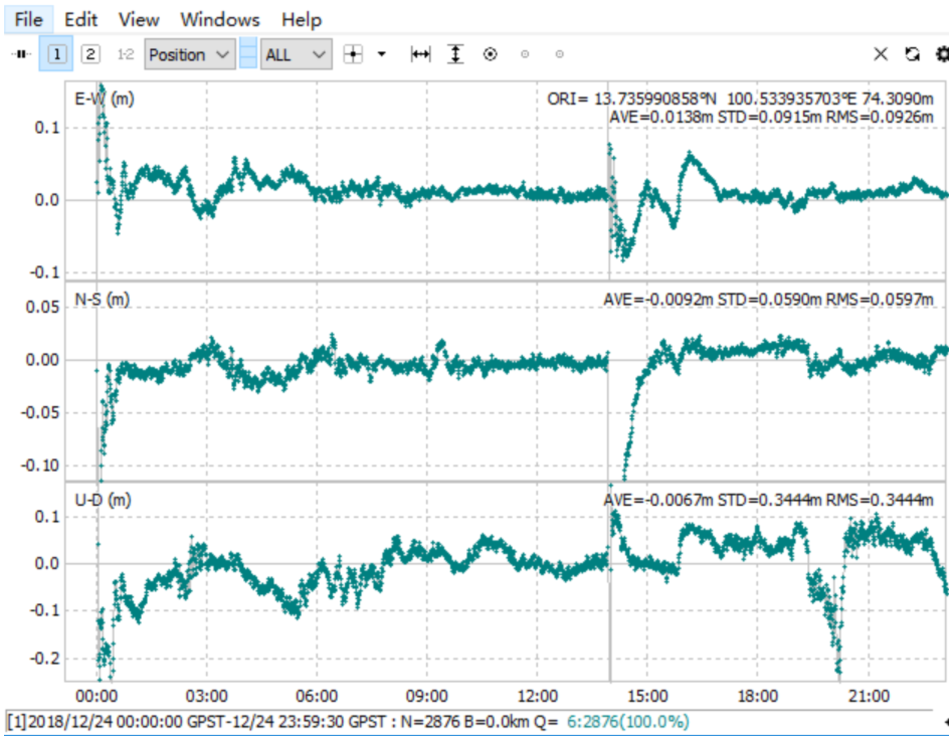
2.3.2 Example of Static PPP using RTKLIB





2.3.2 Example of Kinematic PPP using 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:

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

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

After station differencing:

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

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.

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

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

$$\hat{z} = Z^T \hat{a}, Q_z = Z^T Q_a Z$$

$$\breve{z} = \arg\min_{z \in Z^n} (\hat{z} - z)^T Q_z^{-1} (\hat{z} - z)$$

$$\breve{a} = Z^{-T} \breve{z}$$

2.4.1 Integer Least Square(ILS)

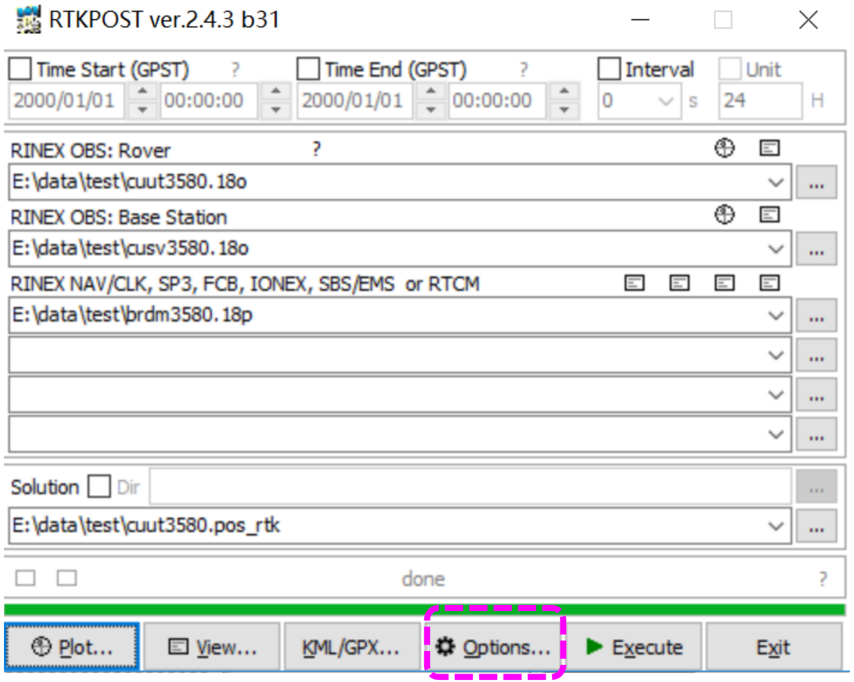
After ambiguity is fixed, the float coordinate solution will updated as:

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

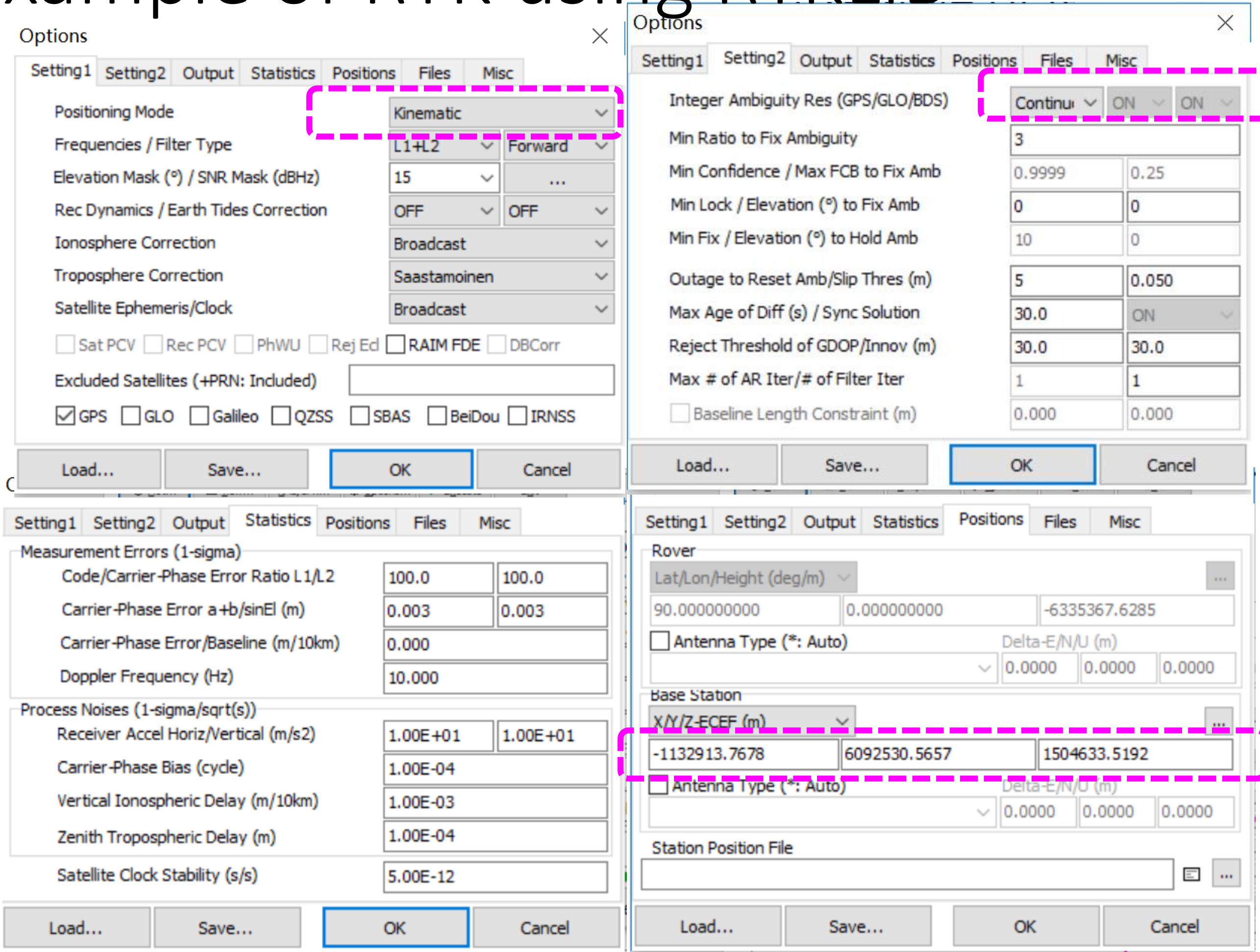
The covariance an also updated as:

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

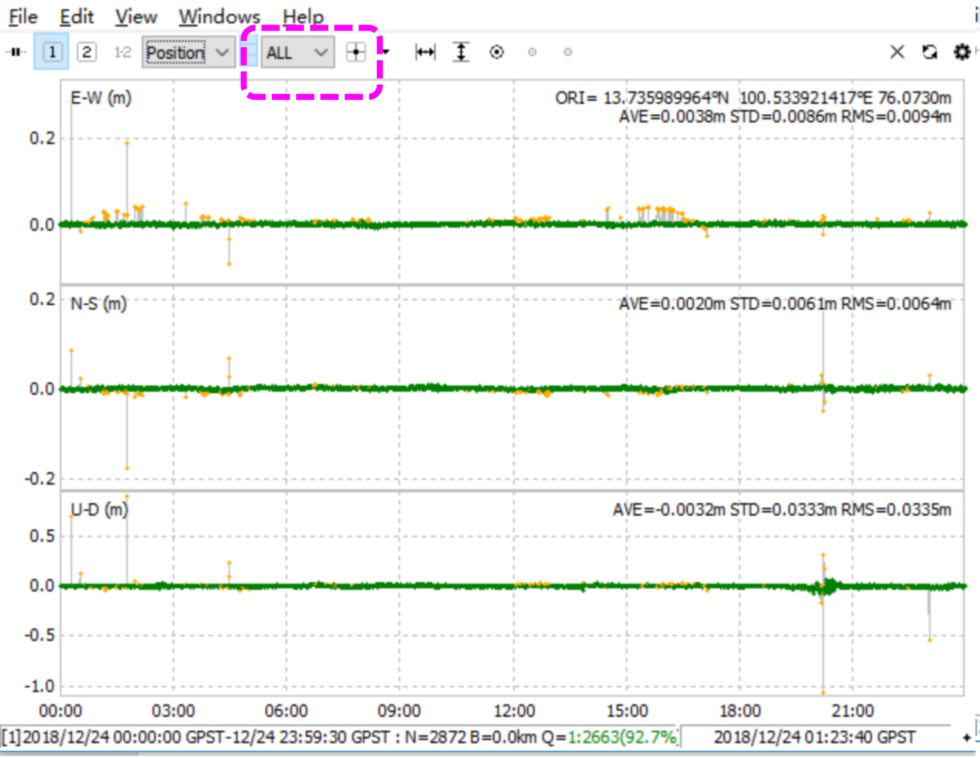
2.4.2 Example of RTK using RTKLIB



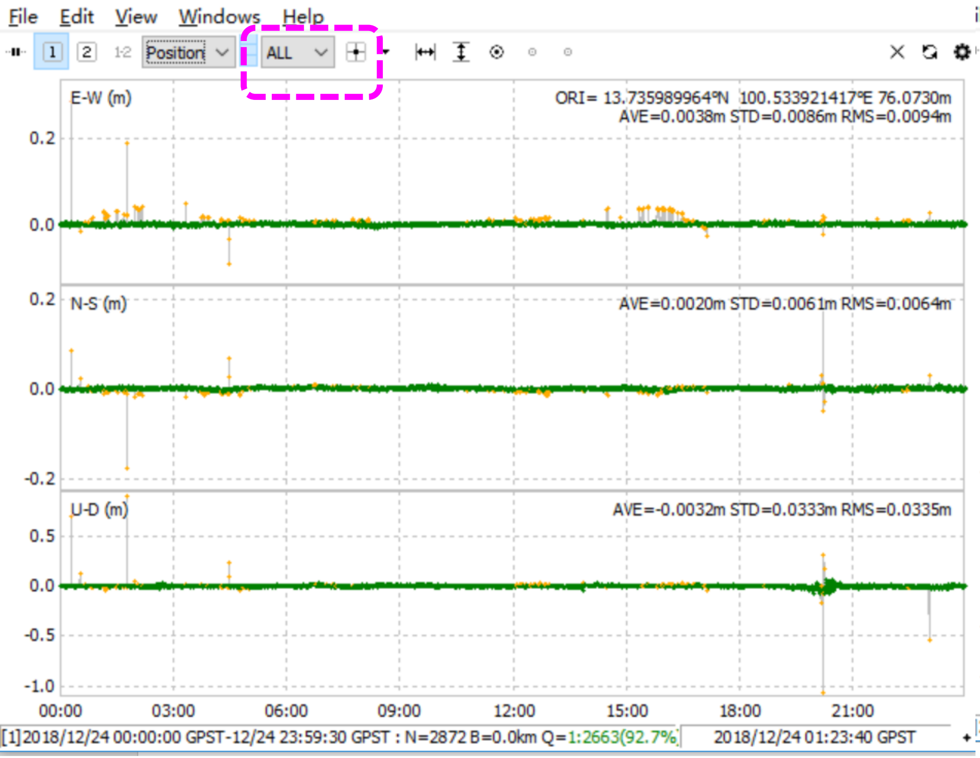
2.4.2 Example of RTK using RTKLIB



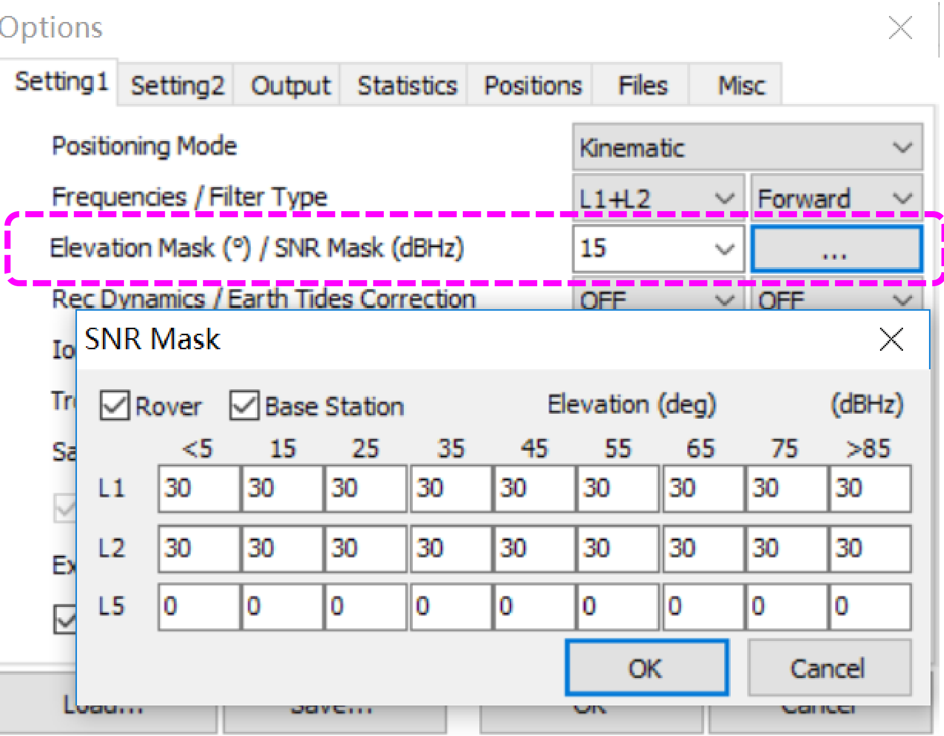
2.4.2 Example of RTK using RTKLIB

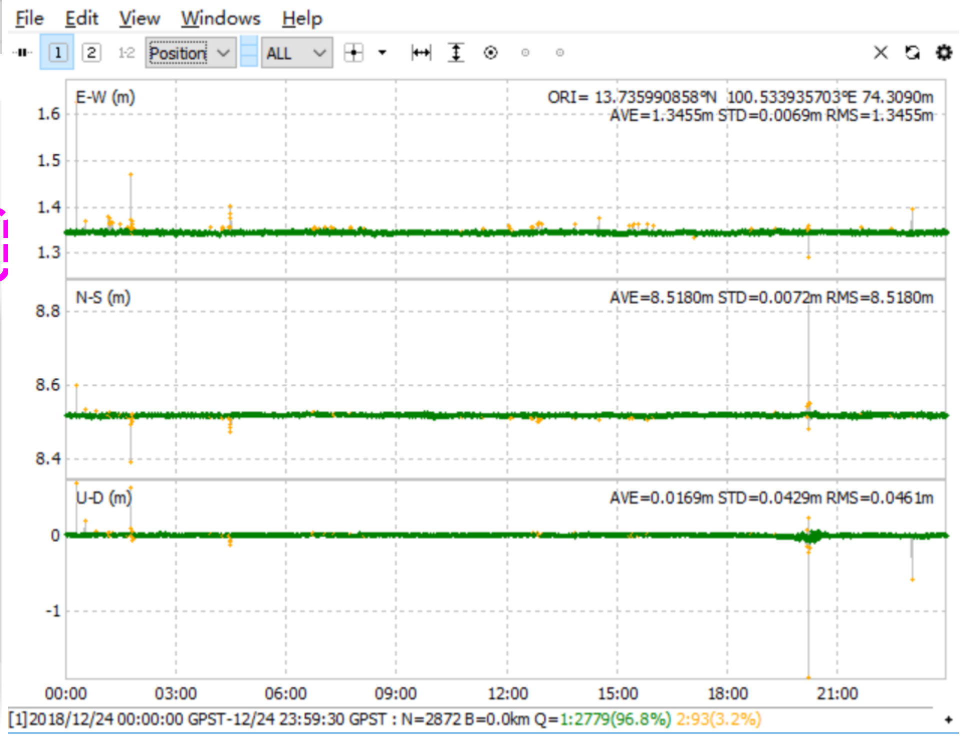


2.4.2 Example of RTK using RTKLIB



2.4.2 If we set SNR Mask





Fix rate will improve from 92.7% to 96.8%

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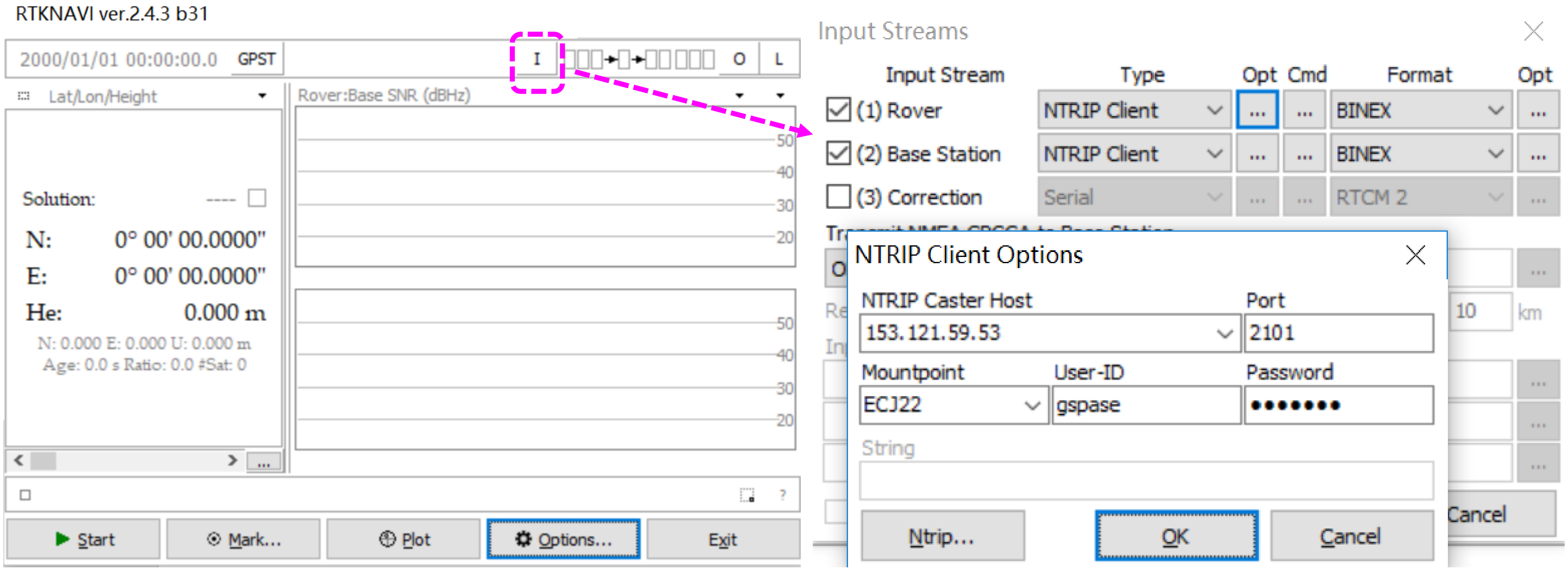
2.5 RTKNAVI

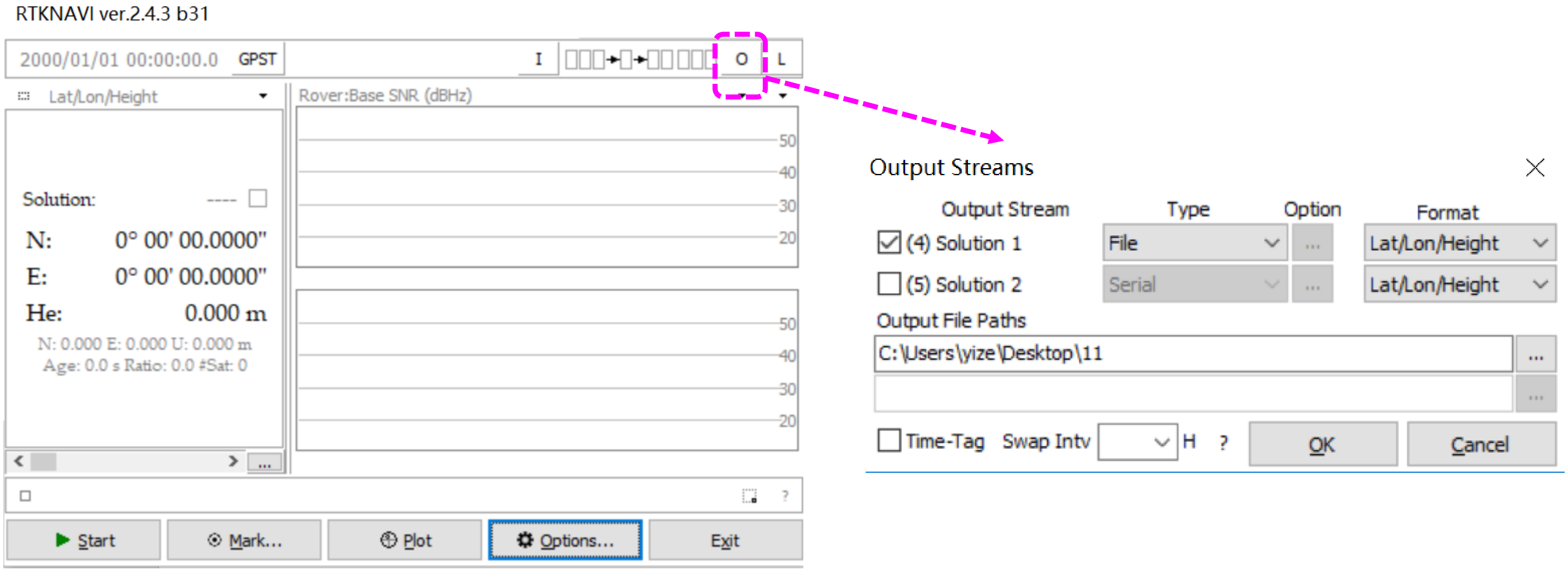
- RTKPOST is for post processing of GNSS data
- For real-time users, RTKNAVI is usually used.

2.5 RTKNAVI



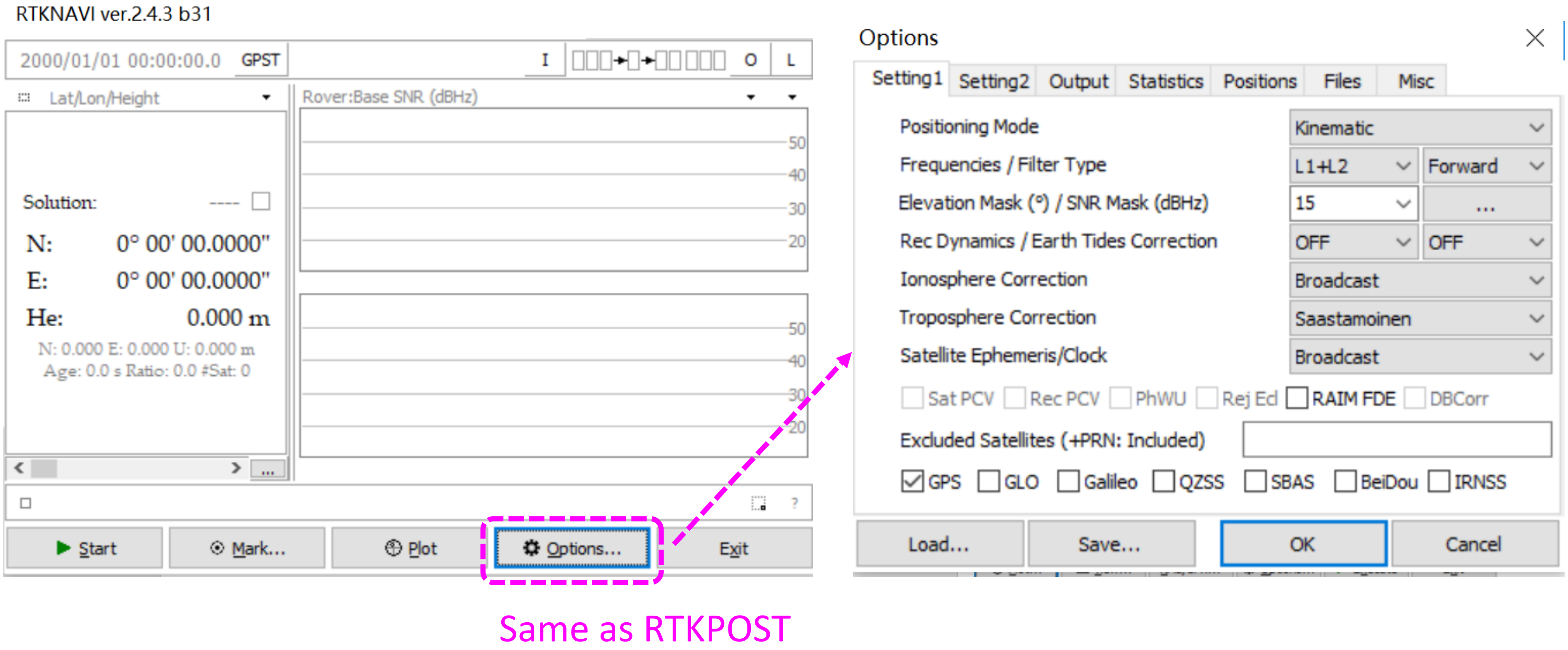
RTKNAVI ver.2.4.3 b31
2000/01/01 00:00:00.0
GPST
I
O
L
Lat/Lon/Height
Rover:Base SNR (dBHz)
Solution:
N: 0° 00' 00.0000"
E: 0° 00' 00.0000"
He: 0.000 m
N: 0.000 E: 0.000 U: 0.000 m
Age: 0.0 s Ratio: 0.0 #Sat: 0
Start
Mark...
Plot
Options...
Exit
Input Streams
Input Stream
Type
Opt
Cmd
Format
Opt
(1) Rover
NTRIP Client
BINEX
(2) Base Station
NTRIP Client
BINEX
(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
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
50
40
30
20
Start
Mark...
Plot
Options...
Exit
Output Streams
Output Stream
Type
Option
Format
(4) Solution 1
File
Lat/Lon/Height
(5) Solution 2
Serial
Lat/Lon/Height
Output File Paths
C:\Users\yize\Desktop\11
Time-Tag
Swap Intv
H
?
OK
Cancel

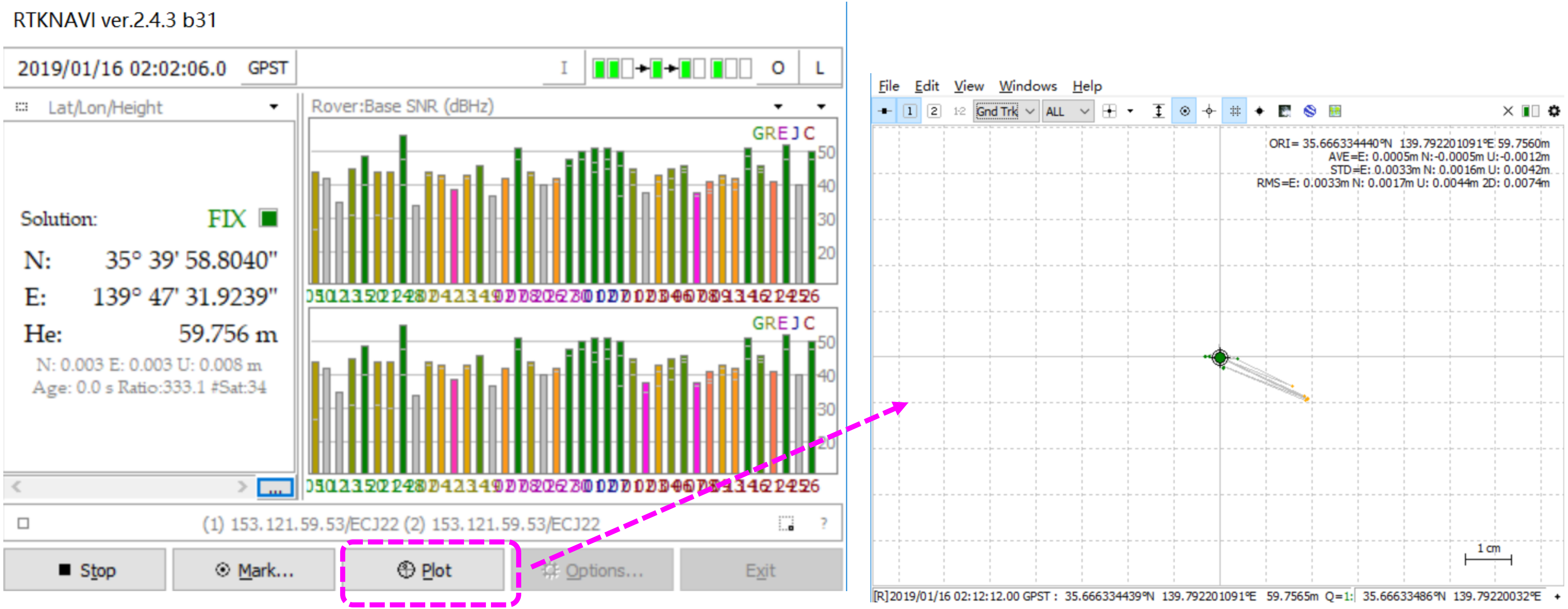
2.5 RTKNAVI



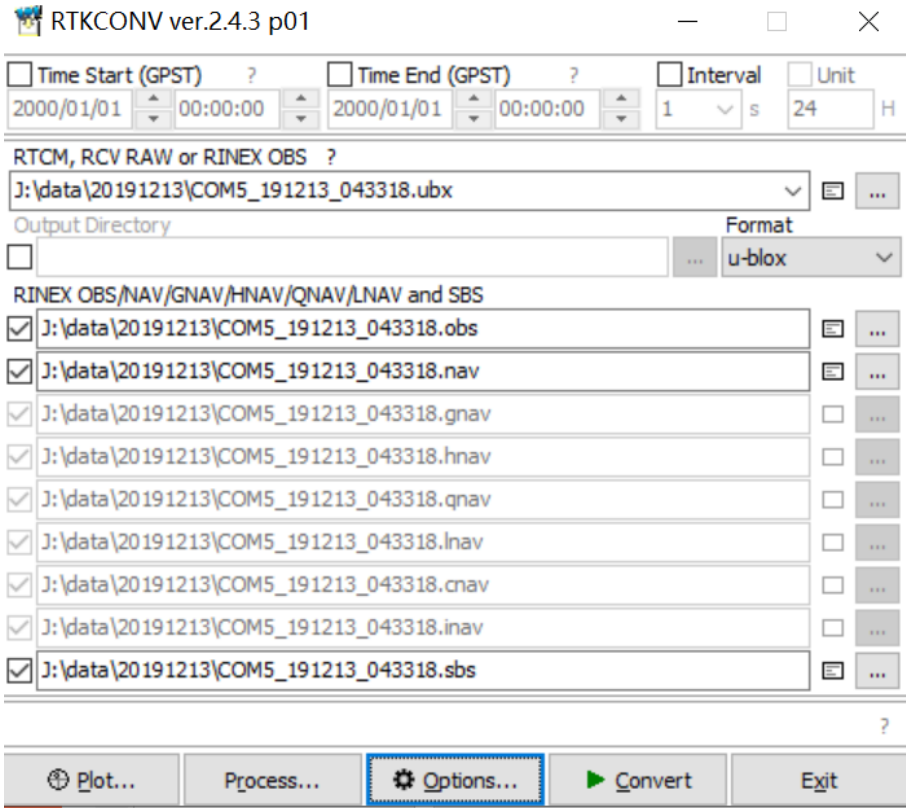
RTKNAVI ver.2.4.3 b31
2000/01/01 00:00:00.0 GPST
Lat/Lon/Height
Rover:Base SNR (dBHz)
Solution:
N: 0° 00' 00.0000"
E: 0° 00' 00.0000"
He: 0.000 m
N: 0.000 E: 0.000 U: 0.000 m
Age: 0.0 s Ratio: 0.0 #Sat: 0
Start
Mark...
Plot
Options...
Exit
Options
Setting1
Setting2
Output
Statistics
Positions
Files
Misc
Positioning Mode
Kinematic
Frequencies / Filter Type
L1+L2
Forward
Elevation Mask (°) / SNR Mask (dBHz)
15
Rec Dynamics / Earth Tides Correction
OFF
OFF
Ionosphere Correction
Broadcast
Troposphere Correction
Saastamoinen
Satellite Ephemeris/Clock
Broadcast
Sat PCV
Rec PCV
PhWU
Rej Ecl
RAIM FDE
DBCorr
Excluded Satellites (+PRN: Included)
GPS
GLO
Galileo
QZSS
SBAS
BeiDou
IRNSS
Load...
Save...
OK
Cancel
Same as RTKPOST

2.5 RTKNAVI

2.5 RTKNAVI


RTKNAVI ver.2.4.3 b31
2019/01/16 02:02:06.0 GPST
Lat/Lon/Height
Rover:Base SNR (dBHz)
Solution: FIX
N: 35° 39' 58.8040"
E: 139° 47' 31.9239"
He: 59.756 m
N: 0.003 E: 0.003 U: 0.008 m
Age: 0.0 s Ratio:333.1 #Sat:34
(1) 153.121.59.53/ECJ22 (2) 153.121.59.53/ECJ22
Stop
Mark...
Plot
Options...
Exit
File Edit View Windows Help
Gnd Trk
ALL
ORI= 35.666334440°N 139.792201091°E 59.7560m
AVE=E: 0.0005m N:-0.0005m U:-0.0012m
STD=E: 0.0033m N: 0.0016m U: 0.0042m
RMS=E: 0.0033m N: 0.0017m U: 0.0044m 2D: 0.0074m
1 cm
[R]2019/01/16 02:12:12.00 GPST : 35.666334439°N 139.792201091°E 59.7565m Q=1: 35.66633486°N 139.79220032°E

3 Other software: Modified RTKCONV v2.4.3 p01

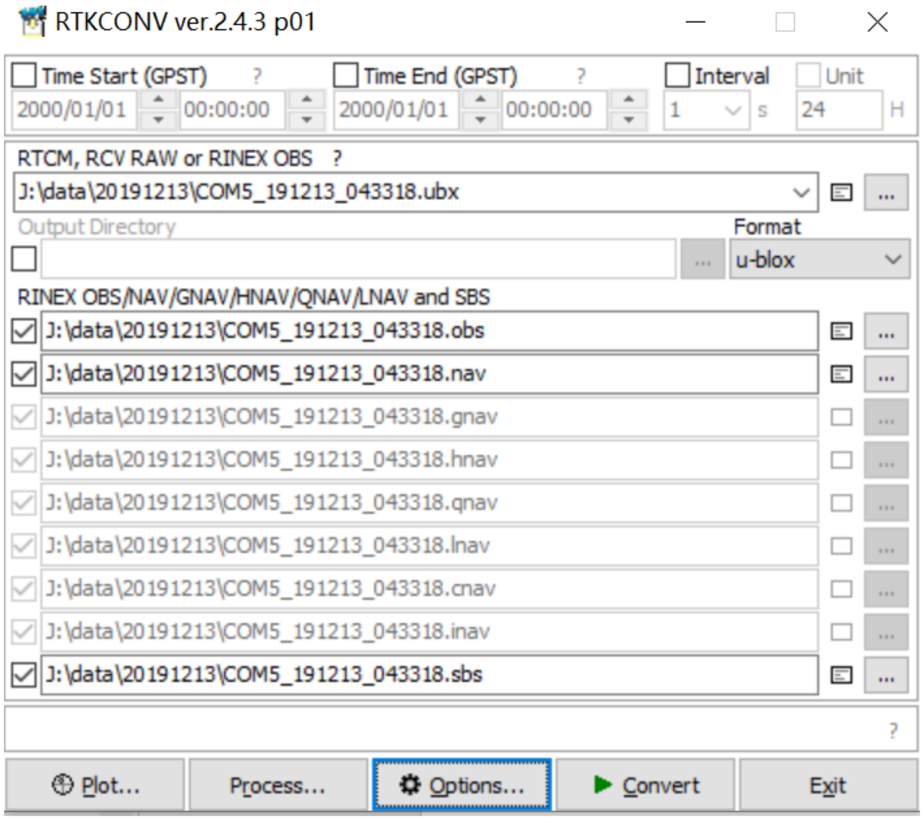


3 Other software

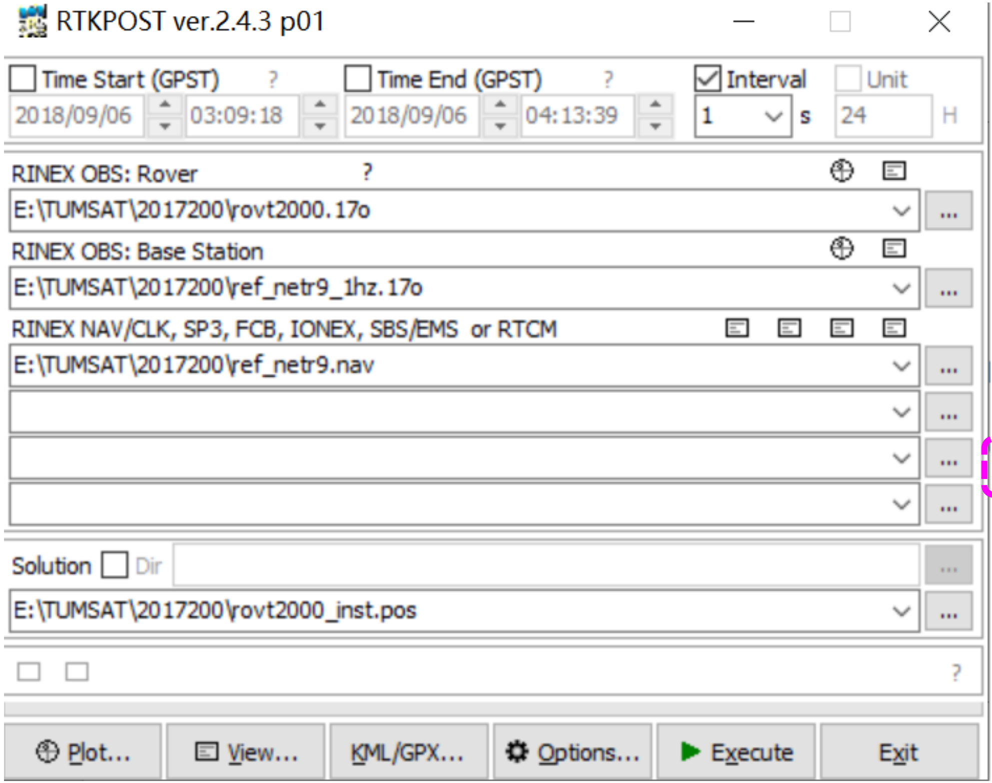
国立大学法人 東京海洋大学
Tokyo University of Marine Science and Technology

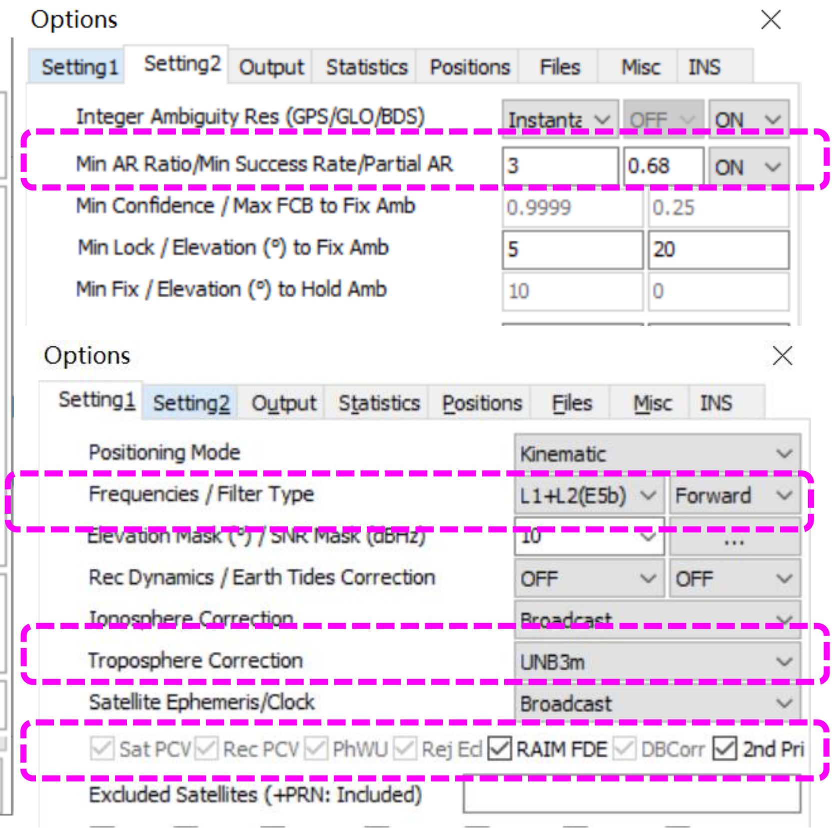
https://onedrive.live.com/?authkey=%21AJql2JkZaRwVhAM&id=CA40E2337C7D7327%2112977&cid=CA40E2337C7D7327

3 Modified RTKCONV v2.4.3 p01



3 Modified RTKPOST v2.4.3 p01





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

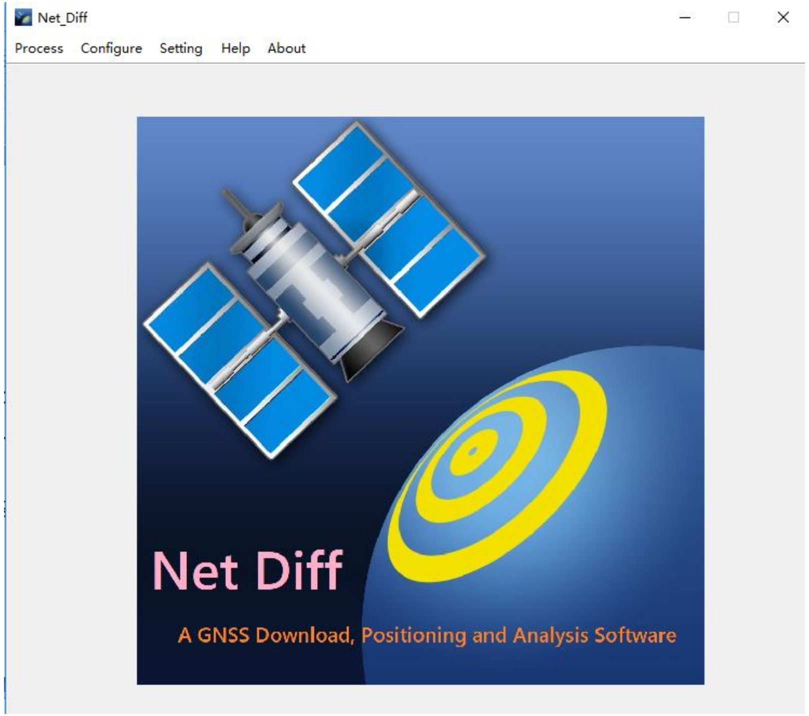
✓4 Data download

✓5 Observation and positioning analysis

✓6 Ntrip receiving, data conversion

✓7 Orbit simulation

- https://github.com/YizeZhang/Net_Diff



Thank you!