GNSS analysis software "GSILIB" for utilizing Multi-GNSS data

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Contents

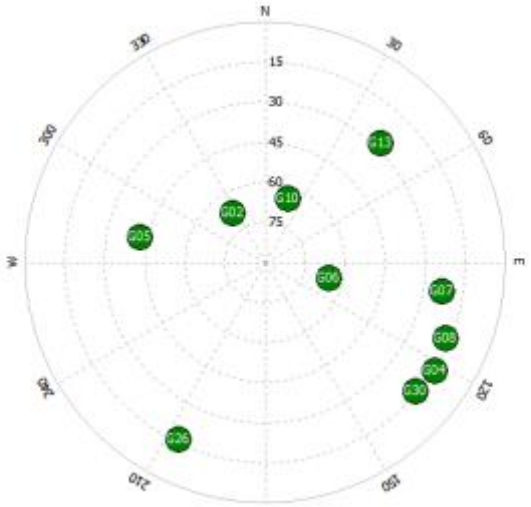
- Benefits of Multi-GNSS constellation
- Biases in Multi GNSS observations
- What is GSILIB?
- Demonstration of GSILIB

Benefits of Multi-GNSS constellation

Benefits of Multi-GNSS

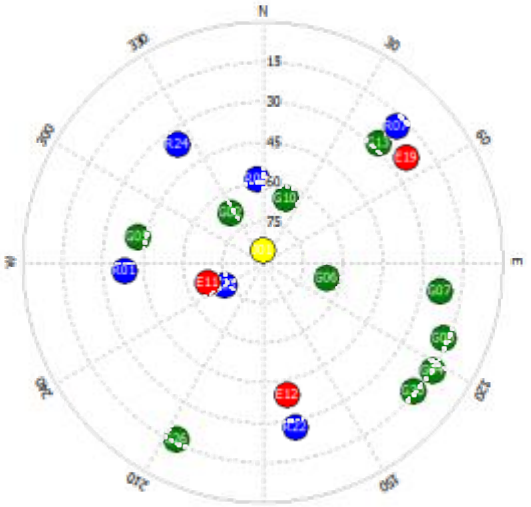
- Significant improvement of number of visible satellites, accuracy, convergence time

GPS



#of SVs 10
PDOP 2.1

GPS+GLO+GAL+QZS

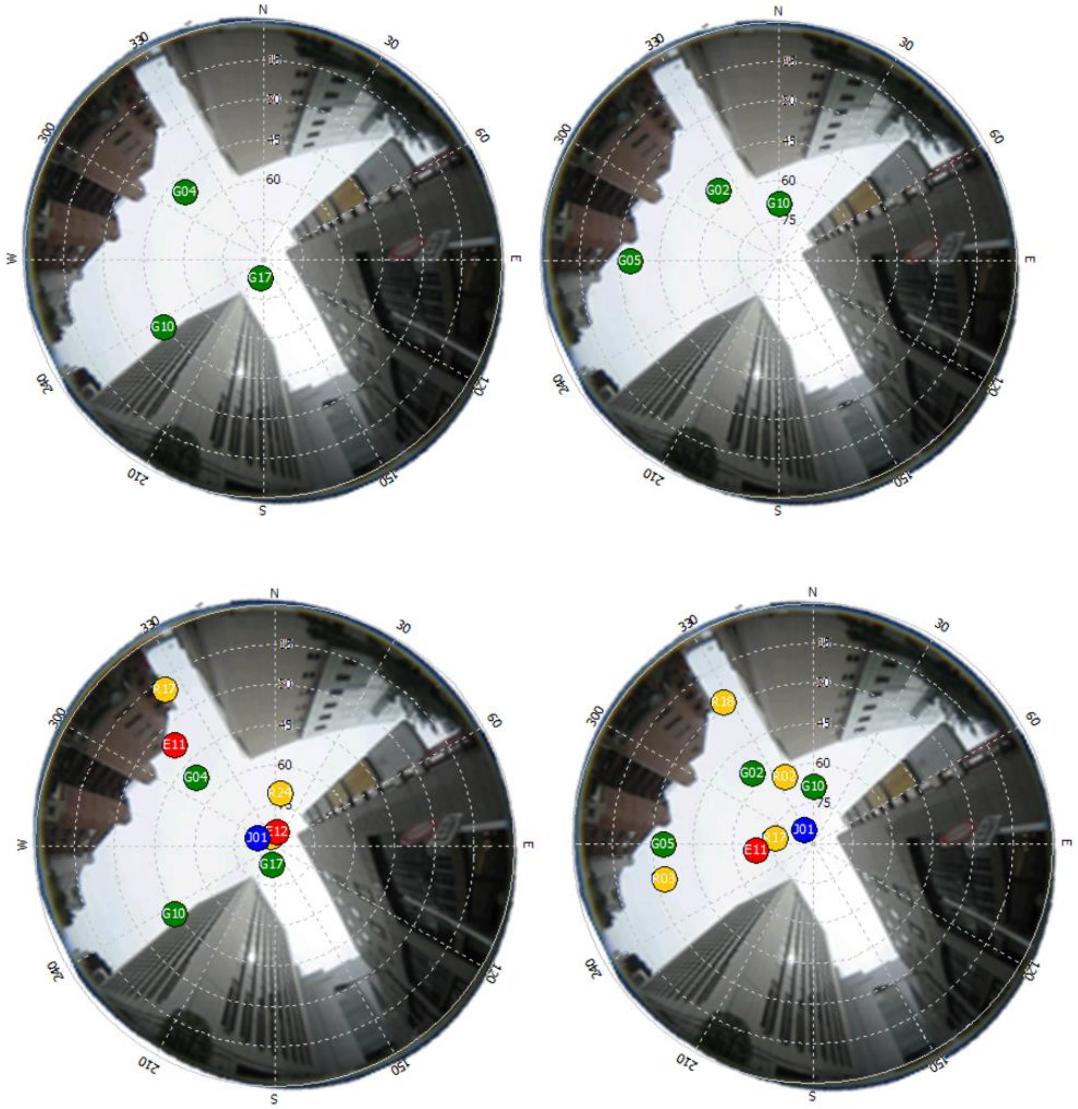


#of SVs 20
PDOP 1.3

2014/08/09 12:00:00 <GPST> Tokyo Japan
Elevation mask is 15deg
Plotted by GSIPLOT

Improvement of satellite visibility

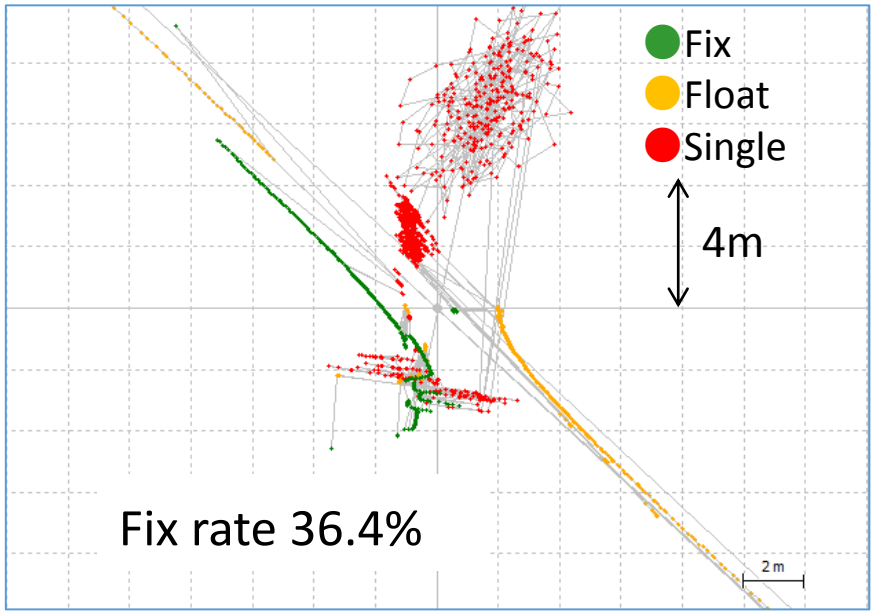
Nov. 13, 2013 at Ginza, Tokyo



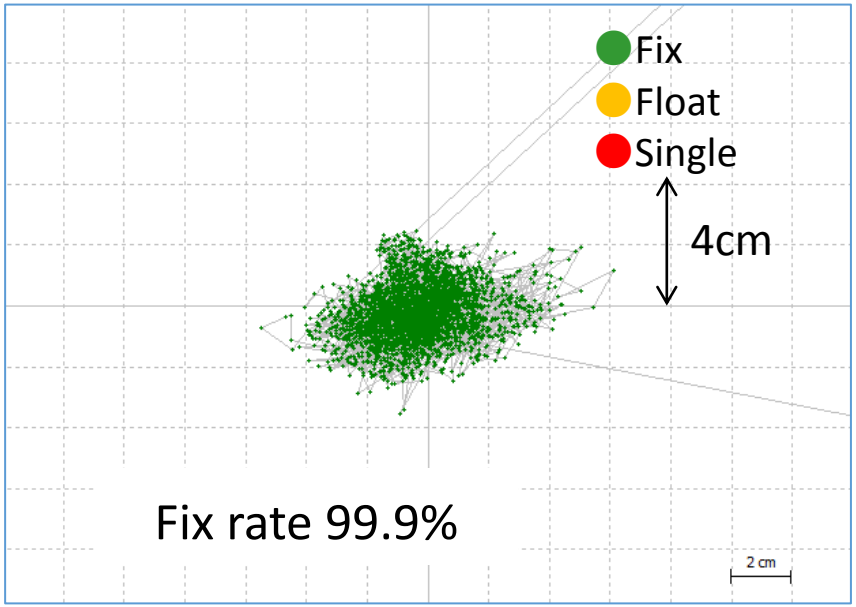
- GPS only:
  - 3 satellites
  - positioning impossible
- Multi-GNSS:
  - **8-9 satellites**
  - enables positioning in urban areas

Improvement of accuracy in urban area

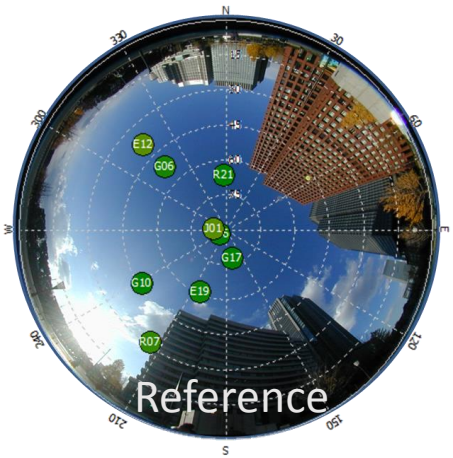
GPS

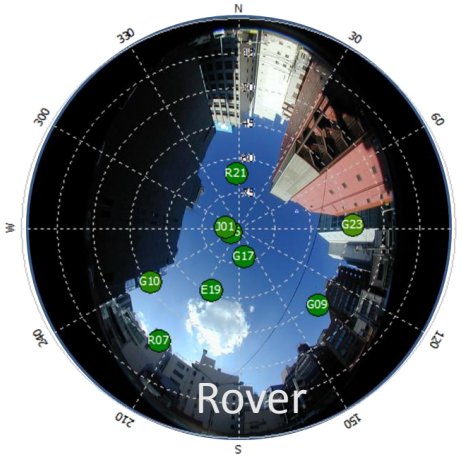


GPS+GLONASS+QZSS+Galileo



Skyview



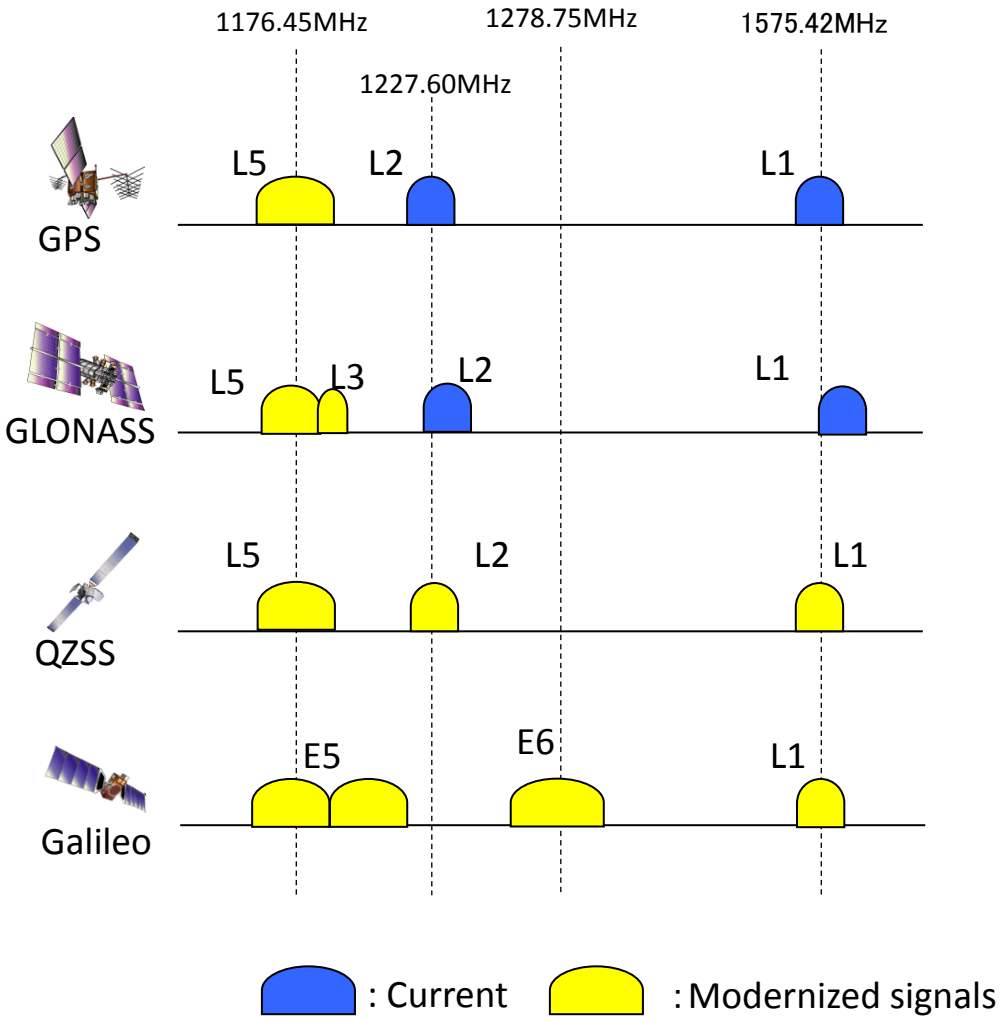


- Positions with GPS only largely degraded in urban area
- Multi-GNSS observation dramatically improved the performance to the cm-level accuracy

Fast convergence using Multiple frequencies

- Dual frequency
  (L1 + L2)

- Triple, Quadruple frequencies
  (L1+L2+L5+E6)
- Enables fast convergence because of increased number of observables

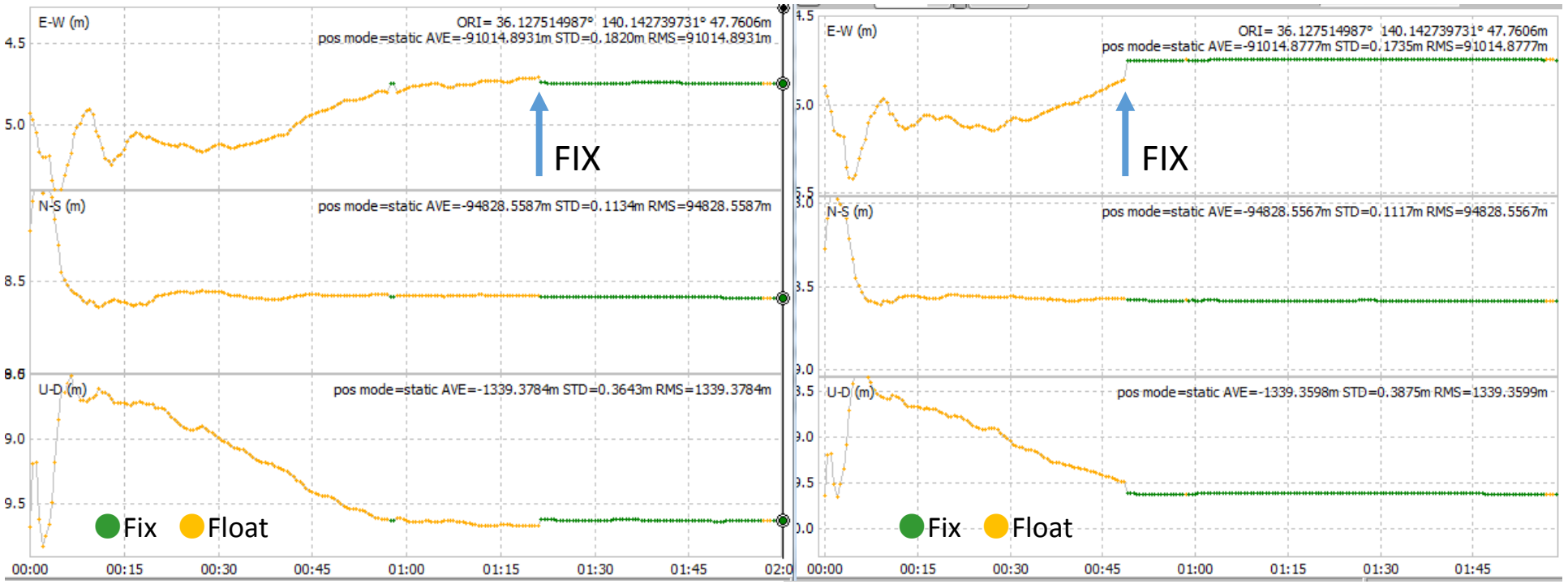


Open signals structure

Positioning with triple frequencies

L1+L2
(Convergence: 82 min.)

L1+L2+L5
(Convergence: 49 min.)



Jan. 1, 2013 0:00～2:00 (UTC)
mode: Static baseline:126.3km

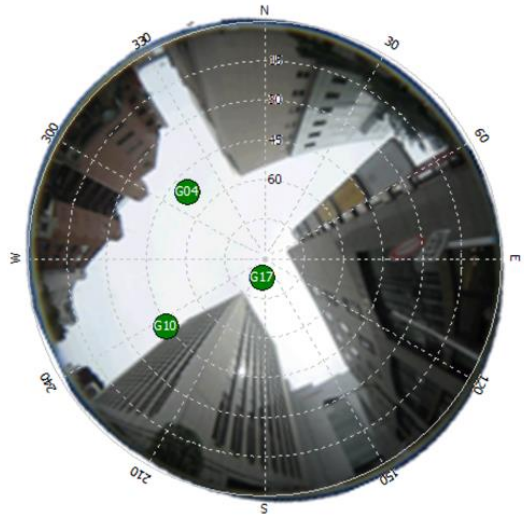
- Triple frequency (L1+L2+L5) accelerate the convergence time (TTF: Time to fix)

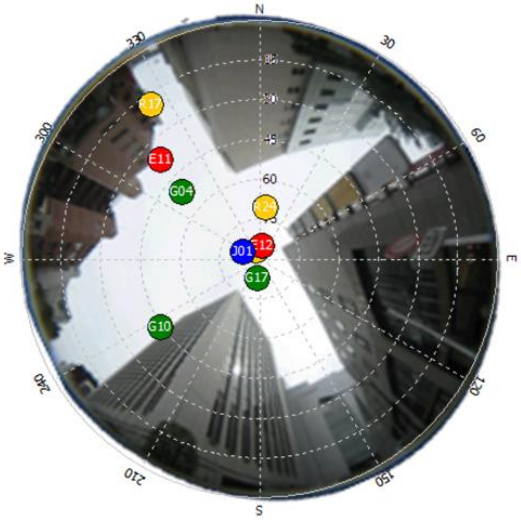
Benefits of Multi-GNSS

- Increased visible satellites

- Improvement of:
  1. Availability
  2. positioning accuracy
  3. convergence time

- Efficient, accurate, reliable positionings





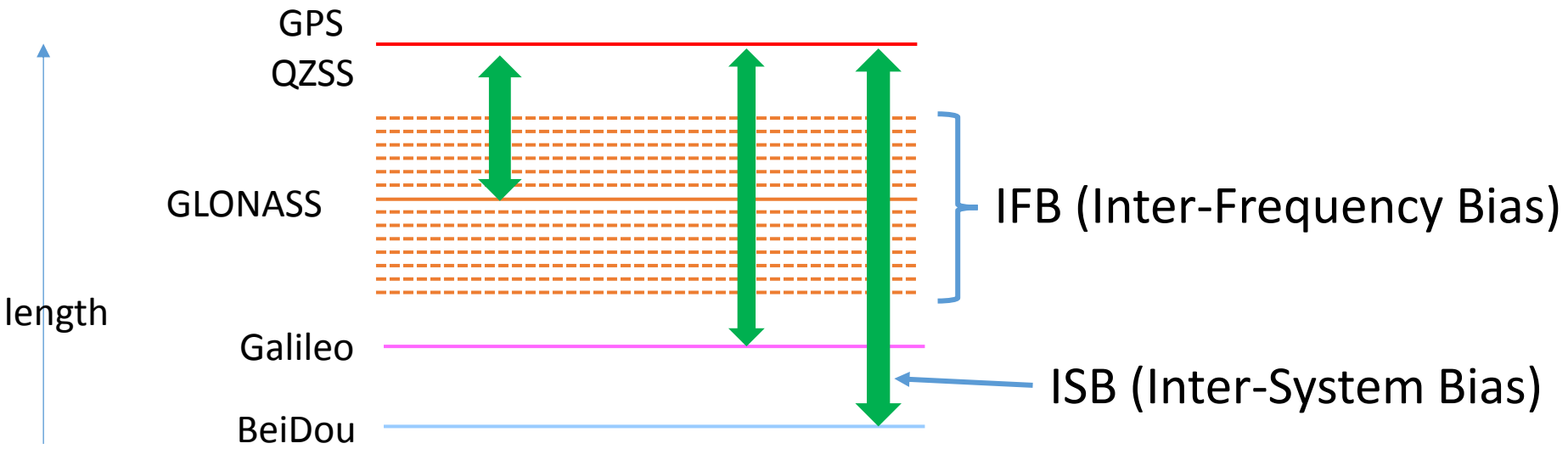
Biases in Multi-GNSS positioning

Biases in Multi-GNSS positioning

- Small delays between the signal transmission and reception of the signal in the GNSS receiver
- Major biases:

1. Inter-System Bias (ISB)
2. Inter-Frequency Bias (IFB)
3. Quarter cycle shift between L2P(Y) and L2C signals

Hardware-induced biases: ISB and IFB



- Inter-System Bias (ISB)

  Inter-system delay due to receiver and satellite hardwares

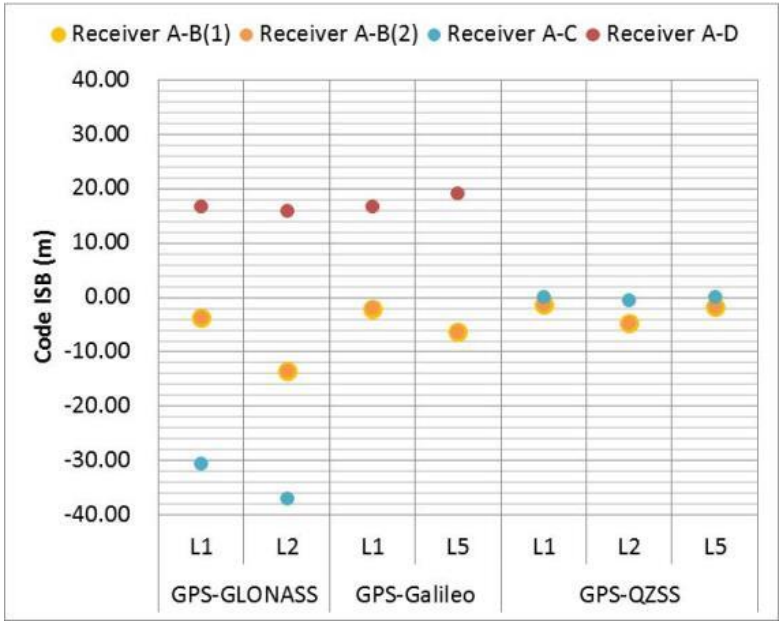
- Inter-Frequency Bias (IFB)

  caused by carrier frequency differences, especially due to FDMA of GLONASS

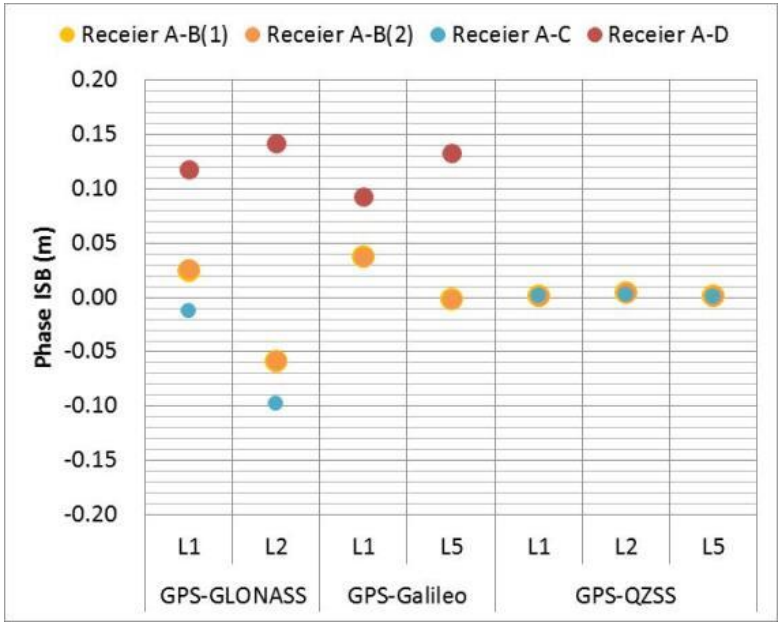
Correction is required for relative positioning using different types of receivers

Inter-System Bias (ISB)

Code ISB



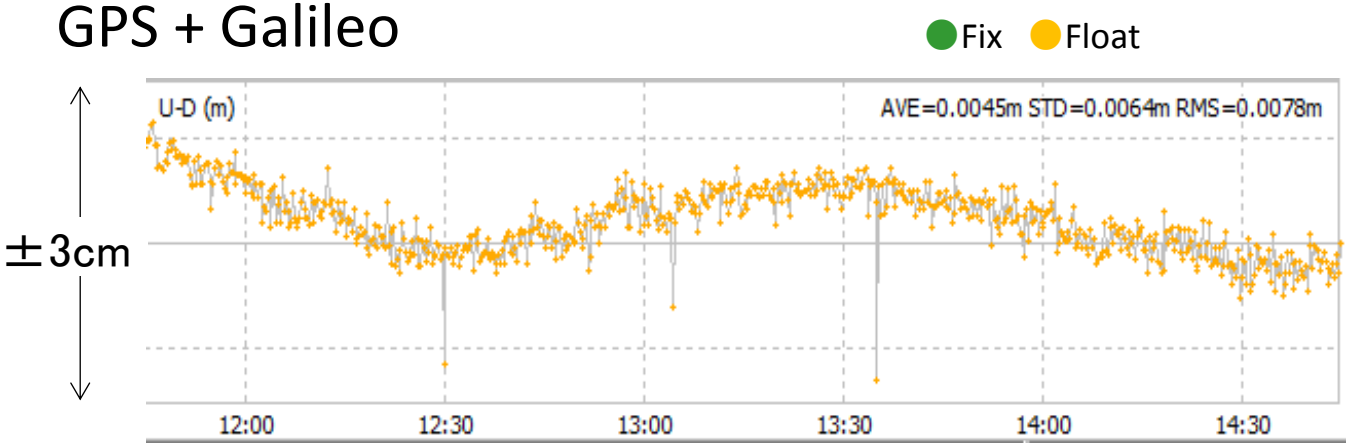
Phase ISB



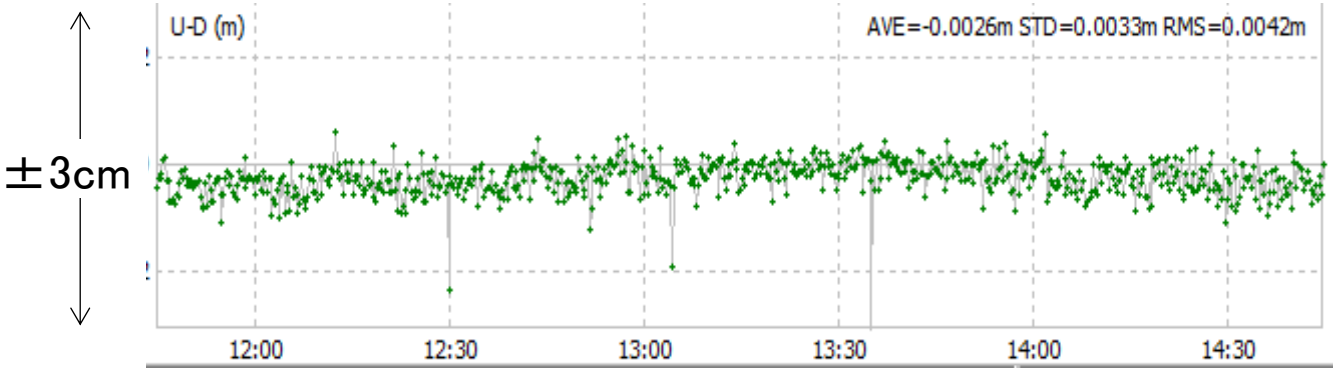
- Found in GPS vs GLONASS vs Galileo data
- Depends on the types of receiver

Inter-System Bias (ISB)

GPS + Galileo



GPS + Galileo (with ISB correction)



mode: kinematic, baseline: 0m, 3hrs

Inter-Frequency Bias (IFB)

IFB model

$$f_{L2,k} = f_{0,L2} + k * df_{L2}$$
$$f_{L1,k} = f_{0,L1} + k * df_{L1}$$
$$k: slot\ number$$

$$\Rightarrow \quad IFB = A * k$$

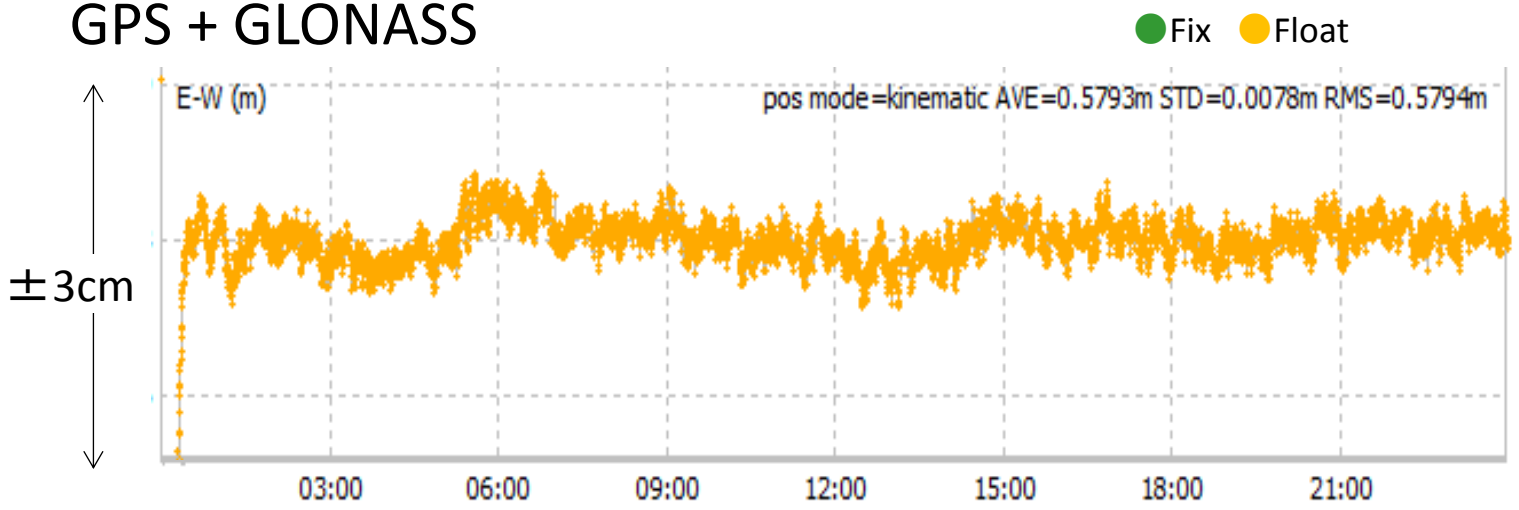
Estimated IFB with respect to receiver A(S/N1)（cm/channel）

	receiver A (S/N2)	receiver B (S/N1)	receiver B (S/N2)	receiver C	receive D
L1	0.03	-0.72	-0.74	-0.50	2.98
L2	-0.04	-1.04	-1.02	-0.49	2.93

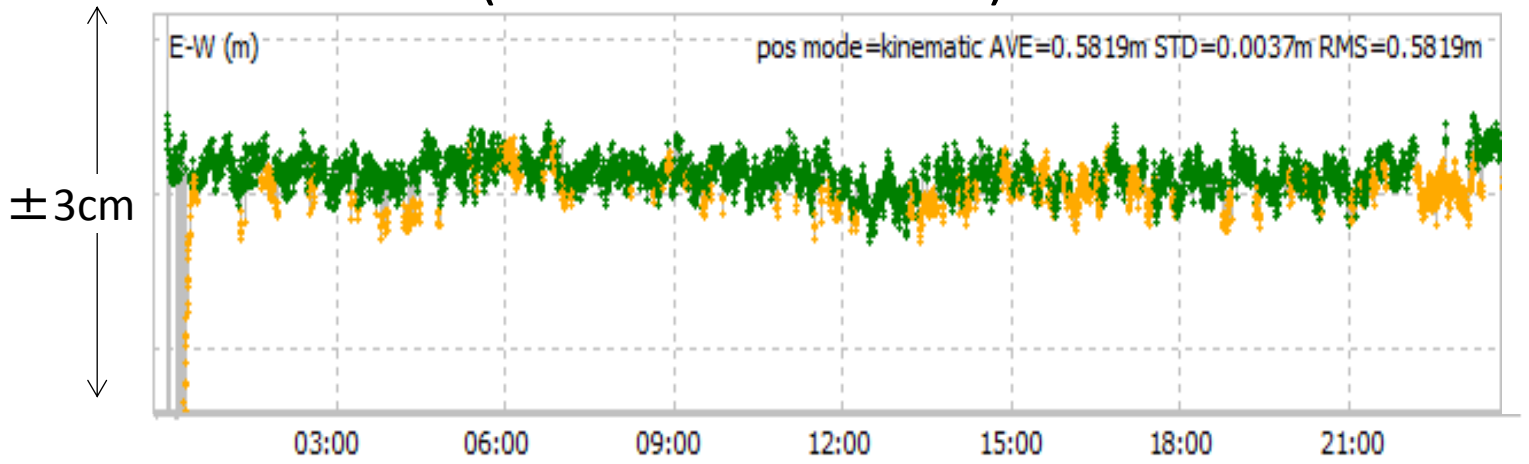
- IFB is frequency dependent hardware-induced bias, especially for the FDMA of GLONASS signals.
- IFB (cm/channel) are consistent between same receiver types.

Inter-Frequency Bias (IFB)

GPS + GLONASS

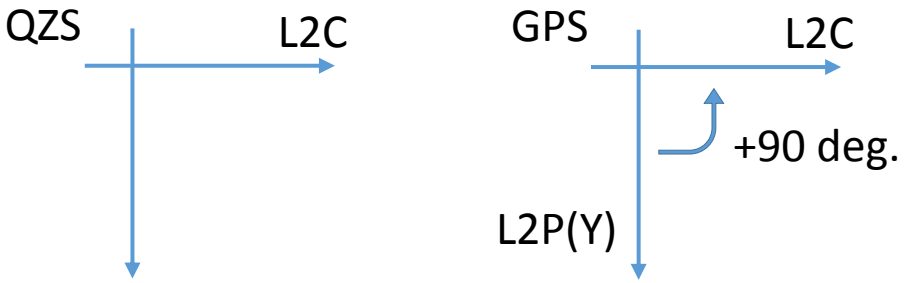


GPS + GLONASS (with IFB correction)



mode: kinematic, baseline: 1m, 24hrs

Quarter-cycle shift for L2C signal

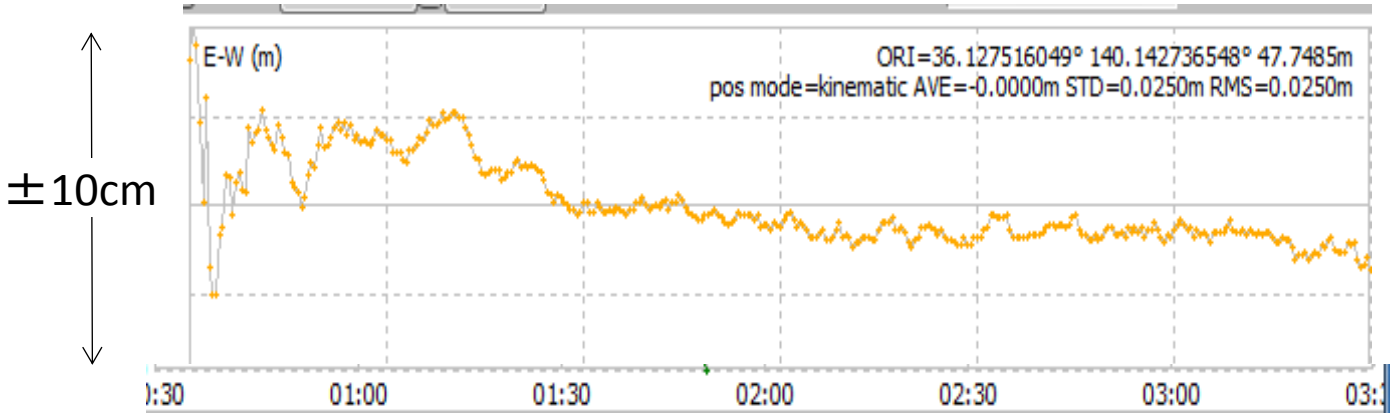


	Receiver A	Receiver B	Receiver C
GPS L2C	L2P(Y) + 1/4 cycle	0 (aligned by receiver)	L2P(Y) - 1/4 cycle
QZSS L2C	L2P(Y) + 1/4 cycle	0 (aligned by receiver)	L2P(Y) - 1/4 cycle

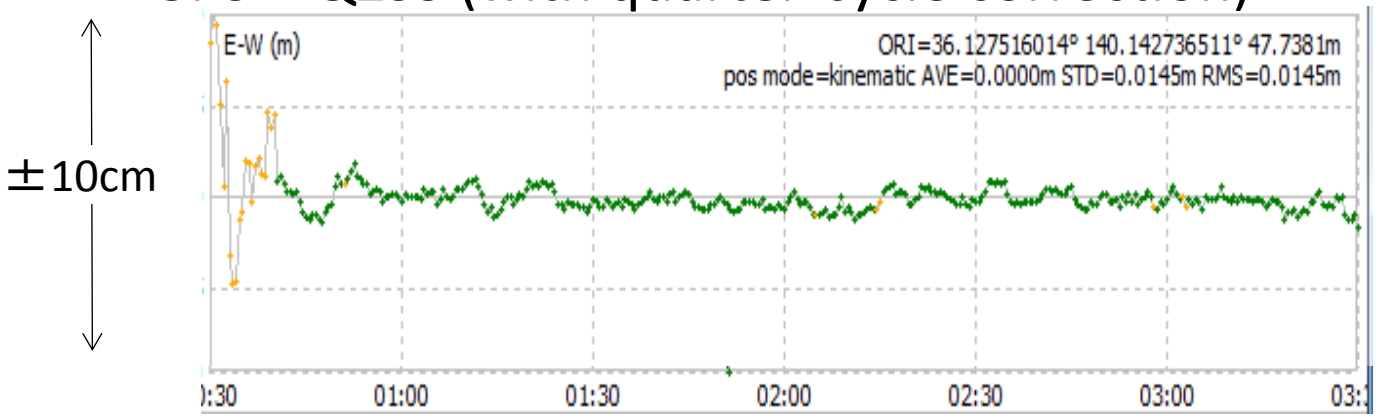
- The difference in the alignment of L2C signal vs L2P(Y)
- Bias arises in the double-differenced observable between L2C and L2P(Y) using different types of receivers

Quarter-cycle shift for L2C signals of GPS and QZSS

GPS + QZSS



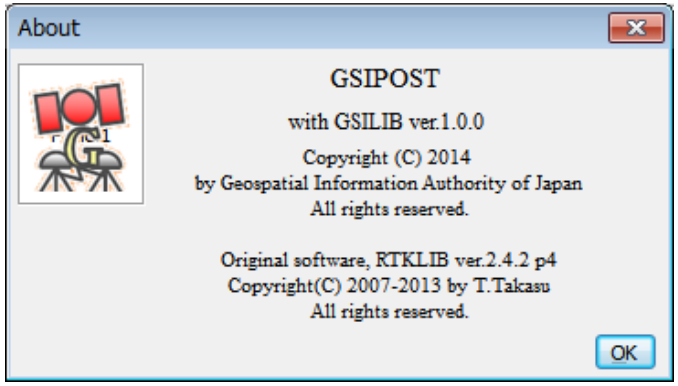
GPS + QZSS (with quarter-cycle correction)



GSILIB
(GNSS Survey Implementation Library)

What's GSILIB?

- Open source software package for GNSS positioning developed by GSI
- Fork of the RTKLIB software (by T. Takasu) with handling of multi-GNSS-related biases

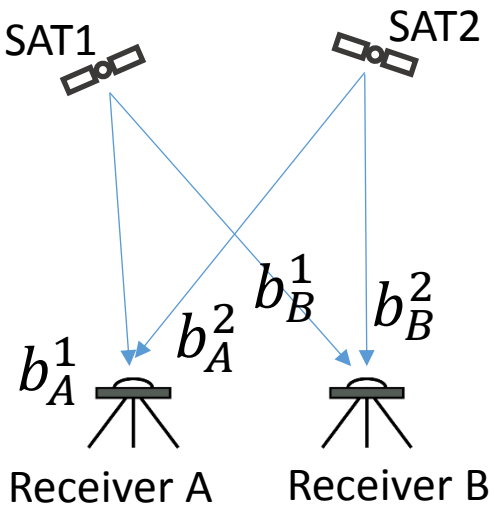


GSILIB: GNSS Surveying Implementation Library
(http://datahouse1.gsi.go.jp/gsilib/gsilib_download_eng.html)

GSILIB Features

- Corrections of biases in multi-GNSS data
  - Quarter-cycle biases
  - Inter frequency bias (IFB)
  - Inter system bias (ISB)
- Inherit all the functions of RTKLIB
  - Multi-GNSS data support: GPS, GLONASS, QZSS, Galileo, SBAS
  - Various positioning modes: RTK, Static, PPP, etc.
- Simple GUI (Windows) and CUI (Windows, Linux) interfaces

The effect of hardware dependent biases



- DD bias:

$$(b_A^{Sat1} - b_B^{Sat1}) - (b_A^{Sat2} - b_B^{Sat2})$$

		ISB	IFB	L2C 1/4 cycle
Sat Sys Rec Type	1 – 1 A – A	Canceled	Canceled	–
Sat Sys Rec Type	1 – 1 A – B	Canceled	**Arise**	**Arise**
Sat Sys Rec Type	1 – 2 A – A	Canceled	–	–
Sat Sys Rec Type	1 – 2 A – B	**Arise**	–	**Arise**

Strategy for bias corrections in GSILIB

1. Calibration of biases in multi-GNSS data
   - Inter system bias (ISB)
   - Inter frequency bias (IFB)
   - Quarter-cycle shift

2. Save the biases to table files

3. Import pre-determined tables in positioning

Demonstration of GSILIB

Summary

- Multi-GNSS environment improves availability, accuracy, reliability, convergence of GNSS positioning
- However, some biases have to be considered
  - IFB, ISB, quarter-cycle shift
- **GSILIB is an open-source software**, which offers the **table-based corrections of IFB, ISB and quarter-cycle shift** to utilize multi-GNSS data

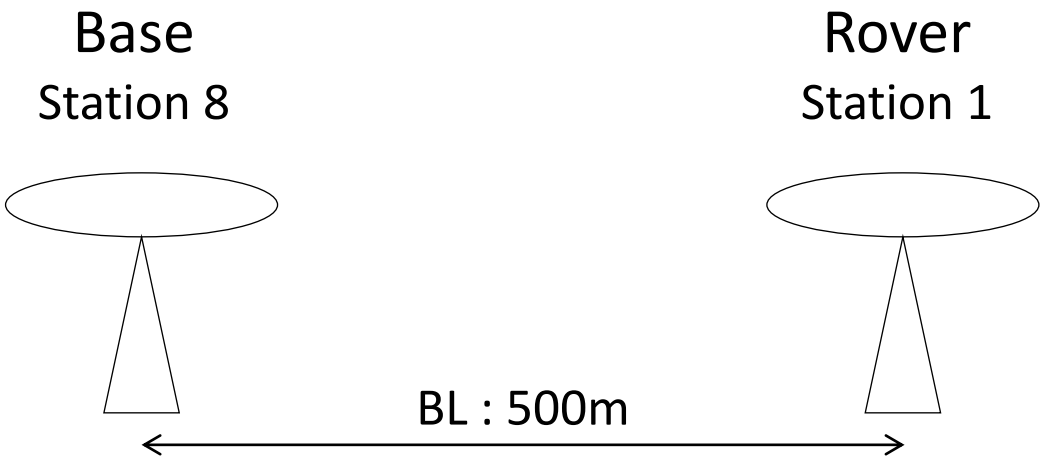
http://datahouse1.gsi.go.jp/gsilib/gsilib_download_eng.html

GSILIB demonstration

1. RTK using GPS (No bias)
2. RTK using GPS + GLONASS (IFB correction)
3. RTK using GPS + QZSS (L2C quarter cycle shift)
4. RTK using GPS + Galileo (ISB correction)
5. RTK using GPS + GLONASS + QZSS + Galileo (all corrections)

GSILIB Demonstration 1

- RTK using GPS



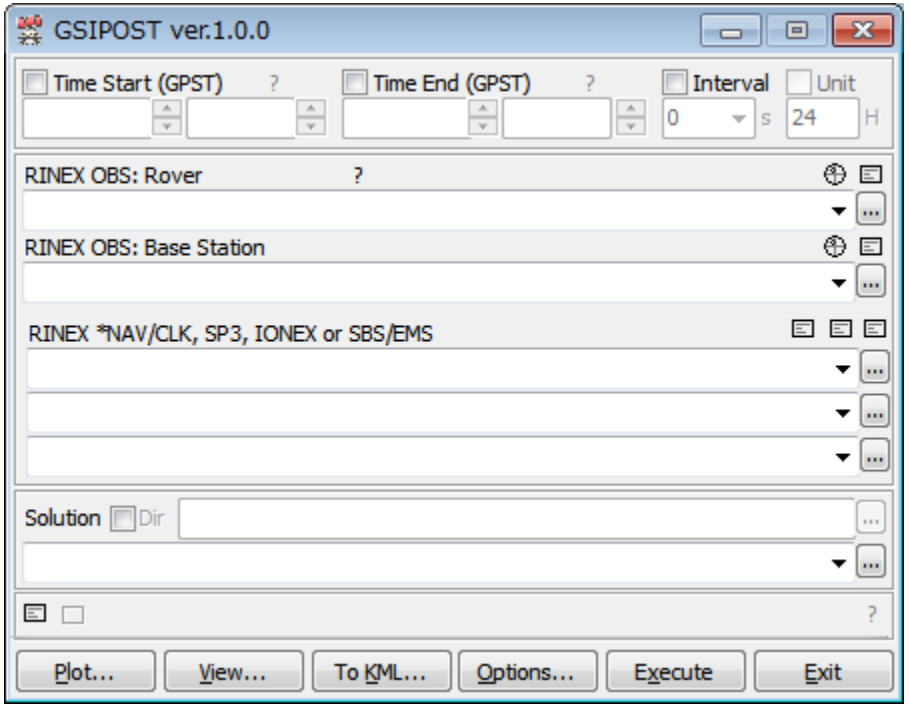
Antenna : JAV_GRANT-G3T
Receiver : JAVAD TRE_G3T DELTA

Flow of analysis

1. Configuration of positioning options
2. Setting of input RINEX files, output directory
3. Start processing
4. Show the result

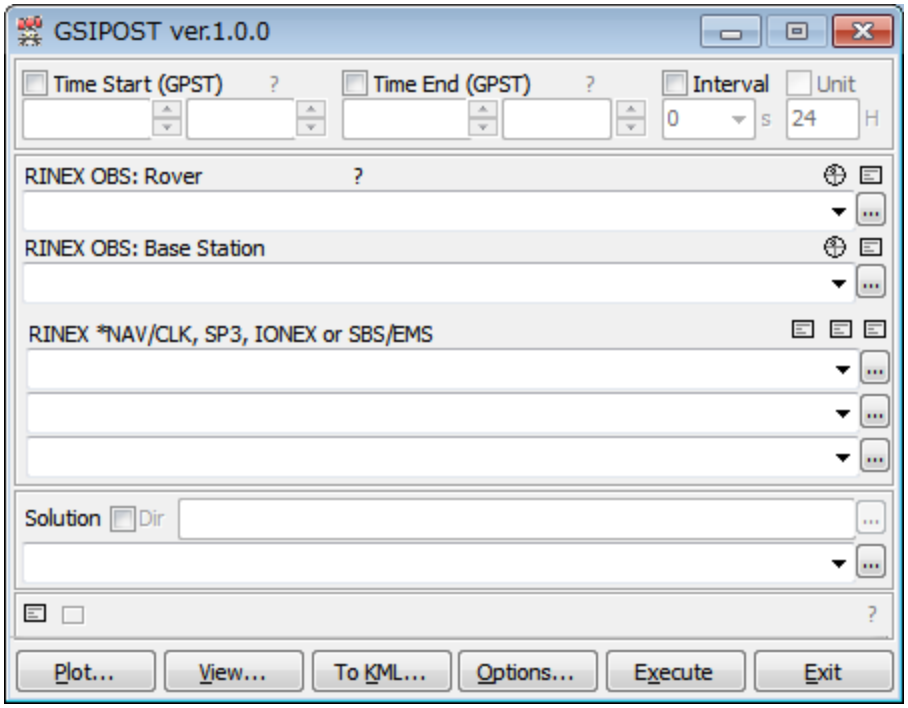
Launch gsipost_gui.exe

gsilib/bin/



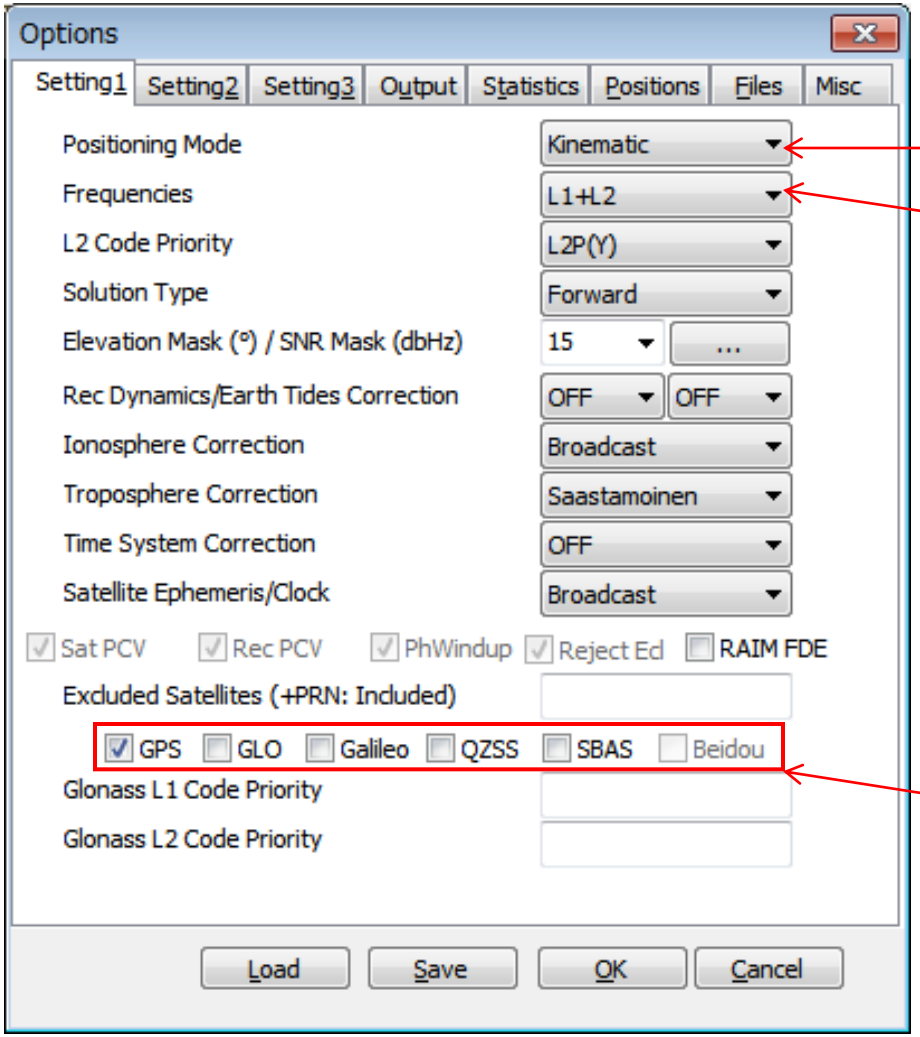
Post Processing tool of GSILIB

1: Configuration



Configure positioning options

(1-1) Positioning options: Setting 1

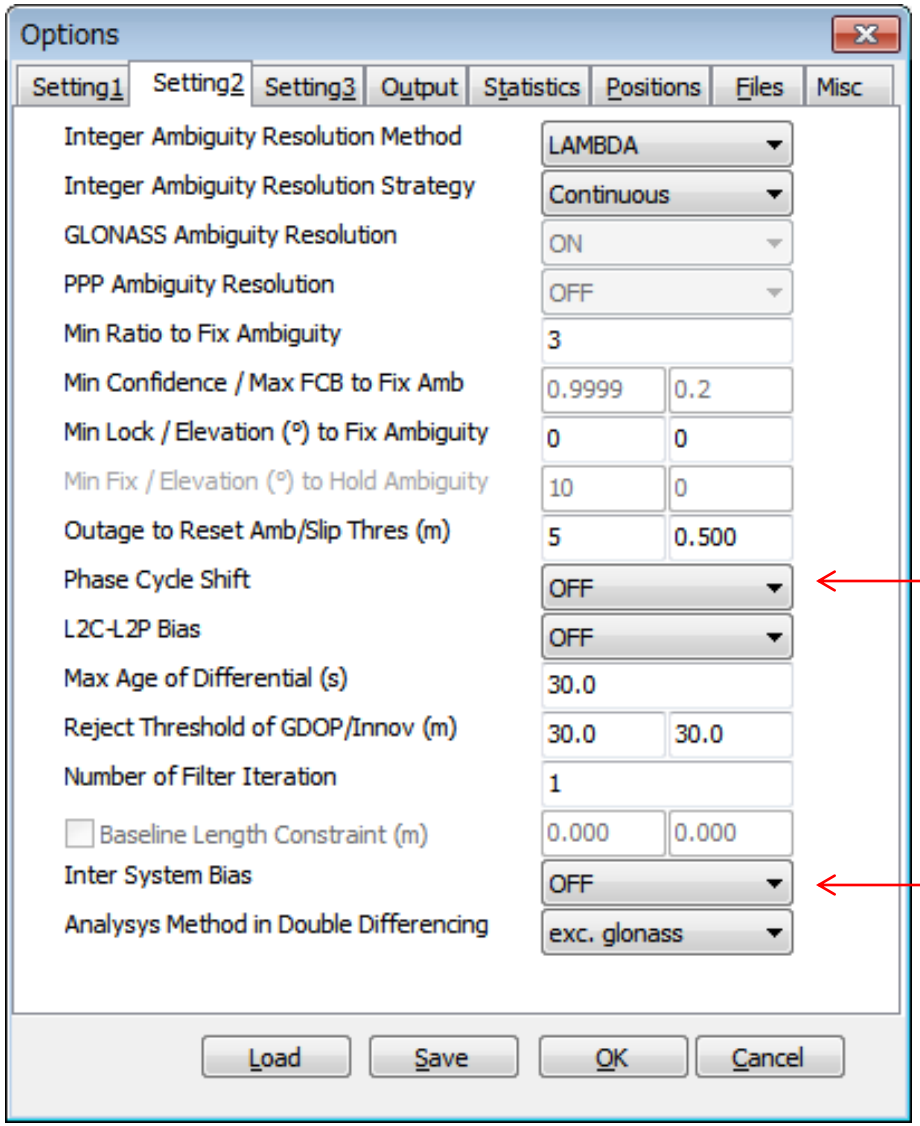


Positioning Mode “Kinematic”

Frequencies “L1+L2”

Satellite types (GPS)

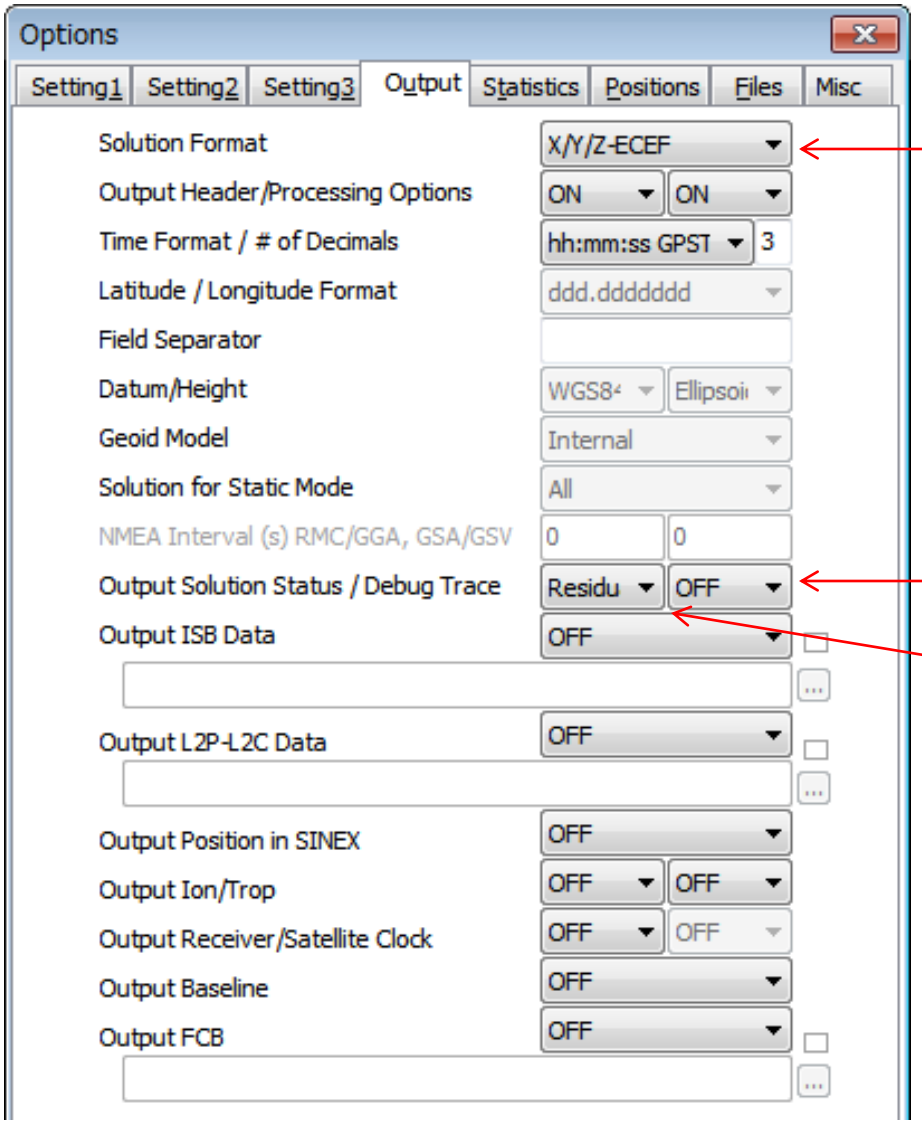
(1-2) Positioning options: Setting 2



Phase Cycle Shift “OFF”

Inter System Bias “OFF”

(1-3) Positioning options: Output

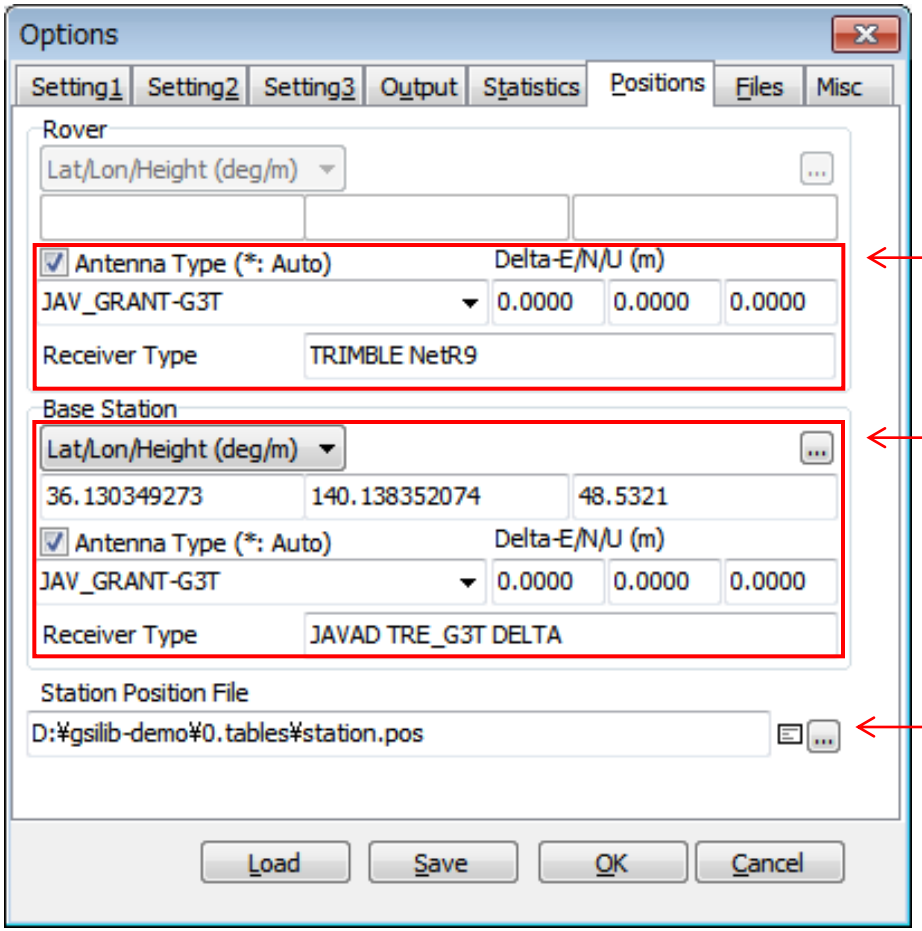


Solution Format

Debug Trace

Solution Status

(1-4) Positioning options: Positions



Rover:
- Antenna type
- Receiver type

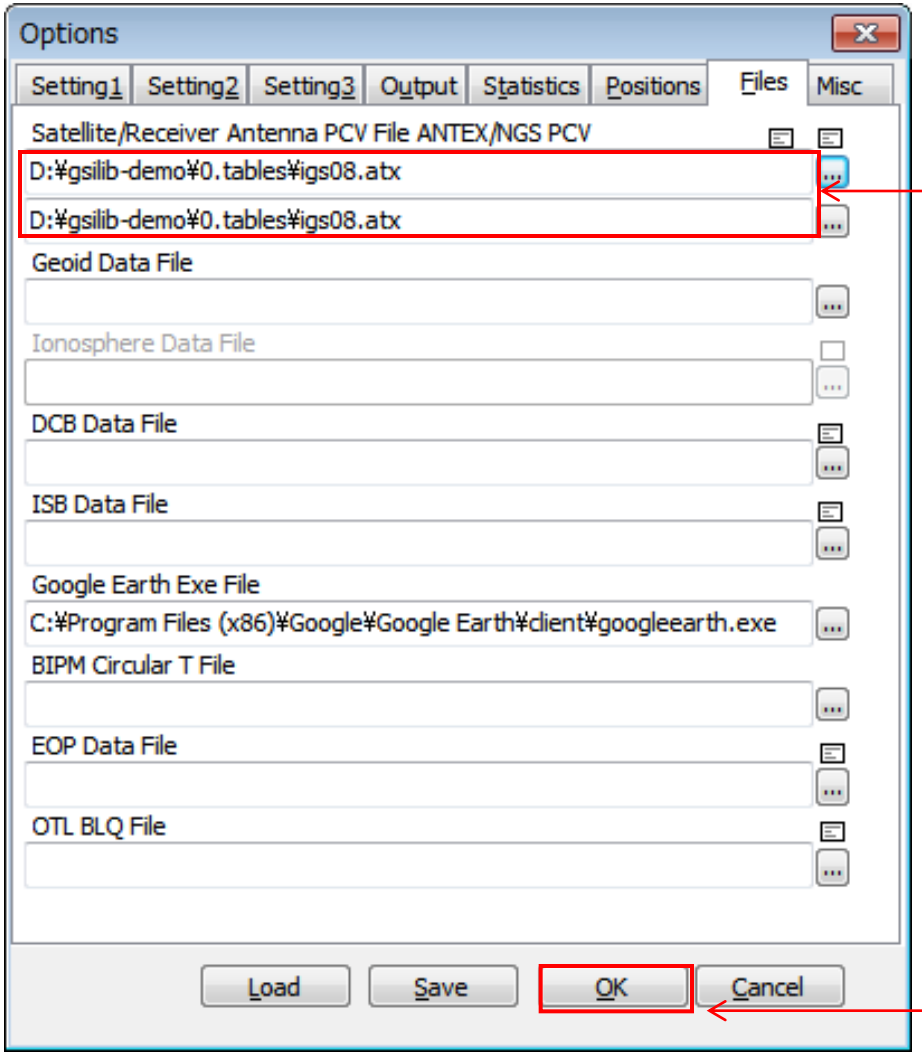
Base:
- Position
- Antenna type
- Receiver type

Position file

```
% latitude longitude  height(elipsoidal) id  name
%-------------------------------------------------------------

  36.130349273 140.138352074 48.5321  Sta8  Base
  36.127346662 140.143000323 47.7168  Sta1  Rover
```

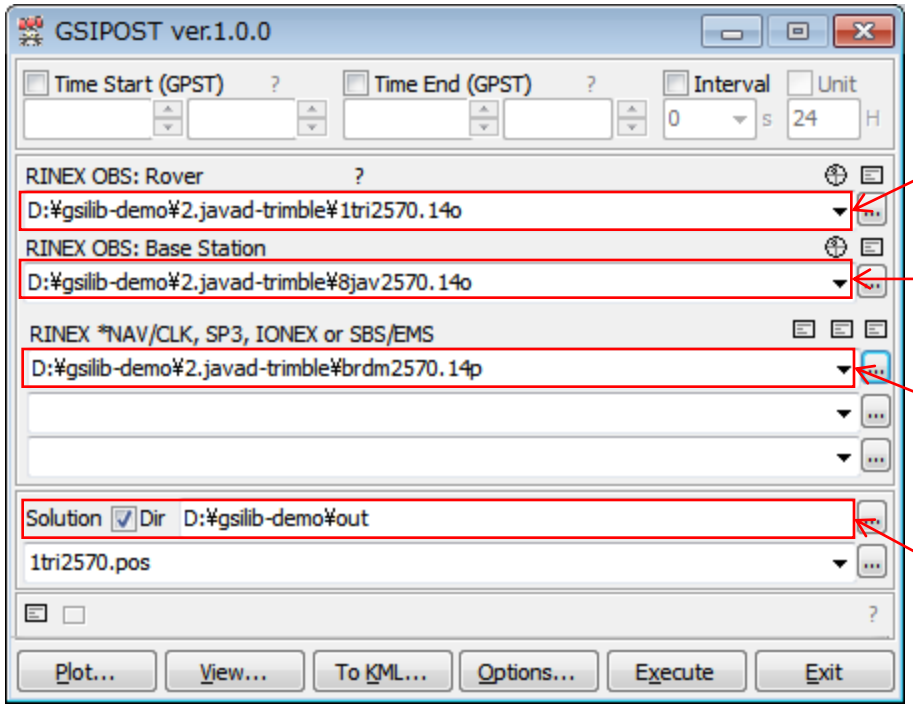
(1-5) Positioning options: Files



Satellite/Receiver Antenna PCV File

Click

(2) RINEX file selection



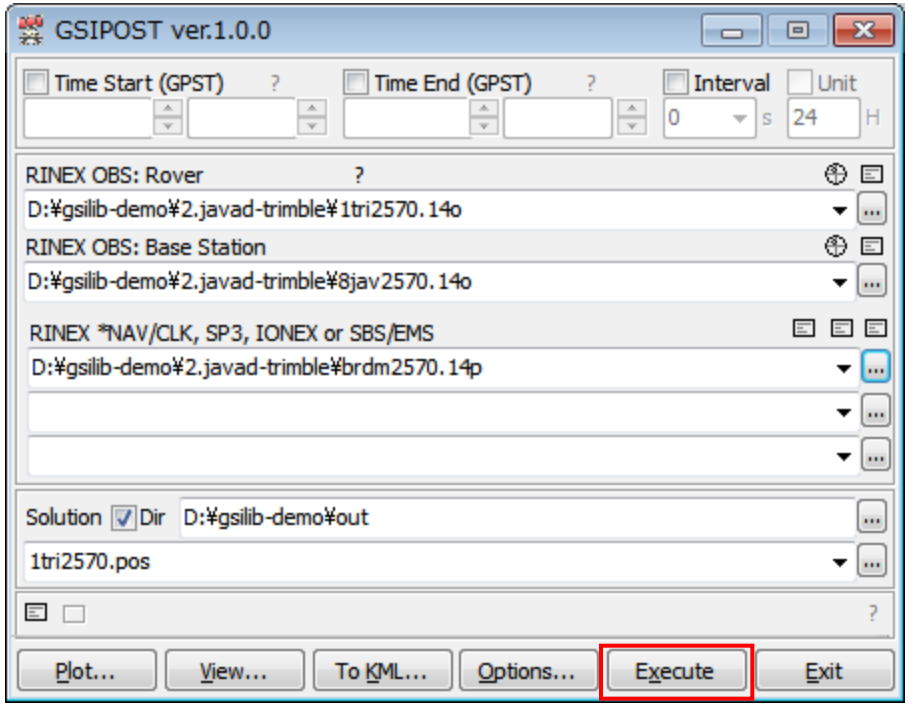
RINEX OBS of rover station (****.yyo)

RINEX OBS of base station (****.yyo)

RINEX NAV (****.yy*)

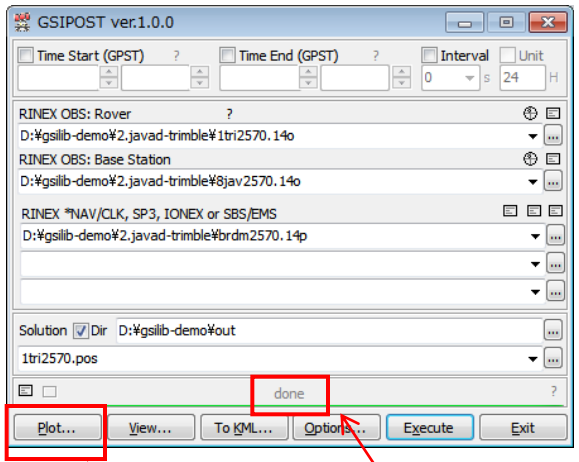
Solution directory for the solution file (****.pos)

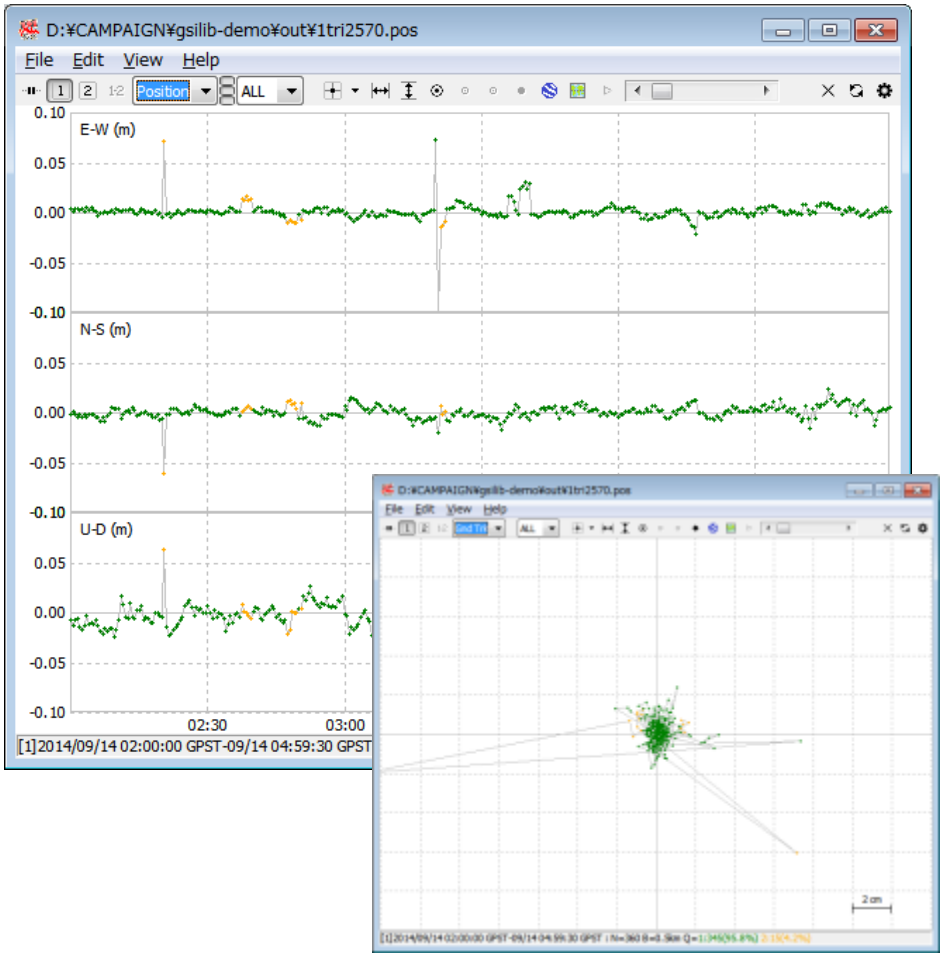
(3) Processing



Start processing

(4) Show result

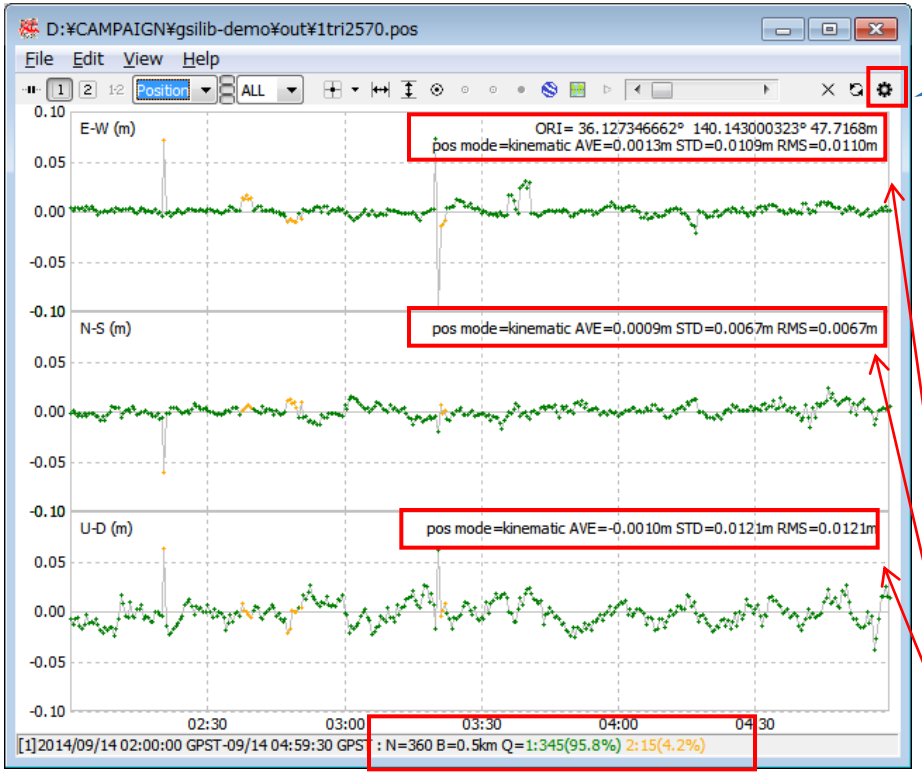


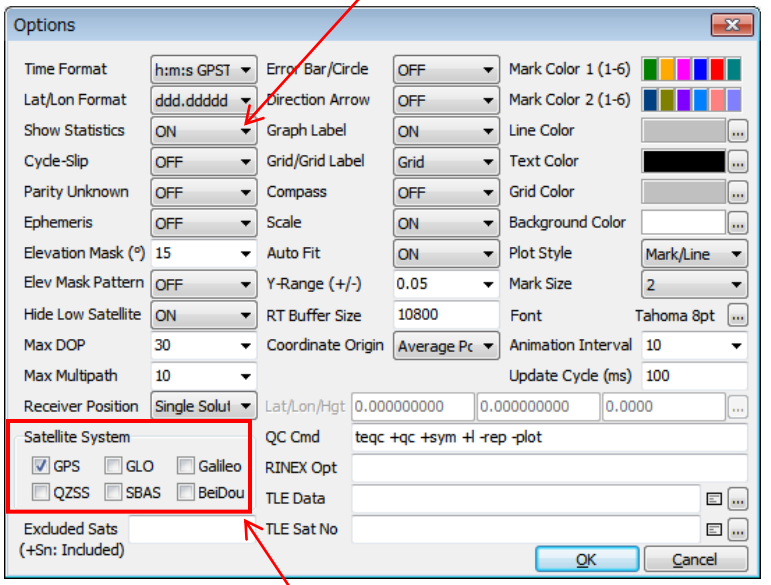


Processing is done

Plot results

(4-2) Plot options





Show Statistics

Satellite System

Baseline length
Fix rate

Average,
Standard deviation,
RMS

(4-3) Show residuals

Residuals

Frequency

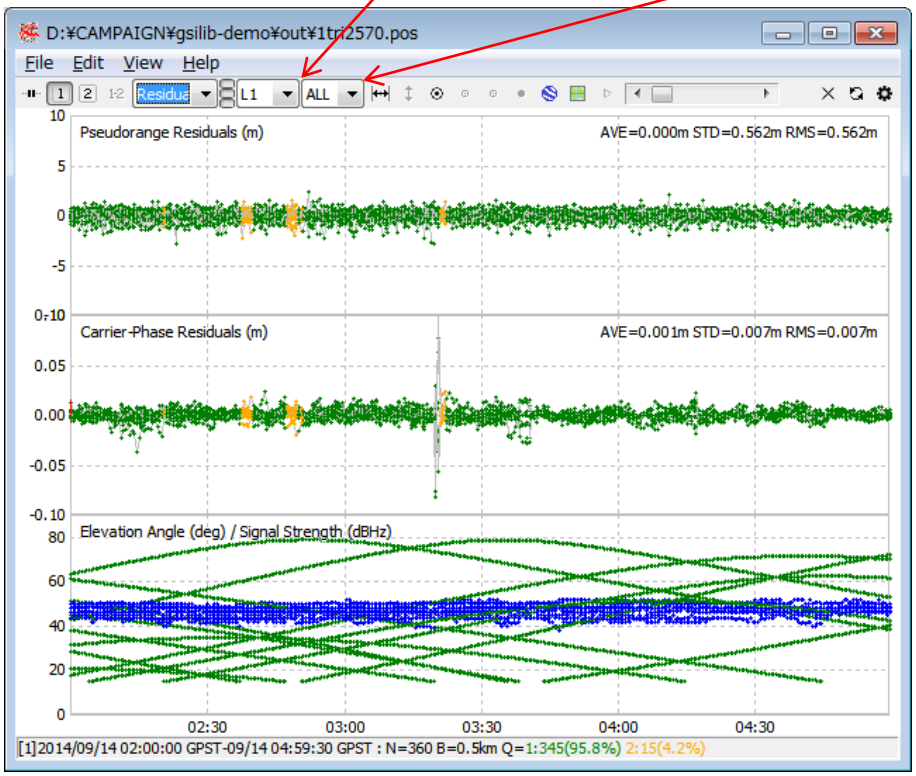
Satellite

Code

Phase

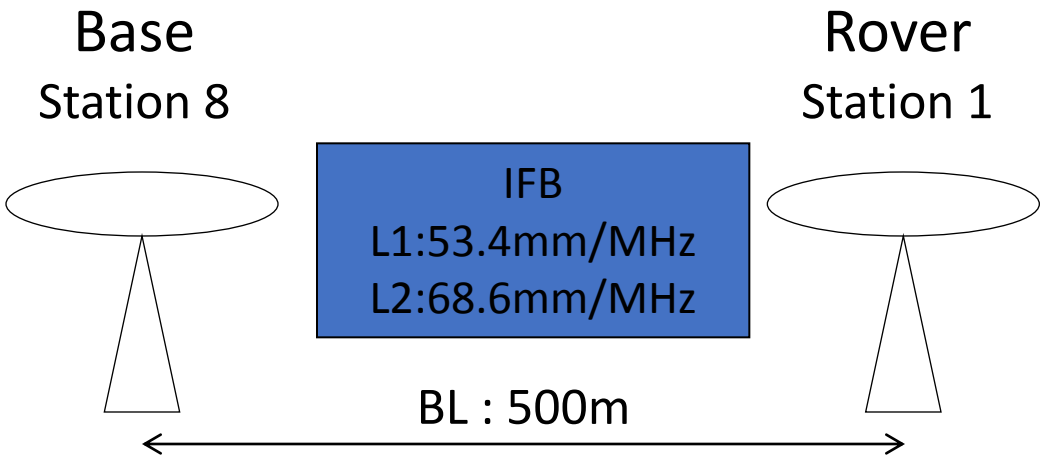
Elevation

SNR



GSILIB Demonstration 2: IFB correction

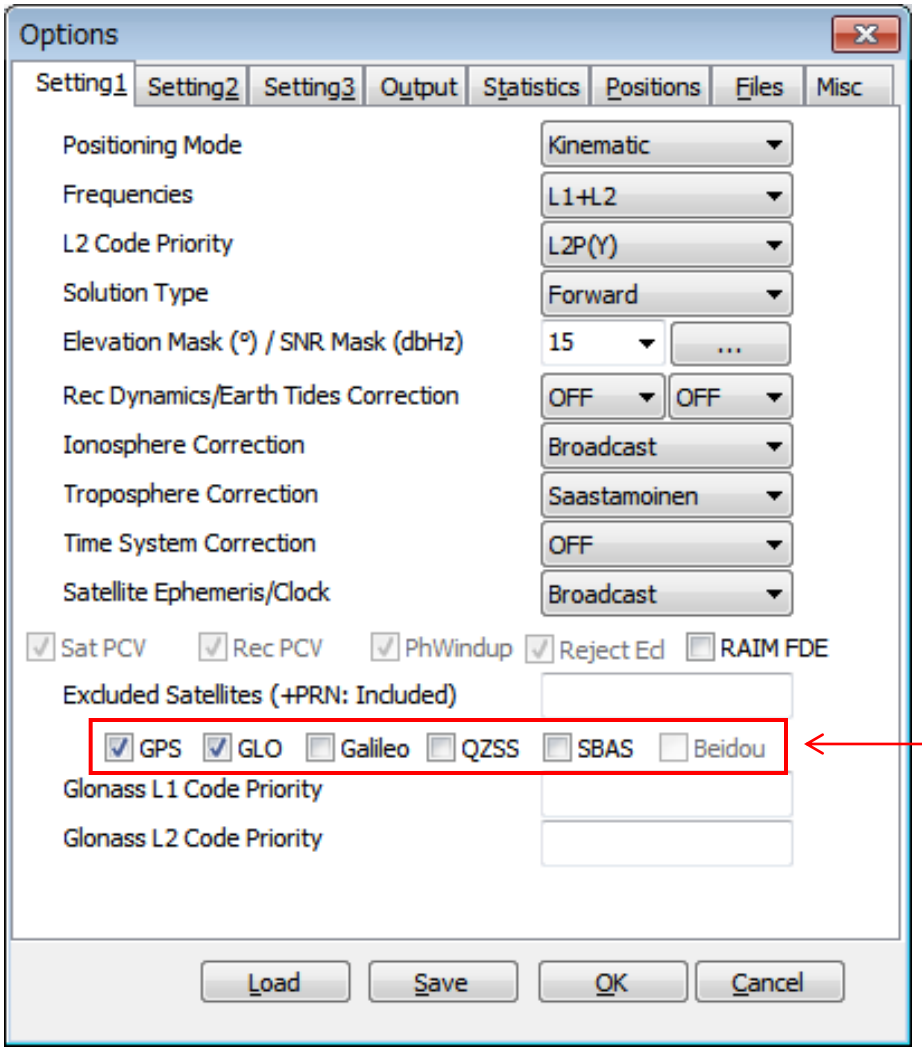
- RTK using GPS + GLONASS (IFB correction)



Antenna : JAV_GRANT-G3T
Receiver : TRIMBLE NetR9

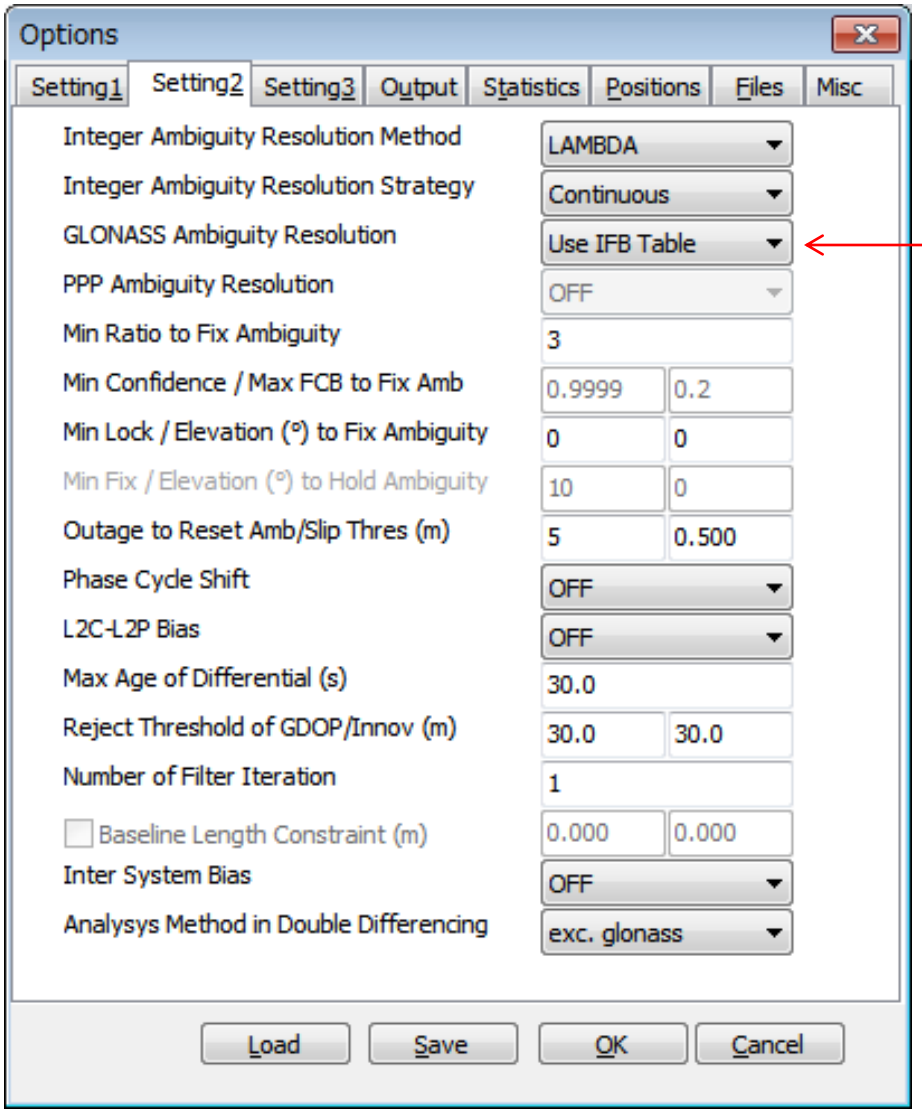
GLONASS
L1 : 1602 MHz + 0.5625 MHz * k
L2 : 1246 MHz + 0.4375 MHz * k (k=-7,-6,…,5,6)

(1-1) Positioning options: Setting 1



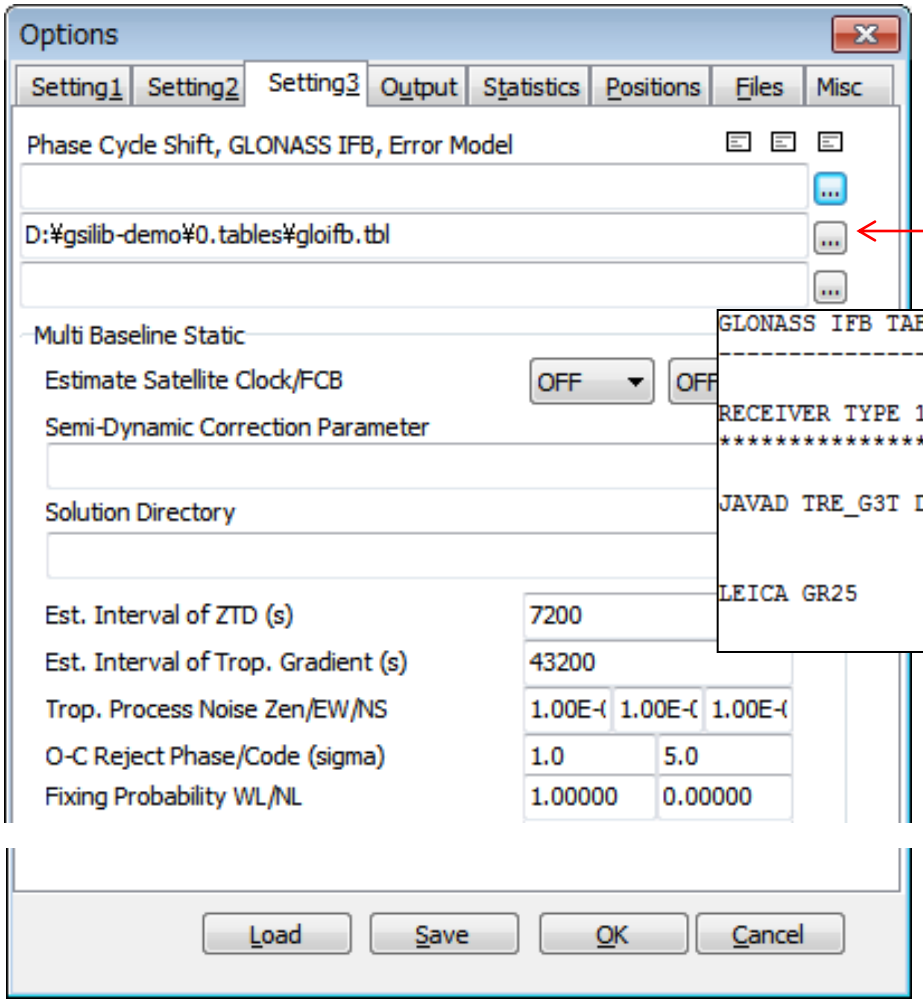
Satellite types (GPS, GLO)

(1-2) Positioning options: Setting 2



GLONASS Ambiguity Resolution
“USE IFB Table”

(1-3) Positioning options: Setting 3



IFB table file

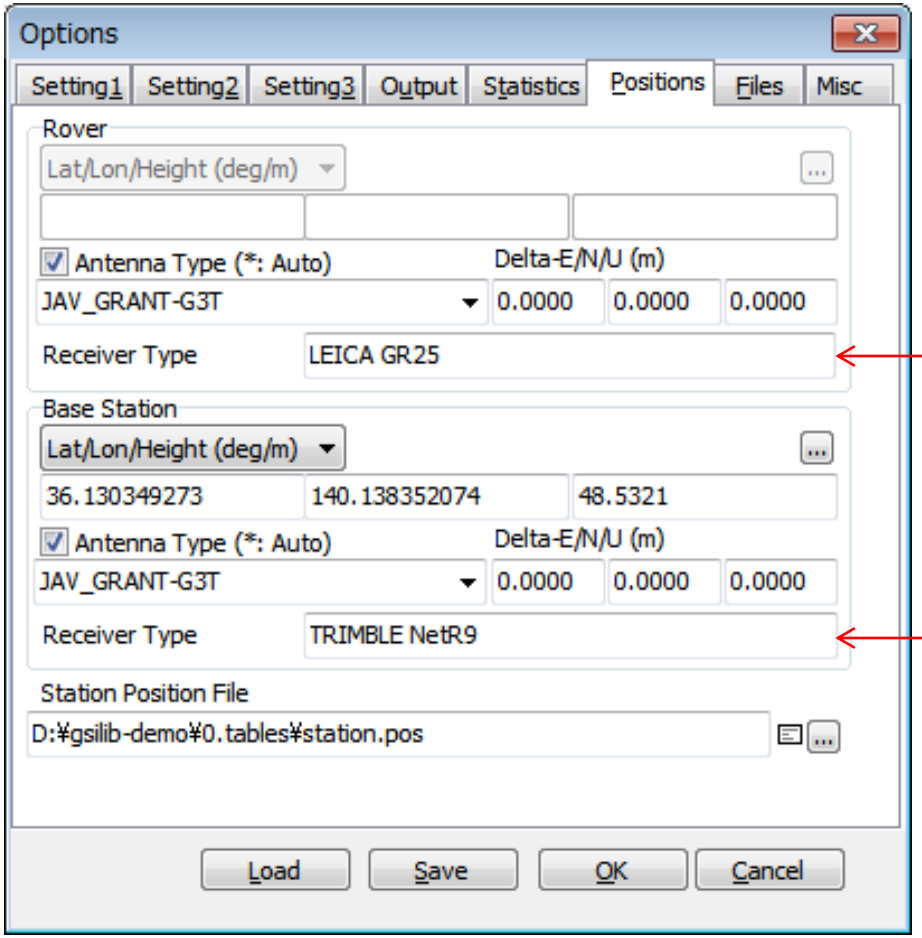
```
GLONASS IFB TABLE                                                    2014/09/29
--------------------------------------------------------------------------------

RECEIVER TYPE 1       RECEIVER TYPE 2       FREQ L* BIAS(m/MHz)    FLAG
********************  ********************        *       ********     *

JAVAD TRE_G3T DELTA   TRIMBLE NetR9                 1       -0.0082
                                                    2       -0.0106

LEICA GR25            TRIMBLE NetR9                 1       -0.0534
                                                    2       -0.0686
```

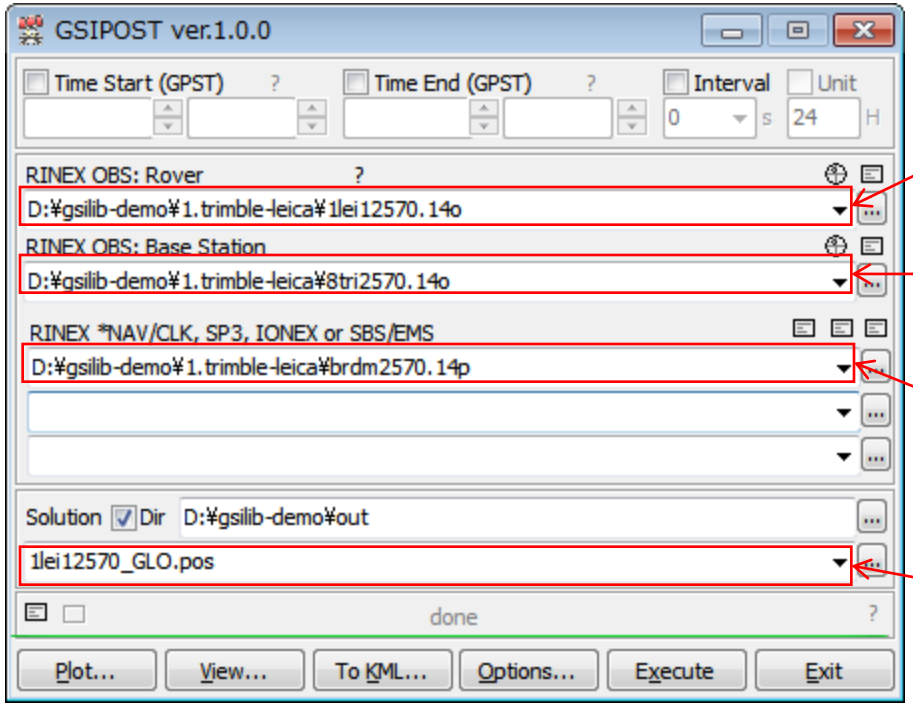
(1-4) Positioning options: Positions



Rover Receiver Type

Base Receiver Type

RINEX file selection



RINEX OBS of rover station (****.yyo)

RINEX OBS of base station (****.yyo)

RINEX NAV (****.yy*)

Solution file (****.pos)

IFB correction result

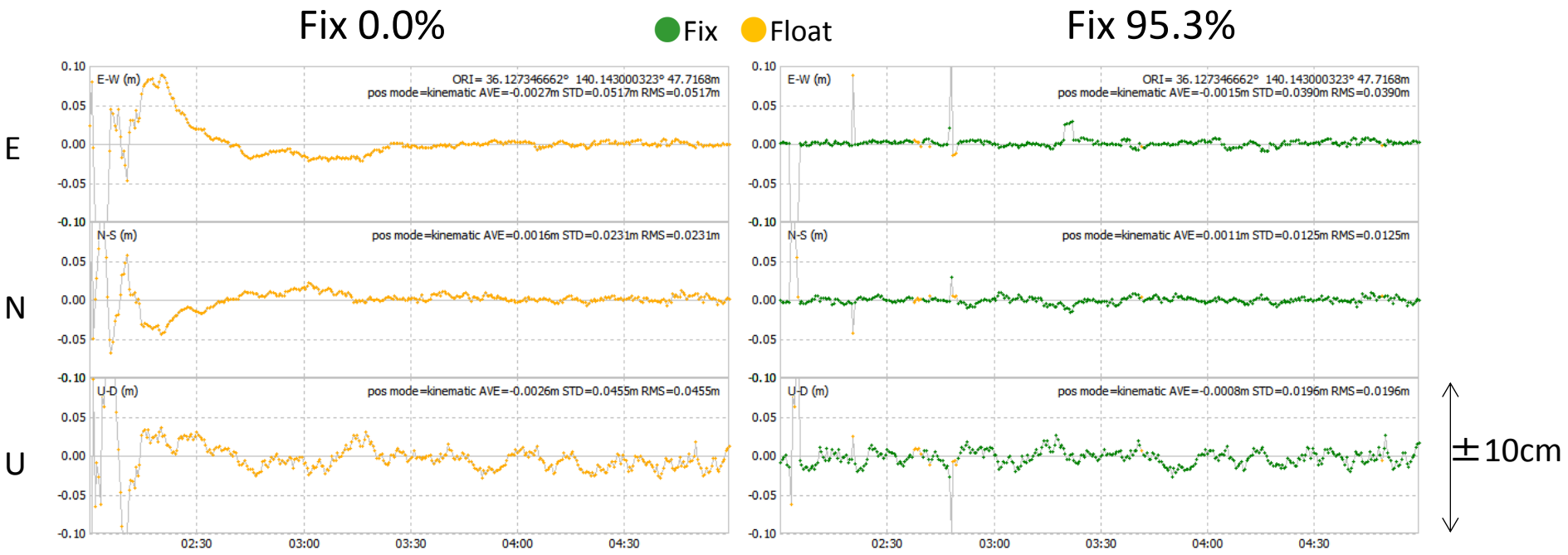
GPS + GLONASS

No IFB correction

Fix 0.0%

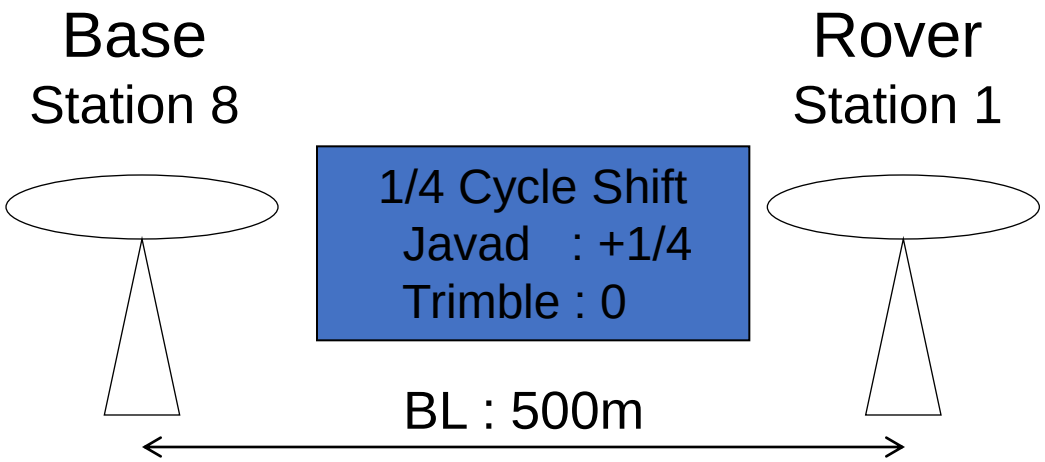
IFB correction

Fix 95.3%



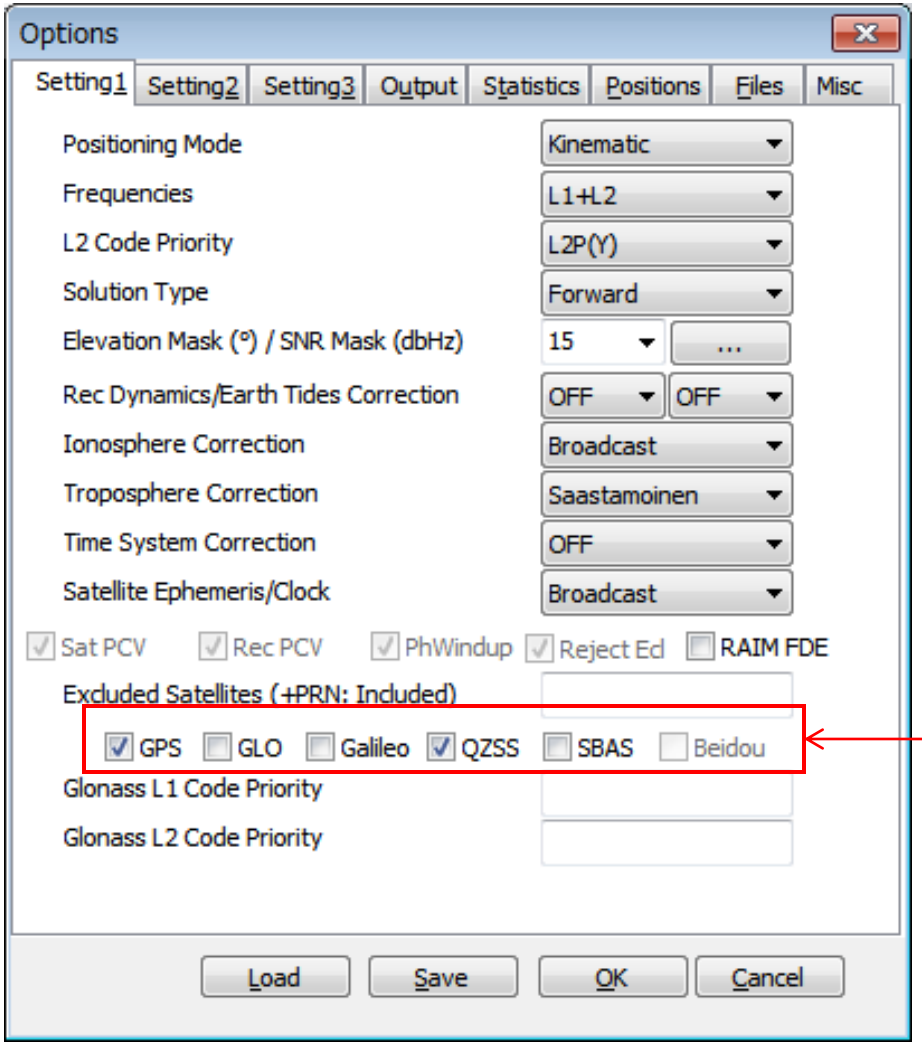
GSILIB Demonstration 3 quarter cycle shift correction

RTK using GPS+QZSS
w/wo L2C quarter cycle bias correction



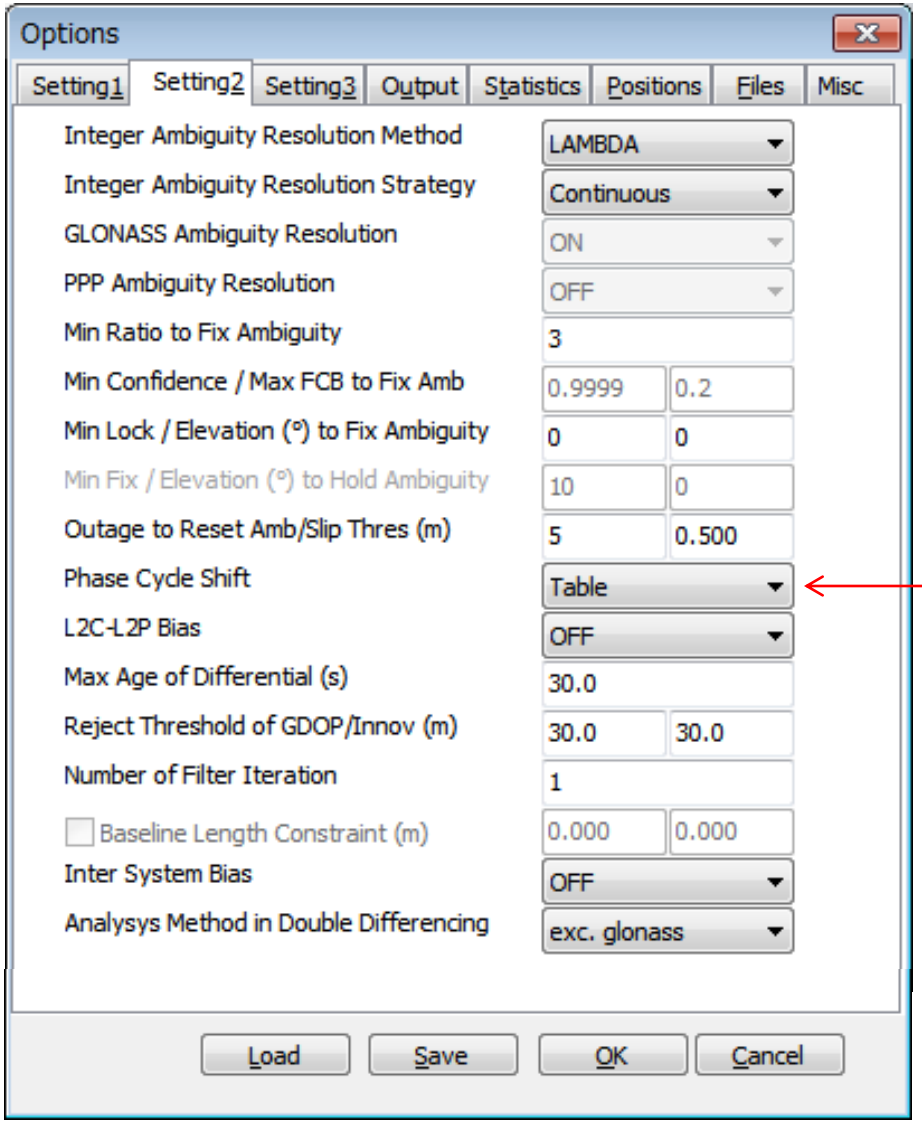
Antenna : JAV_GRANT-G3T
Receiver : JAVAD TRE_G3T DELTA

(1-1) Positioning options: Setting 1



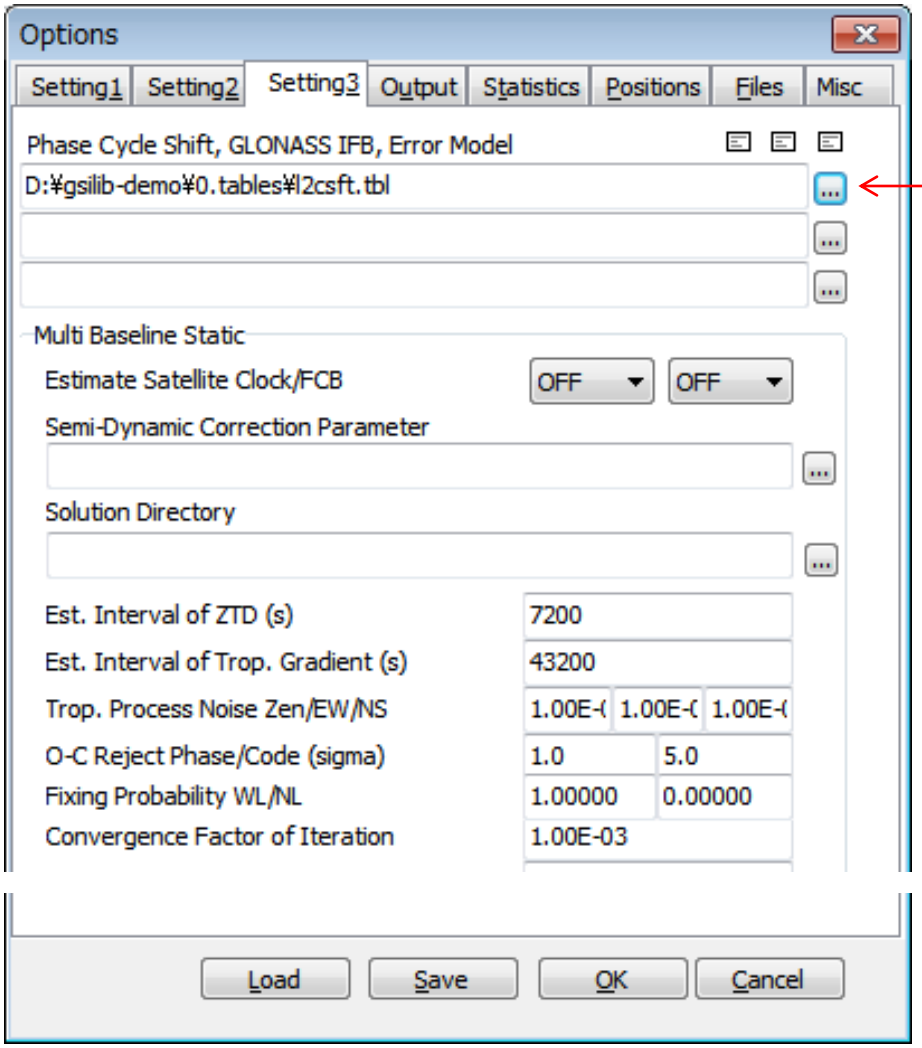
Satellite types (GPS, QZSS)

(1-2) Positioning options: Setting 2



Phase Cycle Shift “Table”

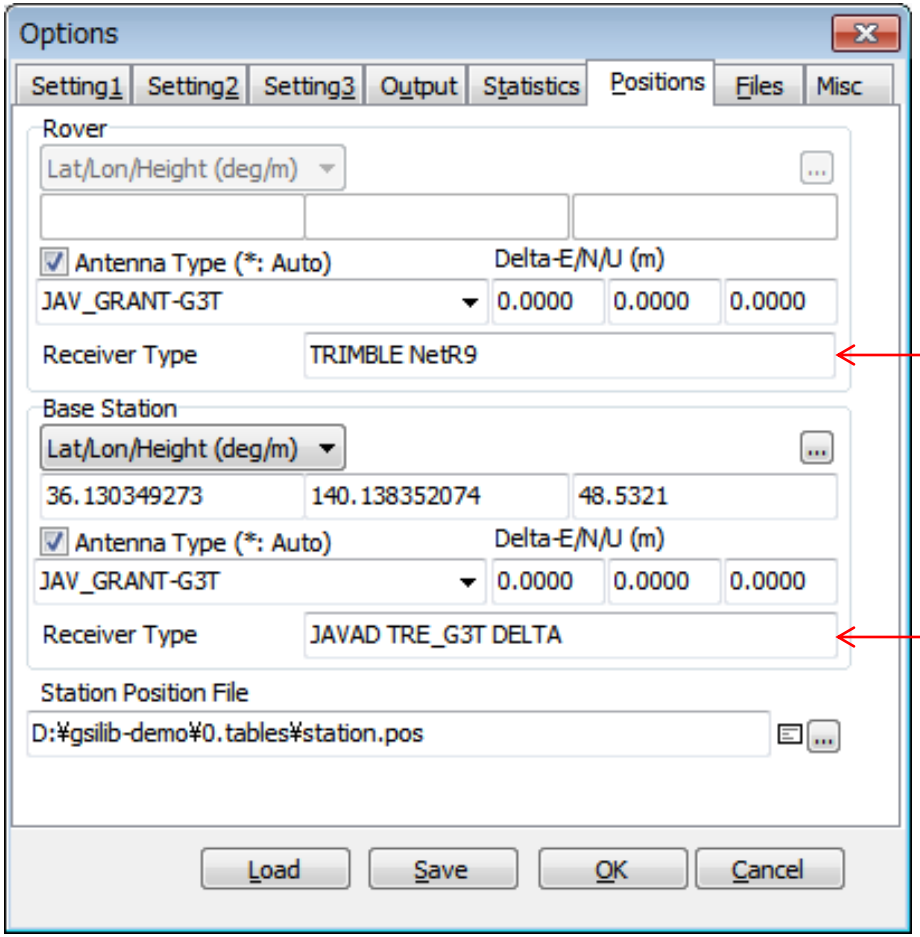
(1-3) Positioning options: Setting 3



Phase Cycle Shift file

```
Quarter-Cycle Phase Shifts Table
--------------------------------------------
RECEIVER TYPE        BIAS
******************** **********************
JAVAD TRE_G3T DELTA                -0.25
```

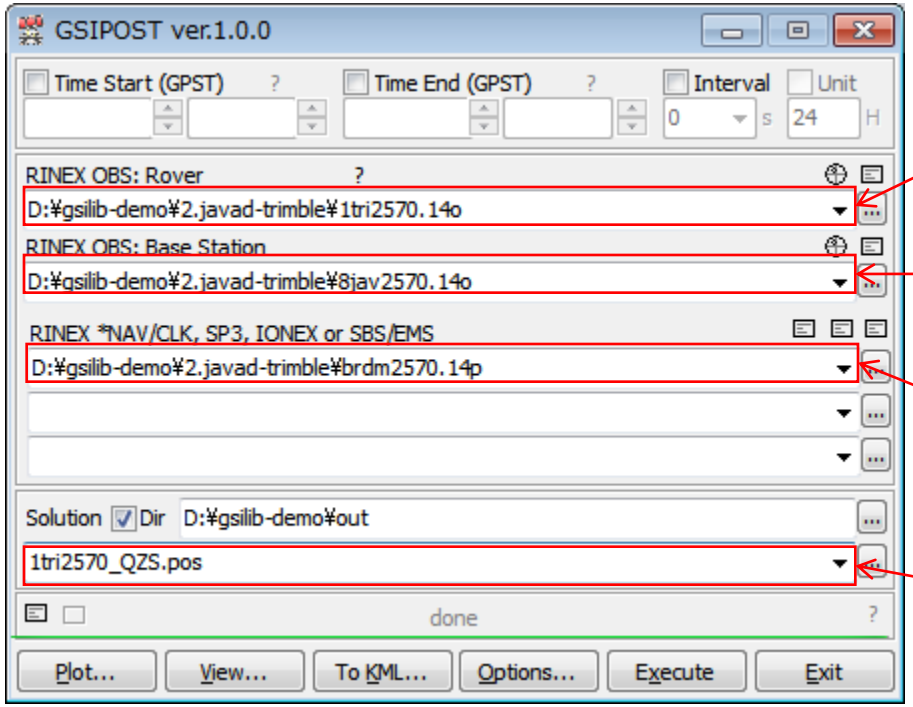
(1-4) Positioning options: Positions



Rover Receiver Type

Base Receiver Type

RINEX file selection



RINEX OBS of rover station (****.yyo)

RINEX OBS of base station (****.yyo)

RINEX NAV (****.yy*)

Solution file (****.pos)

Quarter cycle shift correction result

GPS + QZSS

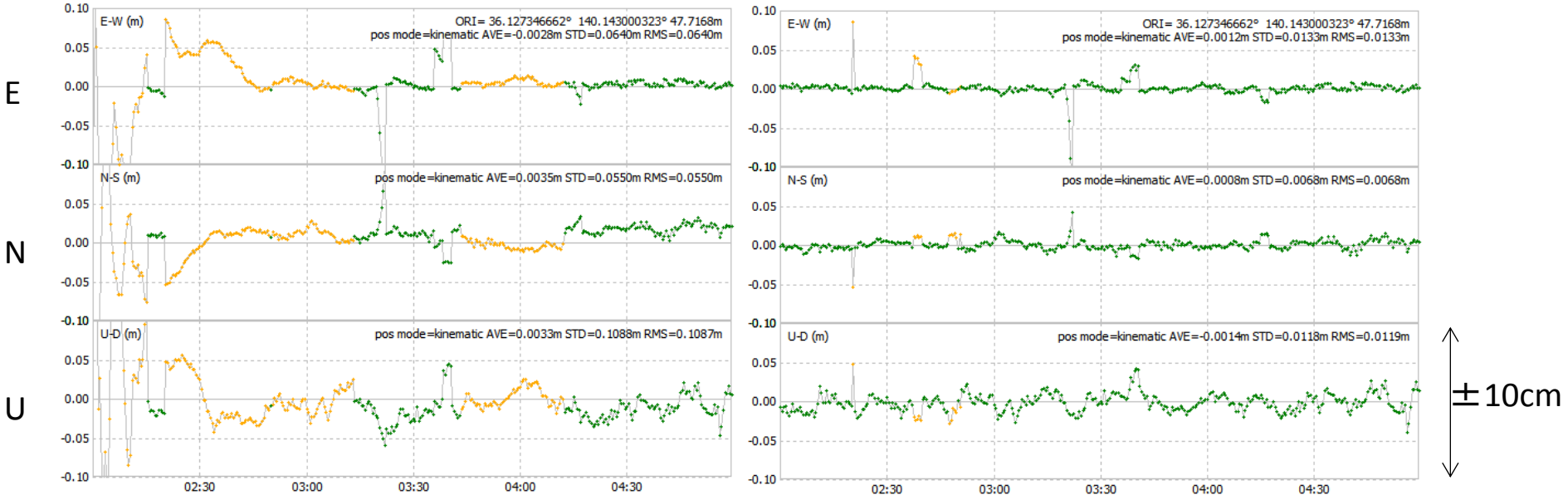
No correction

Fix 46.1%

Quarter cycle shift correction

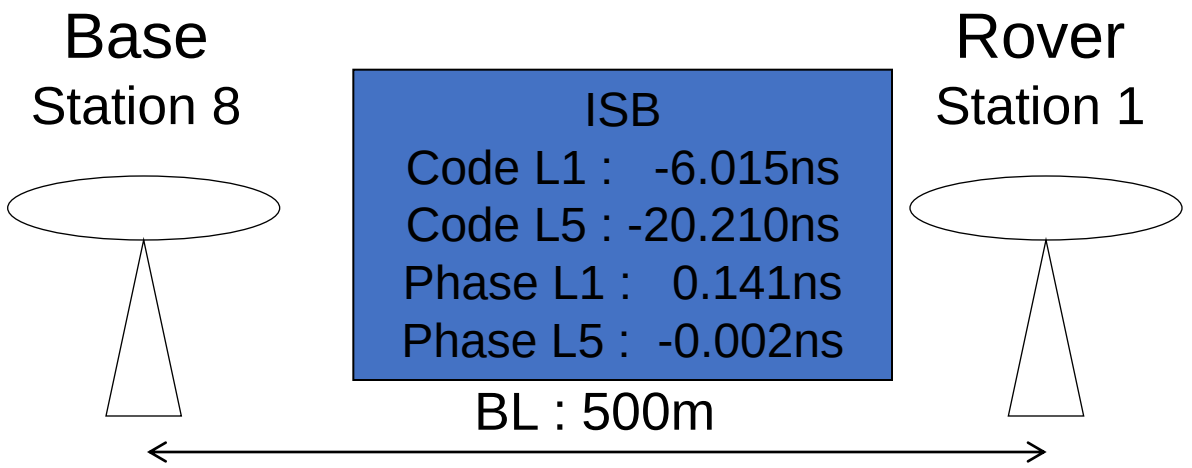
Fix 96.7%

Fix Float



GSILIB Demonstration 4: ISB correction

- RTK using GPS+Galileo
  w/wo ISB correction

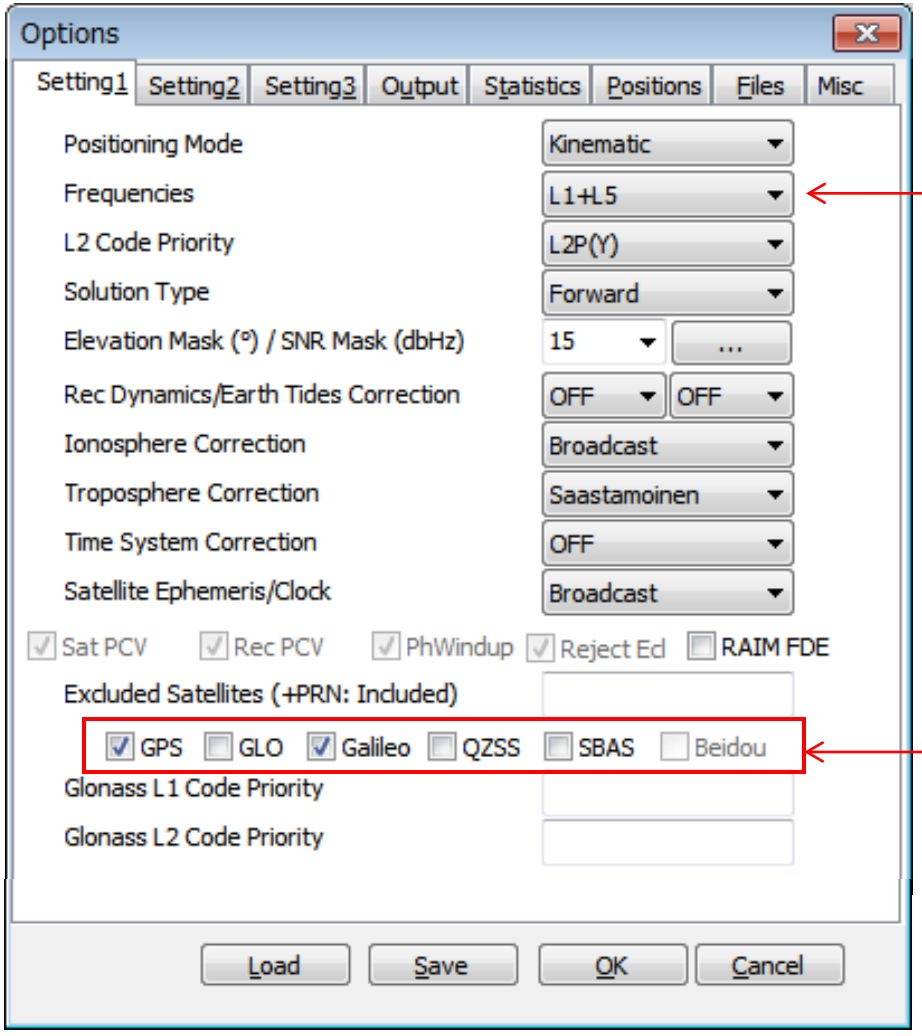


Antenna : JAV_GRANT-G3T
Receiver : JAVAD TRE_G3T DELTA

Antenna : JAV_GRANT-G3T
Receiver : TRIMBLE NetR9

Speed of Light : 0.29979 m / ns

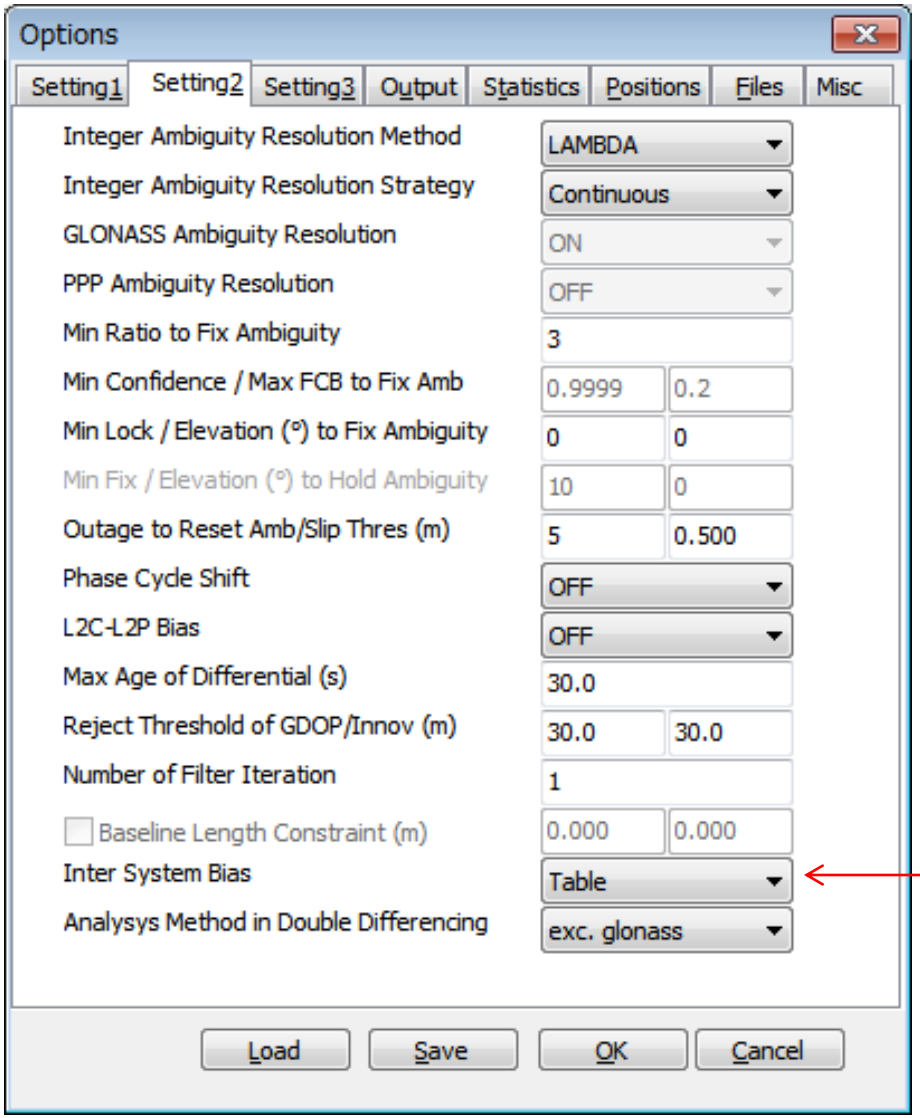
(1-1) Positioning options: Setting 1



Frequencies “L1+L5”

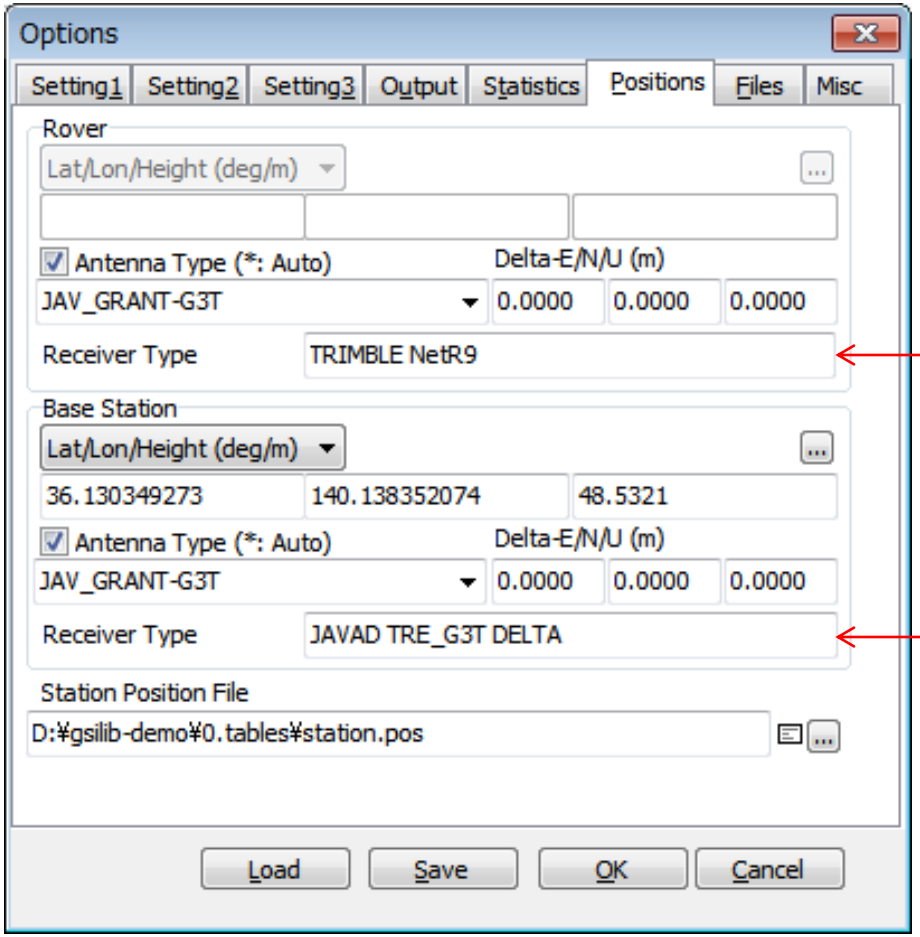
Satellite types (GPS, Galileo)

(1-2) Positioning options: Setting 2



Inter System Bias “Table”

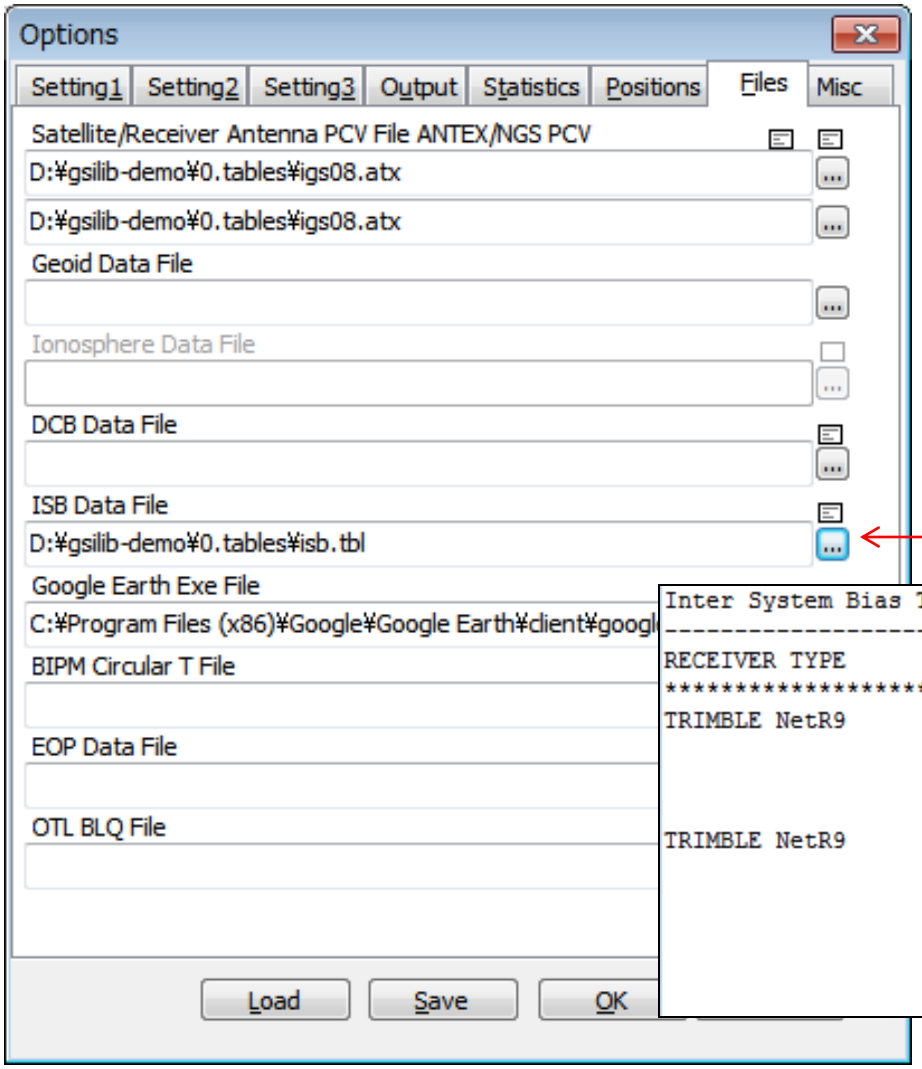
(1-3) Positioning options: Positions



Rover Receiver Type

Base Receiver Type

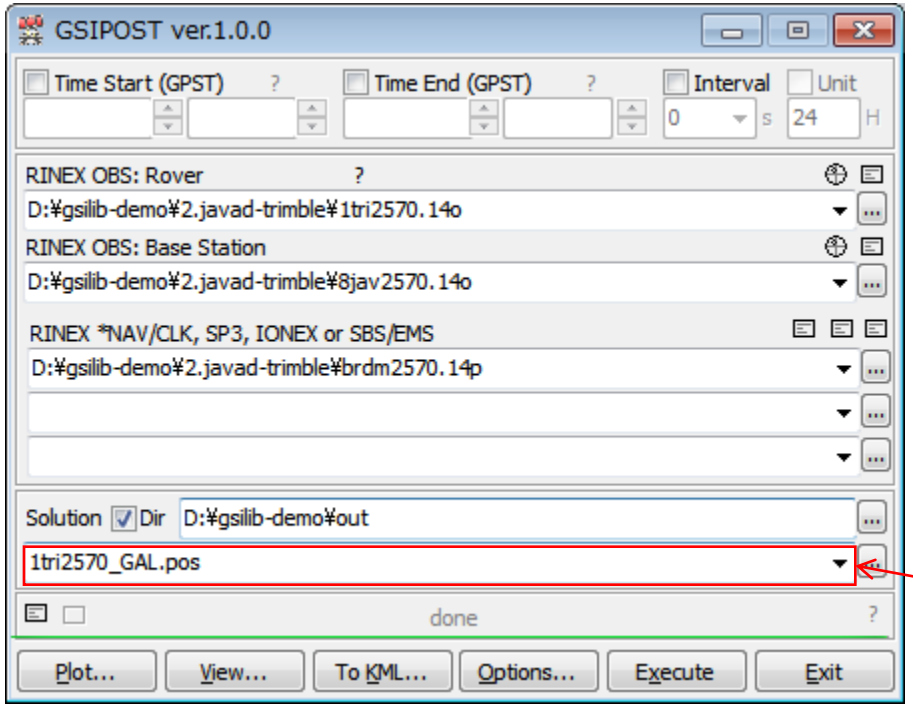
(1-4) Positioning options: Files



ISB Data File

```
Inter System Bias Table
--------------------------------------------------------------------------------
RECEIVER TYPE        RECEIVER TYPE (BASE) S F O                  BIAS(ns)
******************** ******************** * * * **********************
TRIMBLE NetR9        JAVAD TRE_G3T DELTA  E 1 L            0.140597108
                     JAVAD TRE_G3T DELTA  E 5 L           -0.002028744
                     JAVAD TRE_G3T DELTA  E 1 P           -6.014535971
                     JAVAD TRE_G3T DELTA  E 5 P          -20.210058998
TRIMBLE NetR9        JAVAD TRE_G3T DELTA  J 1 L           -0.006256701
                     JAVAD TRE_G3T DELTA  J 2 L            0.013422874
                     JAVAD TRE_G3T DELTA  J 5 L            0.002776976
                     JAVAD TRE_G3T DELTA  J 1 P           -3.393992703
                     JAVAD TRE_G3T DELTA  J 2 P          -11.247084528
                     JAVAD TRE_G3T DELTA  J 5 P           -4.957847311
```

RINEX file selection



Solution file (****.pos)

ISB correction result

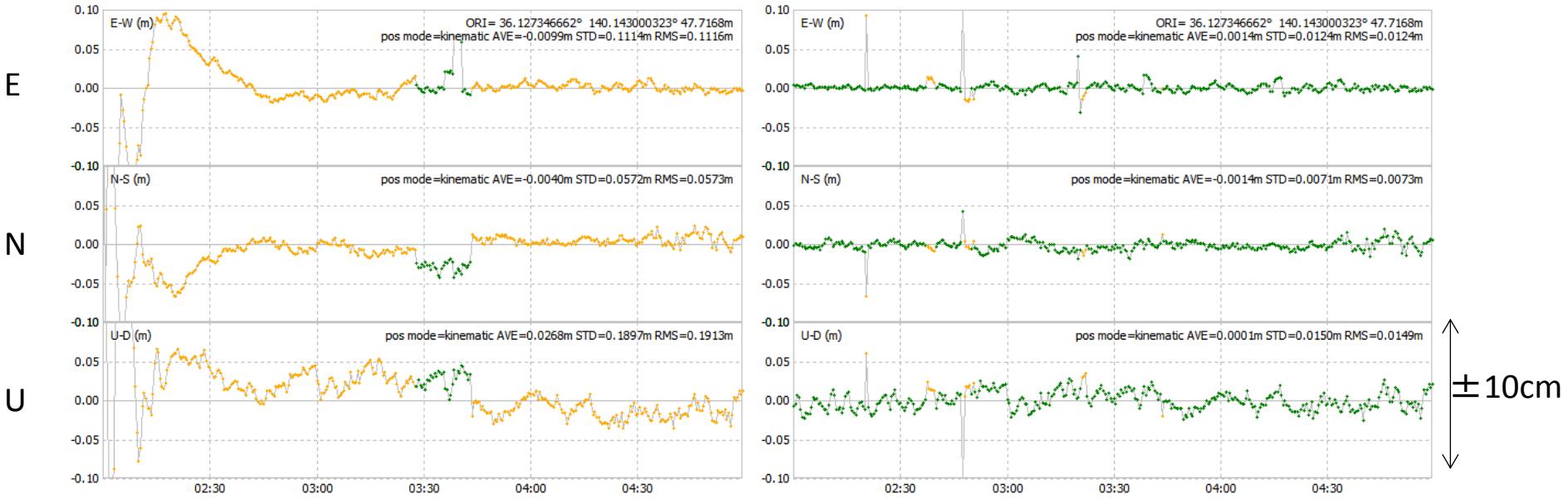
GPS + Galileo

No correction

Fix 8.6%

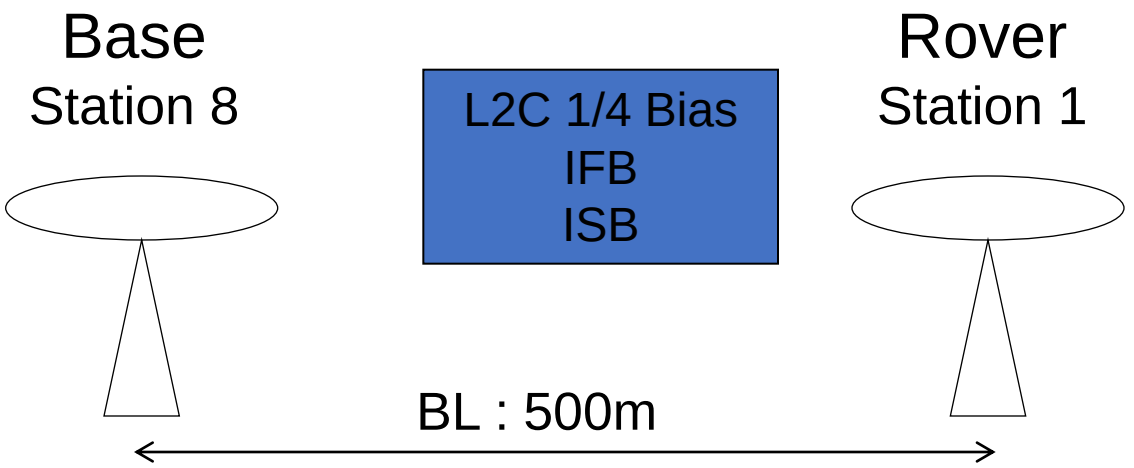
ISB correction

Fix 95.8%



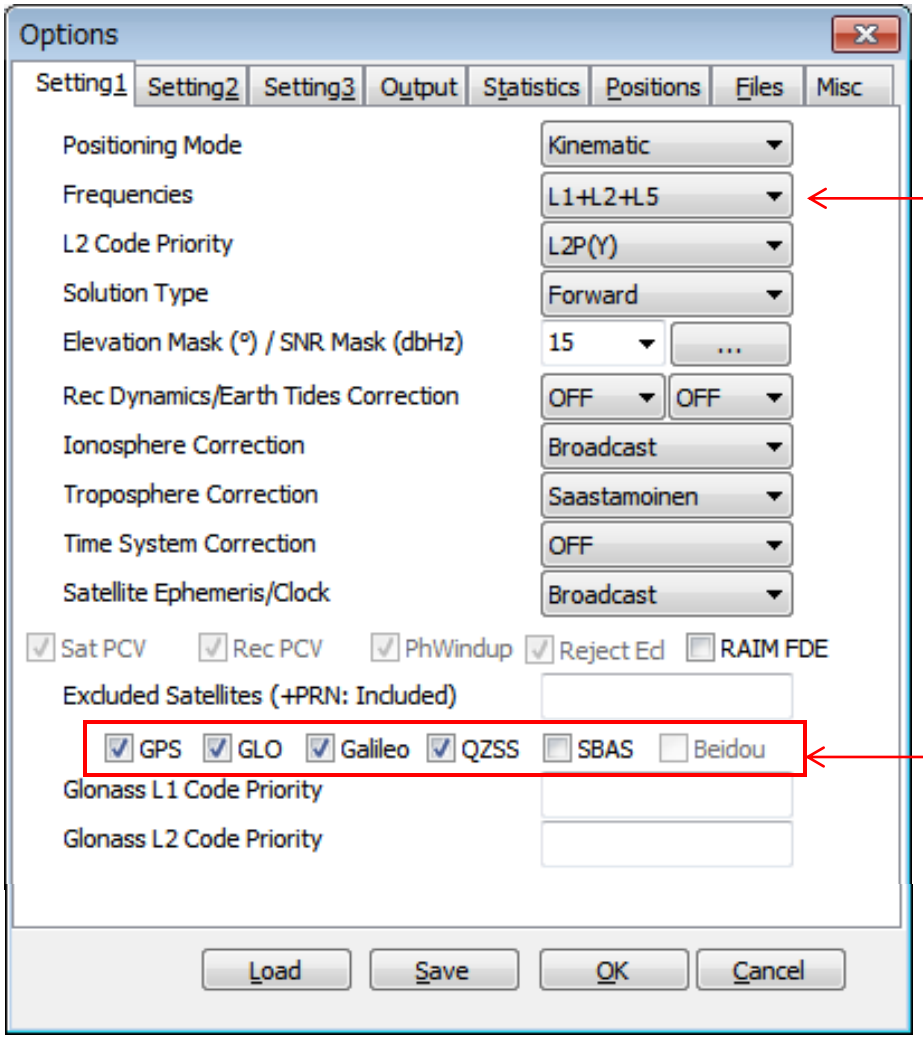
GSILIB Demonstration 5: All corrections

- RTK using GPS+GLONASS+QZSS+Galileo with all corrections



Antenna : JAV_GRANT-G3T
Receiver : JAVAD TRE_G3T DELTA

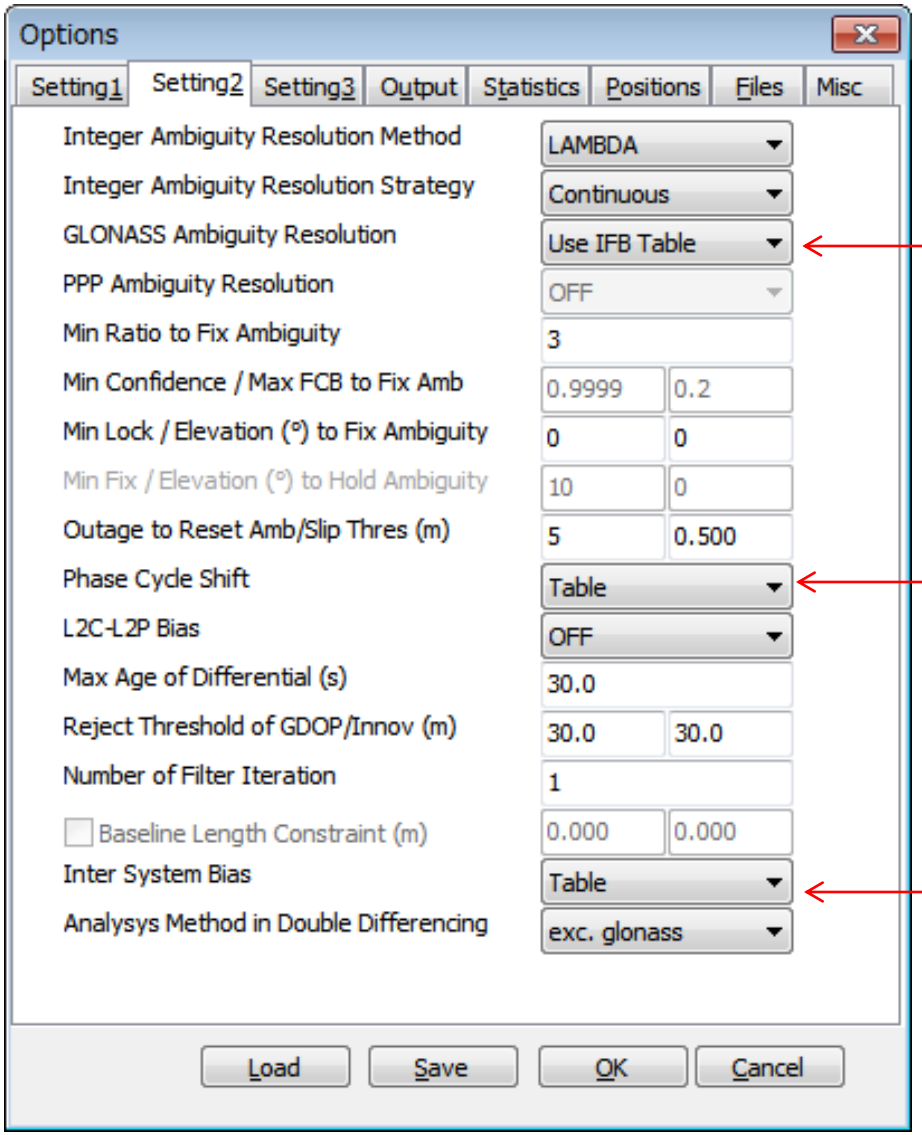
(1-1) Positioning options: Setting 1



Frequencies “L1+L2+L5”

Satellite types
(GPS, GLO, GAL, QZS)

(1-2) Positioning options: Setting 2

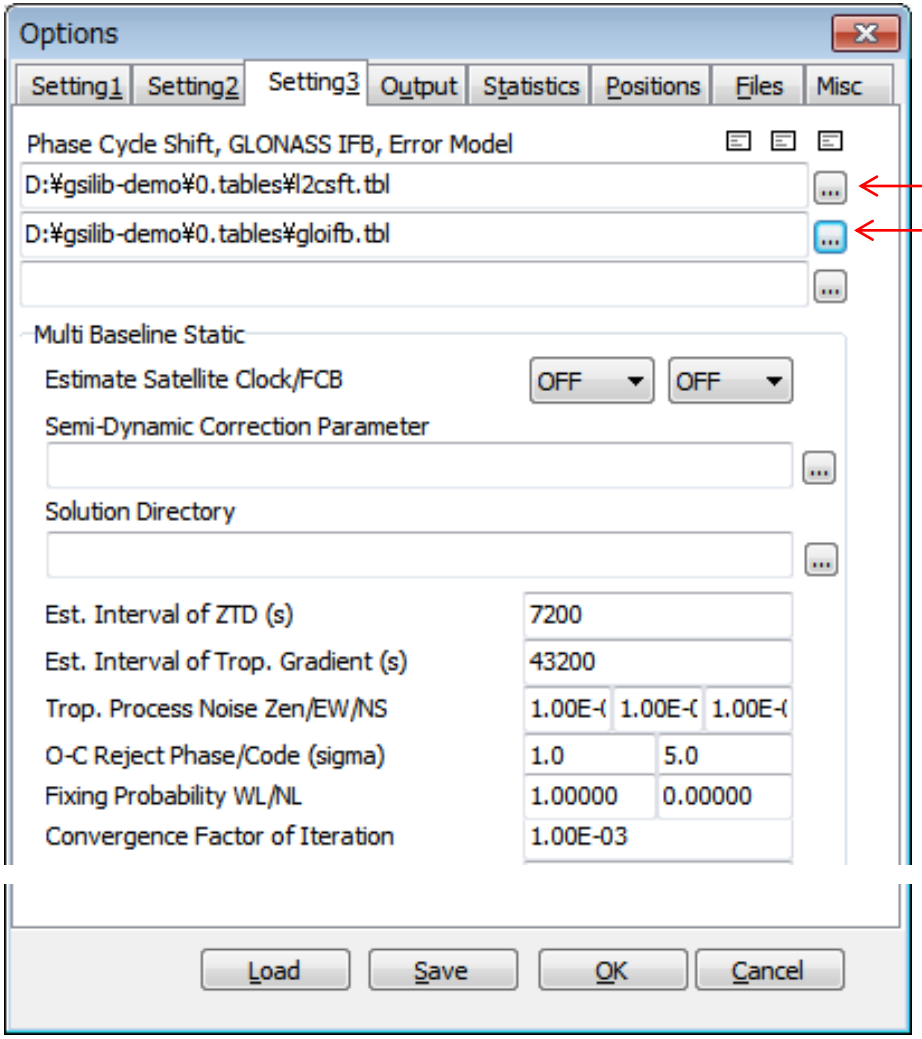


GLONASS Ambiguity Resolution “Use IFB Table”

Phase Cycle Shift “Table”

Inter System Bias “Table”

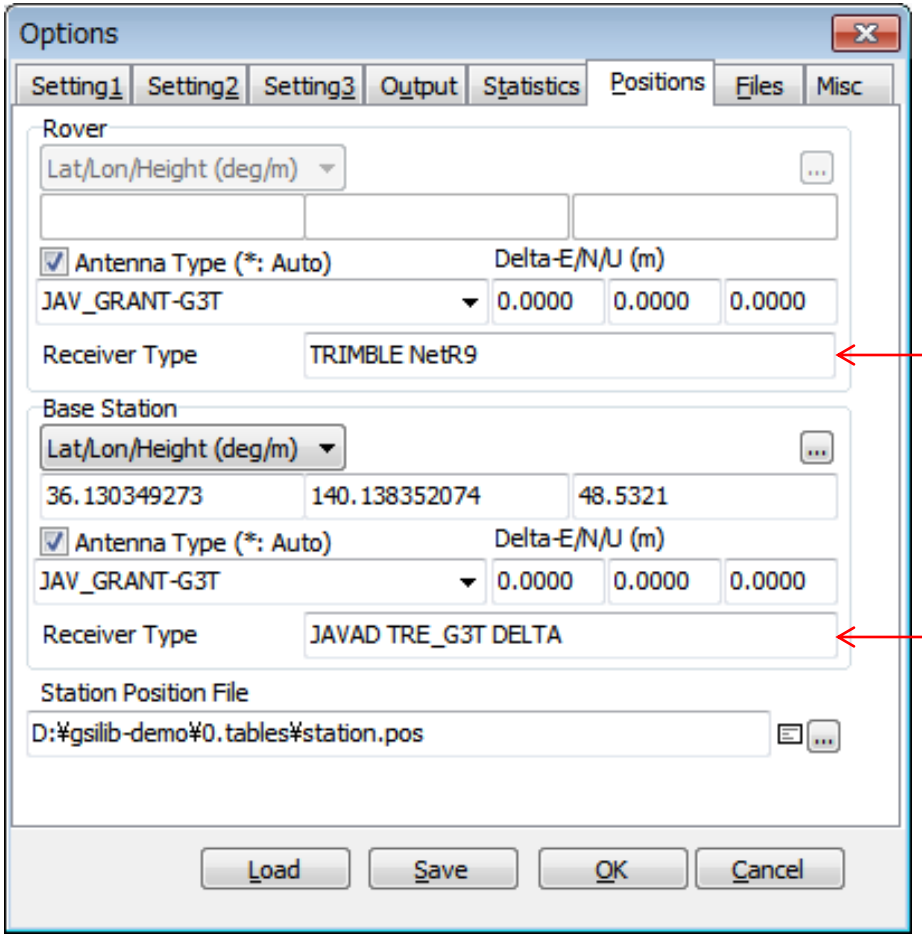
(1-2) Positioning options: Setting 3



Phase Cycle Shift file

GLONASS IFB file

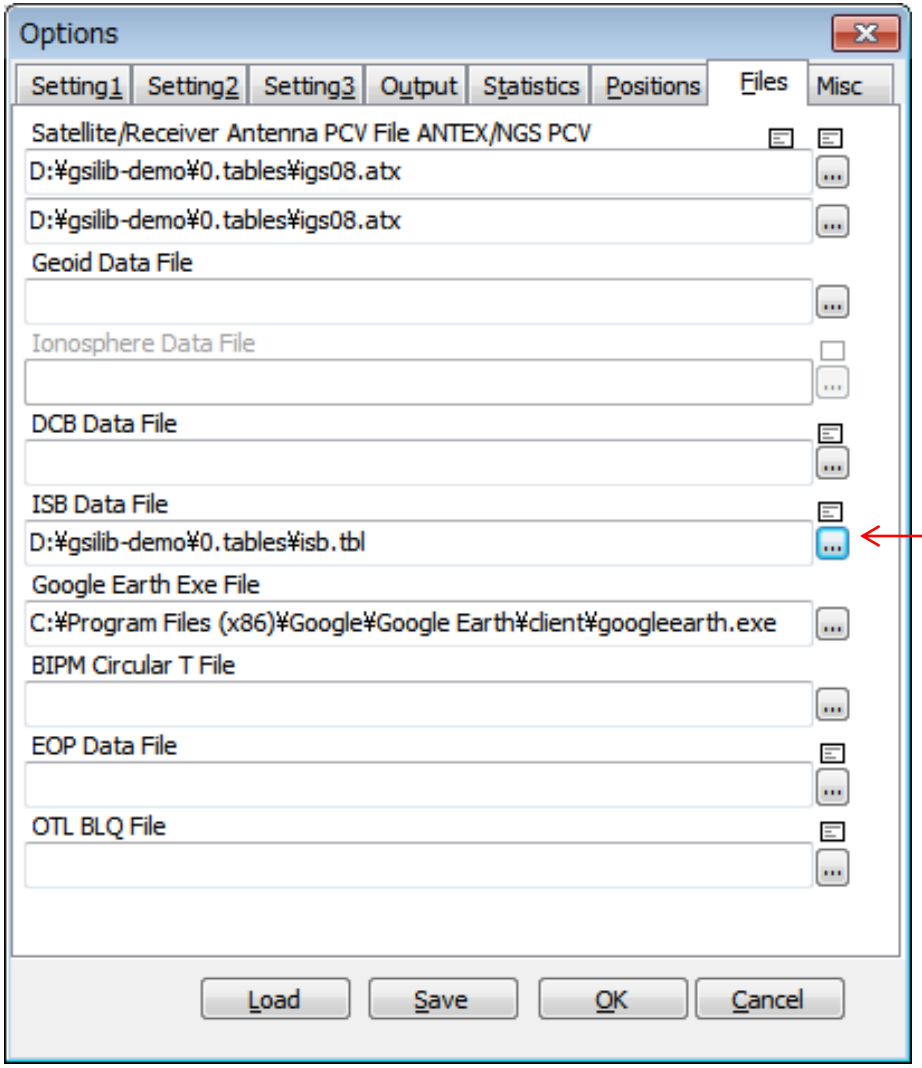
(1-4) Positioning options: Positions



Rover Receiver Type

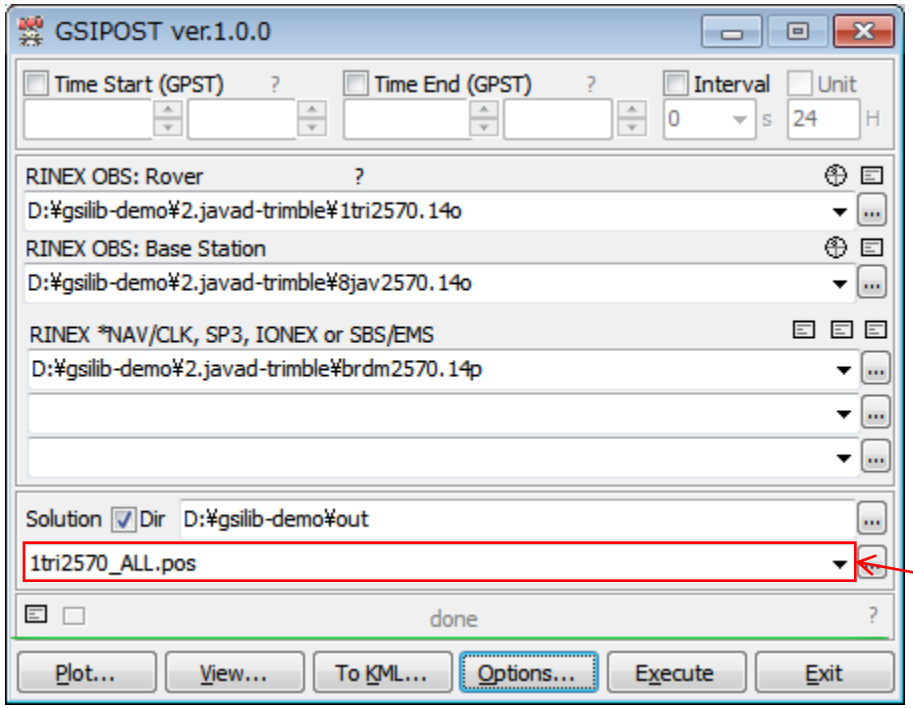
Base Receiver Type

(1-5) Positioning options: Files



ISB Data File

RINEX file selection

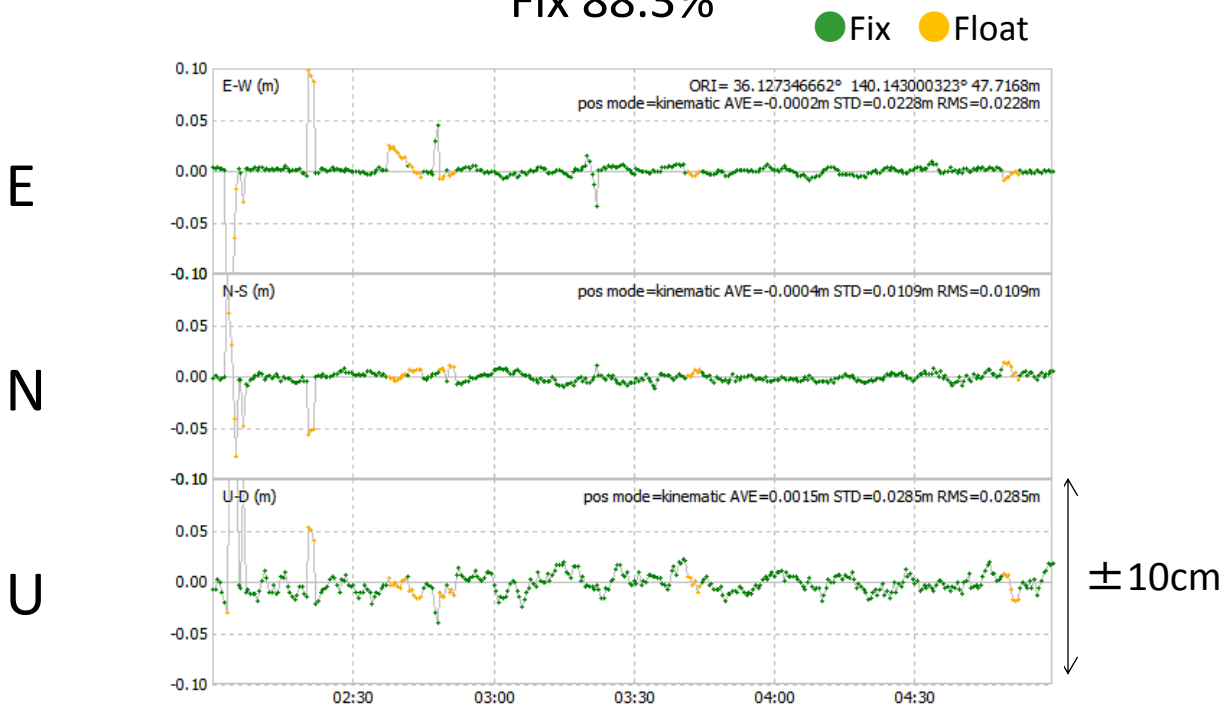


Solution file (****.pos)

Results with all corrections

GPS + GLONASS + QZSS + Galileo

Fix 88.3%



Fix solution

RMS E: 4.9mm N: 3.8mm U: 9.4mm

Summary

- Multi-GNSS environment improves availability, accuracy, reliability, convergence of GNSS positioning
- However, some biases have to be considered
  - IFB, ISB, quarter-cycle shift
- **GSILIB is an open-source software**, which offers the **table-based corrections of IFB, ISB and quarter-cycle shift** to utilize multi-GNSS data

http://datahouse1.gsi.go.jp/gsilib/gsilib_download_eng.html