IPNTJ Summer School on GNSS

RTKLIB Introduction
Theory of Precise Positioning (1)
QZSS Demo and RTKLIB Practice

Tokyo Univ. of Marine Science and Technology
Tomoji TAKASU

2014-07-28 ~ 2014-08-02 @Tokyo, Japan

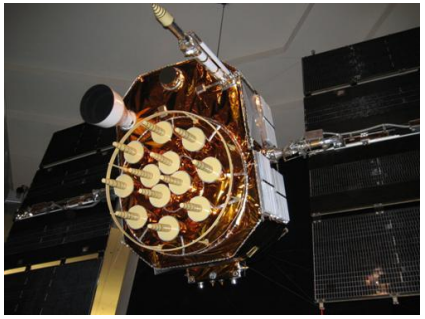
Timetable

B-1	**RTKLIB Introduction**	July 29	8:30- 9:50
B-2	**RTKLIB Practice (1)**		10:10-11:30
B-3	**Theory of Precise Positioning (1)**		12:30-13:50
	JAXA Activities & QZSS Intro by JAXA		14:10-15:30
	QZSS-Demo & RTKLIB Practice (2)		15:50-17:10
B-4	**Theory of Precise Positioning (2)**	July 30	8:30- 9:50
B-5	**RTKLIB Practice (3)**		10:10-11:30
	What is AIS? by JRC		12:30-13:00
	Port Cruise Demo (G-1) & RTKLIB Practice (4)		13:10-14:20
	Port Cruise Demo (G-2) & RTKLIB Practice (4)		14:30-15:40
B-6	**Advanced Topics**		15:50-17:10

B-1
RTKLIB Introduction

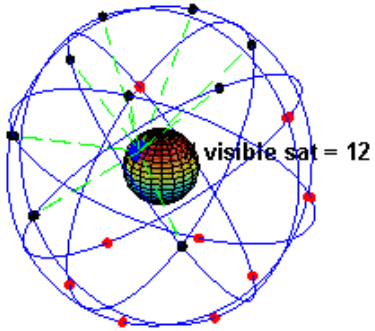
GNSS

- **GNSS (Global Navigation Satellite System)**
  - **GPS** (US)
  - **GLONASS** (Russia)
  - **Galileo** (EU)
  - **BeiDou** (China)



(http://www.ion.org/museum)

- **RNSS (Regional Navigation Satellite System)**
  - **QZSS** (Japan)
  - **IRNSS** (India)
- **SBAS (Satellite Based Augmentation System)**
  - **WAAS, EGNOS, MSAS, SDCM, GAGAN**



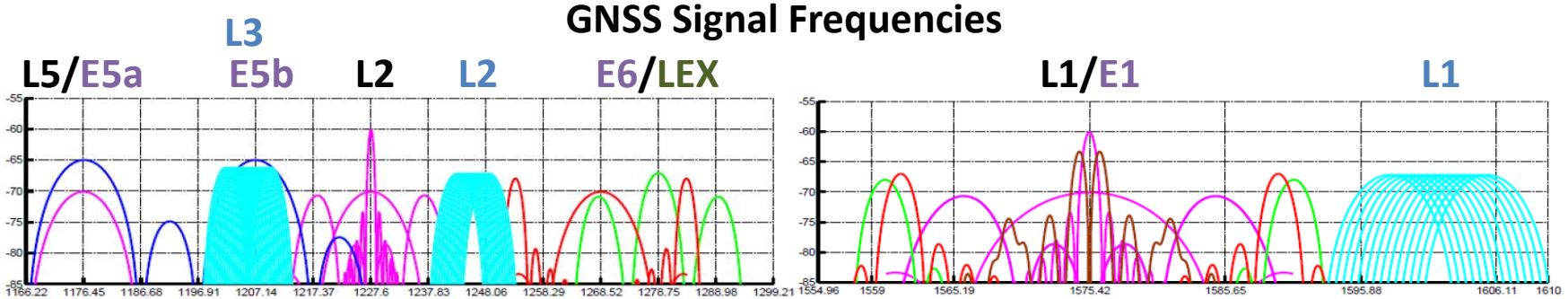
(http://en.wikipedia.org/wiki)

GNSS Constellation

Number of Existing/Planned GNSS Satellites

System	2010	2014	2017	2020
GPS	31	31	32	32
GLONASS	23 (+2)	24 (+3)	24 (+3)	24 (+3)
Galileo	0	4	18	27 (+3)
BeiDou	6	16	35	35
QZSS	1	1	4	7
IRNSS	0	1	7	7
SBAS	7	8	11	11
Total	68	86	134	149

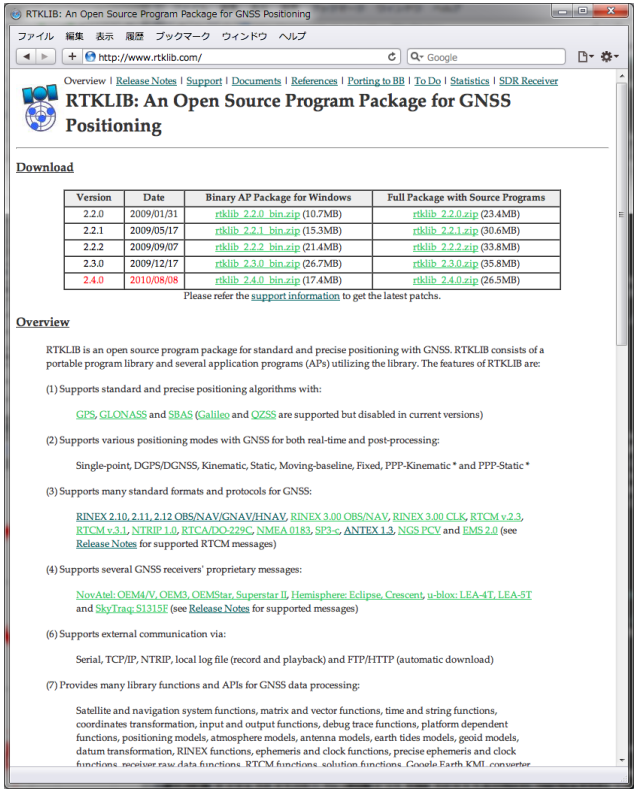
GNSS Signal Frequencies



(Y.Yang, COMPASS: View on Compatibility and Interoperability, 2009)

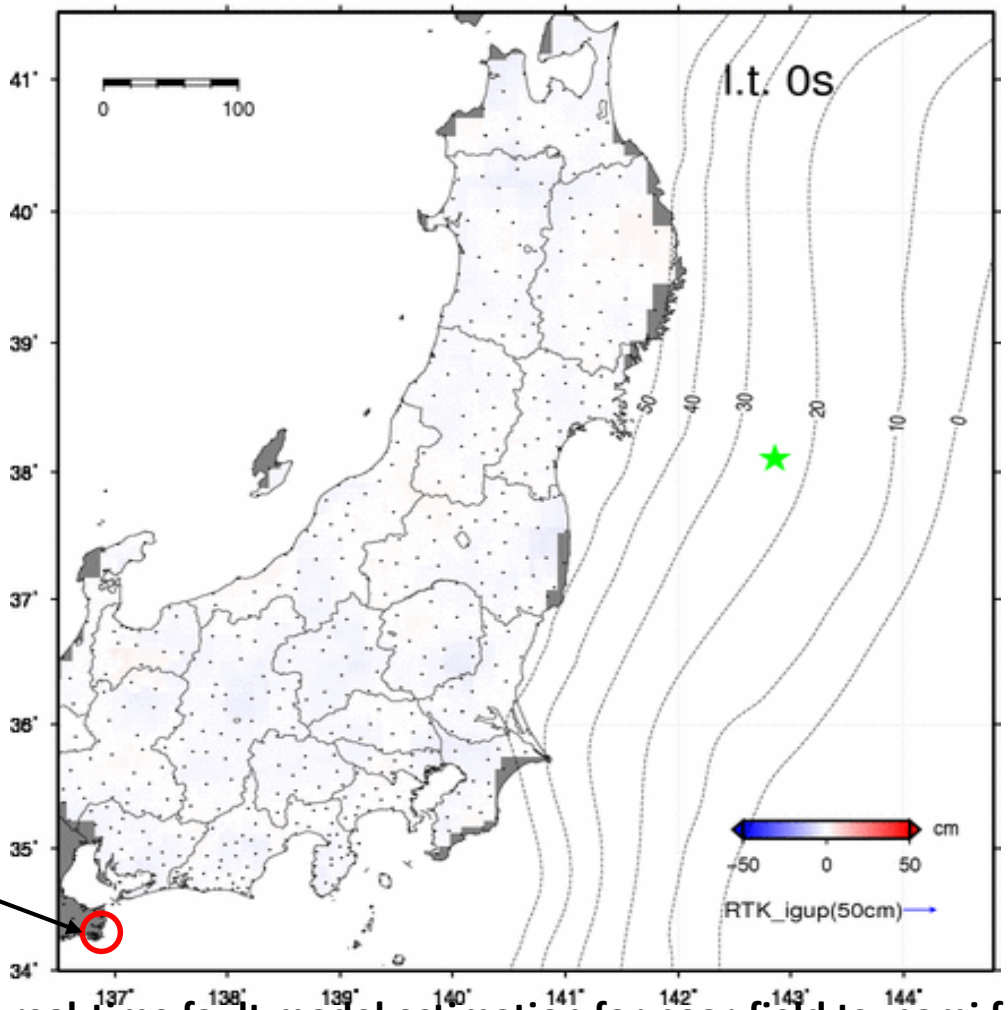
RTKLIB

- **An Open Source Software Package for GNSS Positioning**
  - Has been developed since 2006
  - The latest version 2.4.2 p8 distributed under BSD license
- **Portable APIs and Useful APs**
  - "All-in-one" package for Windows
  - CLI APs for any environments



http://www.rtklib.com or
https://github.com/tomojitakasu/RTKLIB

RTKLIB: Application



Reference Station

Y. Ohta et al., Quasi real-time fault model estimation for near-field tsunami forecasting base on RTK-GPS analysis: Application to the 2011 Tohoku-Oki earthquake (Mw 9.0), JGR-solid earth, 2012

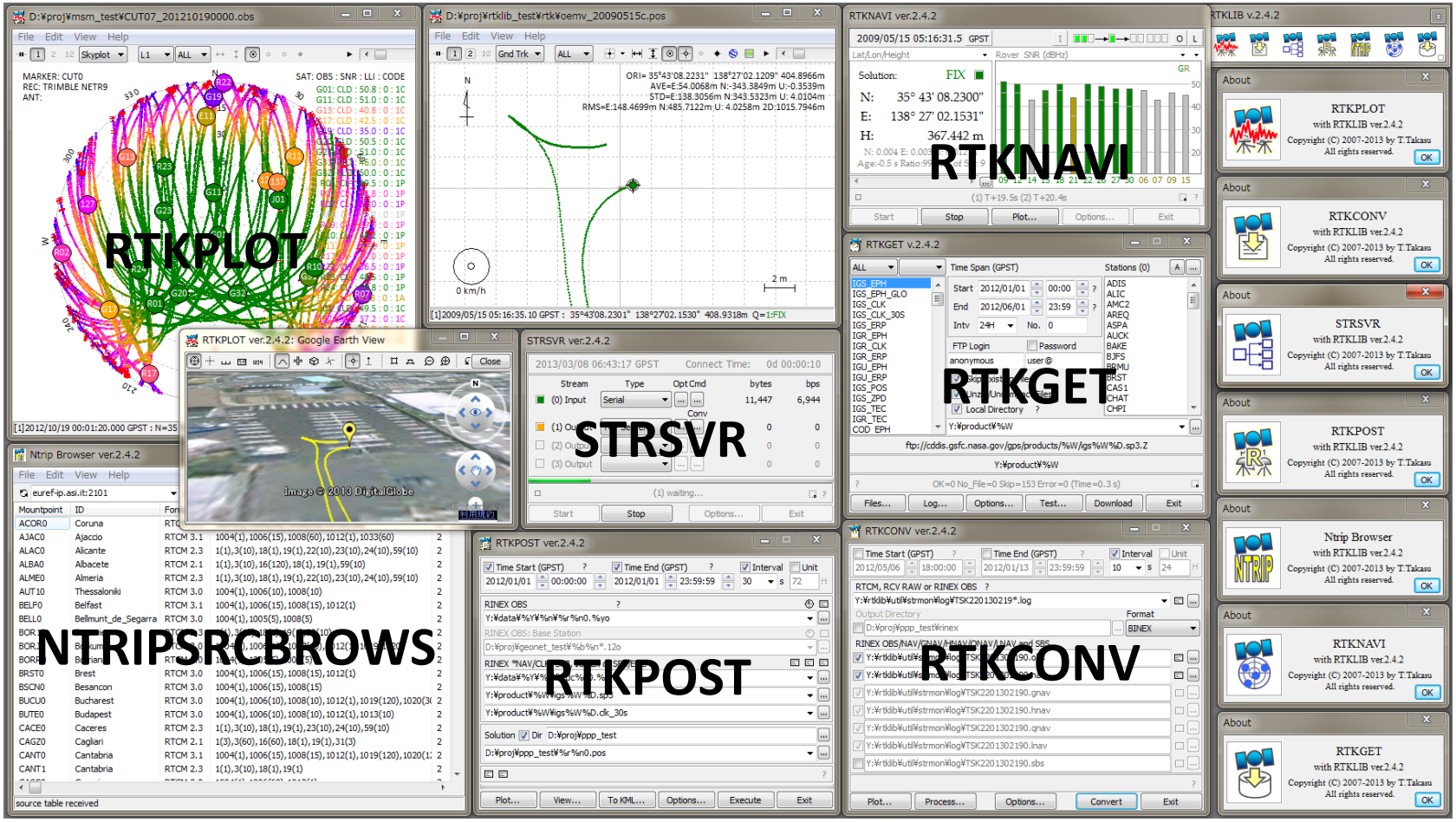
RTKLIB: History

- 2006/4 v.0.0.0 First version for RTK+C program lecture
- 2007/1 v.1.0.0 Simple post processing AP
- 2008/7 v.2.1.0 Add APs, support medium-range
- 2009/1 v.2.2.0 Add real-time AP, support NTRIP, start to distribute as **Open Source S/W**
- 2009/5 v.2.2.1 Support RTCM, NRTK, many receivers
- 2009/12 v.2.3.0 Support GLONASS, several receivers
- 2010/8 v.2.4.0 Support PPP Real-time/Post-processing PPP and Long-baseline RTK (<1000 km)
- 2011/6 v.2.4.1 Support QZSS, JAVAD receiver, …
- 2013/4 v.2.4.2 Support Galileo, Enable BeiDou, …

RTKLIB: Features

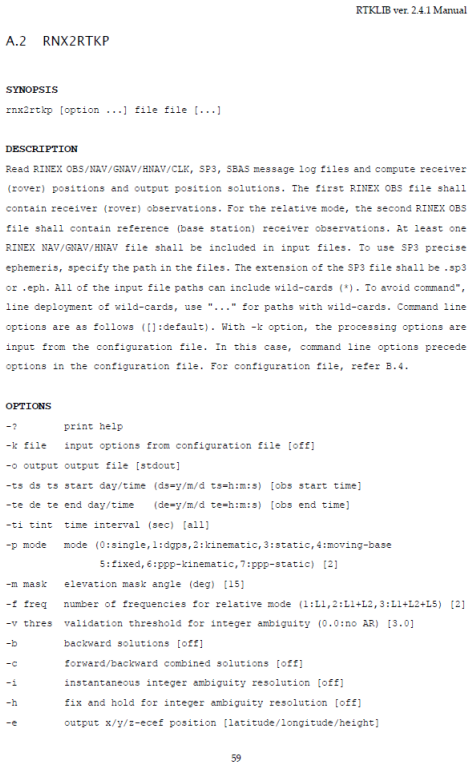
- **Standard and precise positioning algorithms with**:
  - GPS, GLONASS, QZSS, Galileo, BeiDou and SBAS
- **Real-time and post-processing by various modes**:
  - Single, SBAS, DGPS, RTK, Static, Moving-base and PPP
- **Supports many formats/protocols and receivers**:
  - RINEX 2/3, RTCM 2/3, BINEX, NTRIP 1.0, NMEA0183, SP3, RINEX CLK, ANTEX, NGS PCV, IONEX, RTCA-DO-229, EMS,
  - NovAtel, JAVAD, Hemisphere, u-blox, SkyTraq, NVS, …
- **Supports real-time communication via**:
  - Serial, TCP/IP, NTRIP and file streams

RTKLIB: GUI APs



RTKLIB: CLI APs

- **RNX2RTKP (rnx2rtkp)**
  Post-processing Positioning
- **RTKRCV (rtkrcv)**
  Real-time Positioning
- **CONVBIN (convbin)**
  RINEX Translator
- **STR2STR (str2str)**
  Stream Server
- **POS2KML (pos2kml)**
  Google Earth Converter



RTKLIB ver. 2.4.1 Manual

A.2 RNX2RTKP

SYNOPSIS

rnx2rtkp [option ...] file file [...]

DESCRIPTION

Read RINEX OBS/NAV/GNAV/HNAV/CLK, SP3, SBAS message log files and compute receiver (rover) positions and output position solutions. The first RINEX OBS file shall contain receiver (rover) observations. For the relative mode, the second RINEX OBS file shall contain reference (base station) receiver observations. At least one RINEX NAV/GNAV/HNAV file shall be included in input files. To use SP3 precise ephemeris, specify the path in the files. The extension of the SP3 file shall be .sp3 or .eph. All of the input file paths can include wild-cards (*). To avoid command", line deployment of wild-cards, use "..." for paths with wild-cards. Command line options are as follows ([]:default). With -k option, the processing options are input from the configuration file. In this case, command line options precede options in the configuration file. For configuration file, refer B.4.

OPTIONS

```
-?        print help
-k file   input options from configuration file [off]
-o output output file [stdout]
-ts ds ts start day/time (ds=y/m/d ts=h:m:s) [obs start time]
-te de te end day/time   (de=y/m/d te=h:m:s) [obs end time]
-ti tint  time interval (sec) [all]
-p mode   mode (0:single,1:dgps,2:kinematic,3:static,4:moving-base
               5:fixed,6:ppp-kinematic,7:ppp-static) [2]
-m mask   elevation mask angle (deg) [15]
-f freq   number of frequencies for relative mode (1:L1,2:L1+L2,3:L1+L2+L5) [2]
-v thres  validation threshold for integer ambiguity (0.0:no AR) [3.0]
-b        backward solutions [off]
-c        forward/backward combined solutions [off]
-i        instantaneous integer ambiguity resolution [off]
-h        fix and hold for integer ambiguity resolution [off]
-e        output x/y/z-ecef position [latitude/longitude/height]
```

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CLI Command Reference

RTKLIB: Package Structure

rtklib_2.4.2.zip

```
/src                    : Source programs of RTKLIB libraries
     /rcv               : Source programs depending on GPS/GNSS receiv.
/bin                    : Executable binary APs and DLLs for Windows
/data                   : Sample data for APs
/app                    : Build environment for APs
     /rtknavi           : RTKNAVI (GUI)
     /strsvr            : STRSVR (GUI)
     /rtkpost           : RTKPOST (GUI)
     /rtkpost_mkl       : RTKPOST_MKL (GUI)
     /rtkplot           : RTKPLOT (GUI)
     /rtkconv           : RTKCONV (GUI)
     /srctblbrows       : NTRIP source table browser (GUI)
     /rtkrcv            : RTKRCV (console)
     /rnx2rtkp          : RNX2RTKP (console)
     /pos2kml           : POS2KML (console)
     /convbin           : CONVBIN (console)
     /str2str           : STR2STR (console)
     /appcmn            : Common routines for GUI APs
     /icon              : Icon data for GUI APs
/mkl                    : Intel MKL libraries for Borland environment
/test                   : Test program and data
/util                   : Utilities
/doc                    : Document files
```

RTKLIB: APIs

```
/* matrix and vector functions */
mat(),imat(),zeros(),eye(),dot(),norm(),matcpy(),matmul(),matinv(),solve(),lsq(),filter(),smoother(),matprint(),matfprint()
/* time and string functions */
str2num(),str2time(),time2str(),epoch2time(),time2epoch(),gpst2time(),time2gpst(),timeadd(),timediff(),gpst2utc(),utc2gpst(),
timeget(),time2doy(),adjgpsweek(),tickget(),sleepms()
/* coordinates functions */
ecef2pos(),pos2ecef(),ecef2enu(),enu2ecef(),covenu(),covecef(),xyz2enu(),geoidh(),loaddatump(),tokyo2jgd(),jgd2tokyo()
/* input/output functions */
readpcv(),readpos(),sortobs(),uniqeph(),screent()
/* positioning models */
eph2pos(),geph2pos(),satpos(),satposv(),satposiode(),satazel(),geodist(),dops(),ionmodel(),ionmapf(),tropmodel(),tropmapf(),
antmodel(),csmooth()
/* single-point positioning */
pntpos(),pntvel()
/* rinex functions */
readrnx(),readrnxt(),outrnxobsh(),outrnxnavh(),outrnxnavb(),uncompress(),convrnx()
/* precise ephemeris functions */
readsp3(),readsap(),eph2posp(),satposp()
/* receiver raw data functions */
getbitu(),getbits(),crc32(),crc24q(),decode_word(),decode_frame(),init_raw(),free_raw(),input_raw(),input_rawf(),input_oem4(),
input_oem3(),input_ubx(),input_ss2(),input_cres(),input_oem4f(),input_oem3f(),input_ubxf(),input_ss2f(),input_cresf()
/* rtcm functions */
init_rtcm(),free_rtcm(),input_rtcm2(),input_rtcm3(),input_rtcm2f(),input_rtcm3f()
/* solution functions */
readsol(),readsolt(),outsolheads(),outsols(),outsolexs(),outsolhead(),outsol(),outsolex(),setsolopt(),setsolformat(),
outnmea_rmc(),outnmea_gga(),outnmea_gsa(),outnmea_gsv(),
/* SBAS functions */
sbsreadmsg(),sbsreadmsgt(),sbsoutmsg(),sbsupdatestat(),sbsdecodemsg(),sbssatpos(),sbspntpos()
/* integer least-square estimation */
lambda()
/* realtime kinematic positioning */
rtkinit(),rtkfree(),rtkpos()
/* post-processing positioning */
postpos(),postposopt(),readopts(),writeopts()
/* stream data input/output */
strinitcom(),strinit(),strlock(),strunlock(),stropen(),strclose(),strread(),strwrite(),strsync(),strstat(),strsum(), strsetopt(),
strgettime()
/* stream server functions */
strsvrinit(),strsvrstart(),strsvrstop(),strsvrstat()
/* rtk server functions */
rtksvrinit(),rtksvrstart(),rtksvrstop(),rtksvrlock(),rtksvrunlock(),rtksvrostat(),rtksvrsstat() ...
```

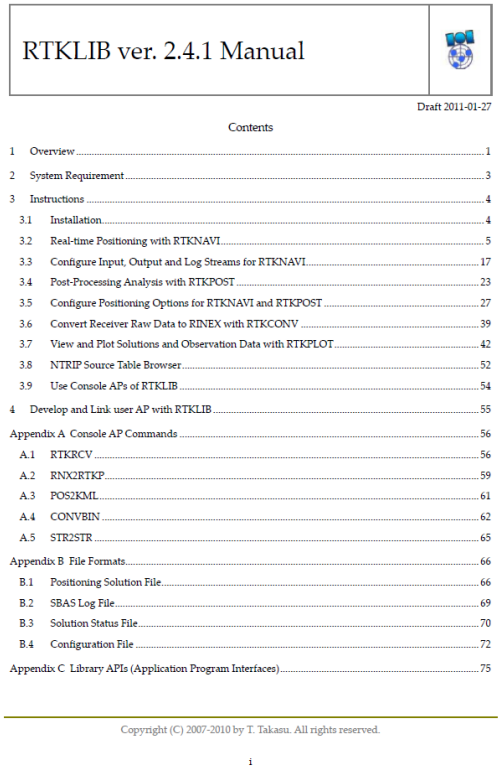
RTKLIB: Supported Receivers

Format	Data Message Types							
	GPS Raw Meas Data	GLONASS Raw Meas	GPS Ephemeris	GLONASS Ephemeris	ION/UTC Parameters	Antenna Info	SBAS Messages	Others
RTCM v.2.3	Type 18, 19	Type 18, 19	Type 17	-	-	Type 3, 22	-	Type 1, 9, 14, 16
RTCM v.3.1	Type 1002, 1004	Type 1010, 1012	Type 1019	Type 1020	-	Type 1005, 1006, 1007, 1008, 1033	-	SSR corrections
NovAtel OEM4/V, OEMStar	RANGEB, RANGECMPB	RANGEB, RANGECMPB	RAWEPHEMB	GLO-EPHEMERISB	IONUTCB	-	RAWWAAS-FRAMEB	-
NovAtel OEM3	RGEB, RGED	-	REPB	-	IONB, UTCB	-	FRMB	-
NovAtel Superstar II	ID#23	-	ID#22	-	-	-	ID#67	ID#20, #21
u-blox LEA-4T, LEA-5T	UBX RXM-RAW	-	UBX RXM-SFRB	-	UBX RXM-SFRB	-	UBX RXM-SFRB	-
Hemisphere Crescent, Eclipse	bin 96	-	bin 95	-	bin 94	-	bin 80	-
SkyTraq S1315F	msg 0xDD (221)	-	msg 0xE0 (224)	-	msg 0xE0 (224)	-	-	msg 0xDC (220)
JAVAD (GRIL/GREIS)	[R*],[r*],[*R], [*r],[P*],[p*], [*p],[D*],[*d], [E*],[*E],[F*]	[R*],[r*],[*R], [*r],[P*],[p*], [*p],[D*],[*d], [E*],[*E],[F*]	[GE],[GD], [gd]	[NE],[LD]	[IO],[UO], [GD]	-	[WD]	[~~],[::],[RD], [SI],[NN],[TC], QZSS Data, Galileo Data
Furuno GW10 II	msg 0x08	-	msg 0x24	-	msg 0x26	-	msg 0x03	msg 0x20

RTKLIB: Portability

- **Programming Language**
  - API, CUI AP : ANSI C (C89)
  - GUI AP : C++
- **Underlying Libraries**
  - TCP/IP Stack : standard socket or WINSOCK
  - Thread : POSIX (pthread) or WIN32 thread
  - GUI Widgets : Borland VCL on Windows
- **Build Environment**
  - CLI AP : GCC, MS VS, Borland C, ...
  - GUI AP : Borland Turbo C++ on Windows

RTKLIB: References



RTKLIB ver. 2.4.1 Manual

Draft 2011-01-27

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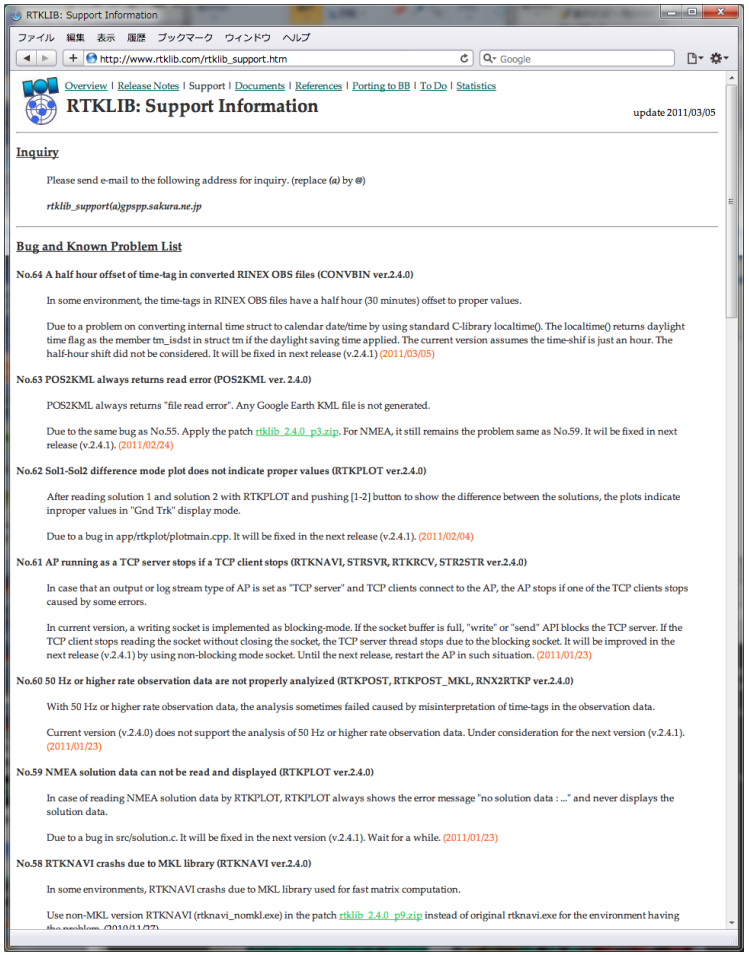
rtklib_2.4.2/doc/manual_2.4.2.pdf



RTKLIB: Support Information

ファイル 編集 表示 履歴 ブックマーク ウィンドウ ヘルプ

http://www.rtklib.com/rtklib_support.htm

Google

Overview | Release Notes | Support | Documents | References | Porting to BB | To Do | Statistics

RTKLIB: Support Information

update 2011/03/05

Inquiry

Please send e-mail to the following address for inquiry. (replace *(a)* by @)

rtklib_support(a)gpspp.sakura.ne.jp

Bug and Known Problem List

No.64 A half hour offset of time-tag in converted RINEX OBS files (CONVBIN ver.2.4.0)

In some environment, the time-tags in RINEX OBS files have a half hour (30 minutes) offset to proper values.

Due to a problem on converting internal time struct to calendar date/time by using standard C-library localtime(). The localtime() returns daylight time flag as the member tm_isdst in struct tm if the daylight saving time applied. The current version assumes the time-shif is just an hour. The half-hour shift did not be considered. It will be fixed in next release (v.2.4.1) (2011/03/05)

No.63 POS2KML always returns read error (POS2KML ver. 2.4.0)

POS2KML always returns "file read error". Any Google Earth KML file is not generated.

Due to the same bug as No.55. Apply the patch rtklib_2.4.0_p3.zip. For NMEA, it still remains the problem same as No.59. It wil be fixed in next release (v.2.4.1). (2011/02/24)

No.62 Sol1-Sol2 difference mode plot does not indicate proper values (RTKPLOT ver.2.4.0)

After reading solution 1 and solution 2 with RTKPLOT and pushing [1-2] button to show the difference between the solutions, the plots indicate inproper values in "Gnd Trk" display mode.

Due to a bug in app/rtkplot/plotmain.cpp. It will be fixed in the next release (v.2.4.1). (2011/02/04)

No.61 AP running as a TCP server stops if a TCP client stops (RTKNAVI, STRSVR, RTKRCV, STR2STR ver.2.4.0)

In case that an output or log stream type of AP is set as "TCP server" and TCP clients connect to the AP, the AP stops if one of the TCP clients stops caused by some errors.

In current version, a writing socket is implemented as blocking-mode. If the socket buffer is full, "write" or "send" API blocks the TCP server. If the TCP client stops reading the socket without closing the socket, the TCP server thread stops due to the blocking socket. It will be improved in the next release (v.2.4.1) by using non-blocking mode socket. Until the next release, restart the AP in such situation. (2011/01/23)

No.60 50 Hz or higher rate observation data are not properly analyized (RTKPOST, RTKPOST_MKL, RNX2RTKP ver.2.4.0)

With 50 Hz or higher rate observation data, the analysis sometimes failed caused by misinterpretation of time-tags in the observation data.

Current version (v.2.4.0) does not support the analysis of 50 Hz or higher rate observation data. Under consideration for the next version (v.2.4.1). (2011/01/23)

No.59 NMEA solution data can not be read and displayed (RTKPLOT ver.2.4.0)

In case of reading NMEA solution data by RTKPLOT, RTKPLOT always shows the error message "no solution data : ..." and never displays the solution data.

Due to a bug in src/solution.c. It will be fixed in the next version (v.2.4.1). Wait for a while. (2011/01/23)

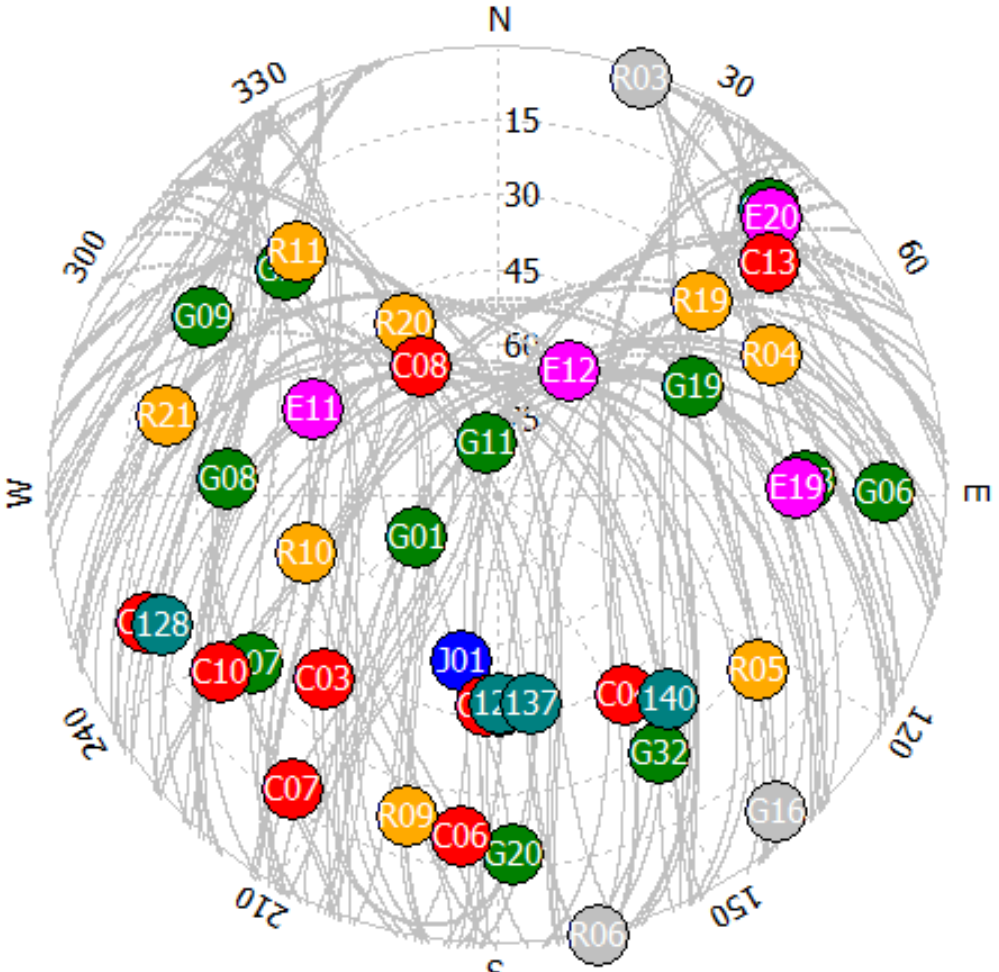
No.58 RTKNAVI crashs due to MKL library (RTKNAVI ver.2.4.0)

In some environments, RTKNAVI crashs due to MKL library used for fast matrix computation.

Use non-MKL version RTKNAVI (rtknavi_nomkl.exe) in the patch rtklib_2.4.0_p9.zip instead of original rtknavi.exe for the environment having

http://www.rtklib.com

Multi-GNSS Support



2013-06-12 10:20 GPST

Visibility at Tokyo by RTKPLOT

- **GPS (12)**
- **GLONASS (8)**
- **Galileo (4)**
- **QZSS (1)**
- **BeiDou (10)**
- **SBAS (4)**

 # Total (39)
(El>10deg)

RINEX

- **RINEX (Receiver Independent Exchange)**
  - Text-based Standard GNSS data file format
  - Mainly for post-processing
- **RINEX Types**
  - OBS: Observation data
  - NAV: navigation data, (GNAV: GLONASS, HNAV: SBAS)
  - MET: Meteorological data
  - CLK: Clock product
- **RINEX Version**
  - ver. 2 (2.10, 2.11, 2.12), ver. 3 (3.00, 3.01, 3.02m, ...)

RINEX OBS (Observation Data)

```
2.10           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
RTKCONV 2.4.0                      20110423 090647 UTC PGM / RUN BY / DATE
                                                       MARKER NAME
                                                       MARKER NUMBER
                                                       OBSERVER / AGENCY
                                                       REC # / TYPE / VERS
                                                       ANT # / TYPE
        0.0000        0.0000        0.0000             APPROX POSITION XYZ
        0.0000        0.0000        0.0000             ANTENNA: DELTA H/E/N
     1     1                                           WAVELENGTH FACT L1/2
     8    C1    L1    D1    S1    P2    L2    D2    S2  # / TYPES OF OBSERV
  2010    10    15     0     0   0.0000000      GPS     TIME OF FIRST OBS
  2010    10    15     2    28  54.0000000      GPS     TIME OF LAST OBS
                                                       END OF HEADER

 10 10 15  0  0  0.0000000  0 10G 6G23G16G19G21G13G 3G31S29S37
  20849928.484  109567124.316       1939.684            45.000    20849930.125
  85377001.480       1511.441         41.000
  22450960.859  117980618.953       1062.035            42.000    22450959.898
  91932917.910        827.555         38.000
  20790247.117  109253470.496        334.336            45.000    20790246.844
  85132587.789        260.520         41.000
  24794846.031  130297776.969       3763.289            38.000    24794848.422
 101530723.414       2932.430         32.000
  23378478.469  122854746.020        860.133            40.000    23378477.977
  95730986.191        670.234         34.000
  24155219.492  126936537.238       2611.234            35.000    24155223.109
  98911564.082       2034.727         33.000
  21765068.656  114376223.133       3035.375            42.000    21765071.242
  89124339.934       2365.223         38.000
  21044041.703  110587188.461      -1456.918            45.000    21044041.797
  86171830.961      -1135.266         42.000
  37172827.633  195344531.559          2.965            38.000

  37203973.328  195508183.188         -0.992            39.000

 10 10 15  0  0  1.0000000  0 10G 6G23G16G19G21G13G 3G31S29S37
  20849559.430  109565184.891       1939.090            45.000    20849561.062
```

Receiver Time Tag

Types of OBS

- C,P*: Pseudorange
- L*: Carrier-phase
- D*: Doppler Freq
- S*: CN0 (dBHz)

Satellite List

- nn, Gnn: GPS
- Rnn: GLONASS
- Jnn: QZSS
- Enn: Galileo
- Snn: SBAS

RINEX NAV (Navigation Data)

```
 2.10           N: GPS NAV DATA                         RINEX VERSION / TYPE
RTKCONV 2.4.0                           20110423 090647 UTC PGM / RUN BY / DATE
    1.1176E-08  0.0000E+00 -5.9605E-08  0.0000E+00           ION ALPHA
    9.0112E+04  0.0000E+00 -1.9661E+05  0.0000E+00           ION BETA
    -.838190317154E-08 -.310862446895E-13    61440     1606 DELTA-UTC: A0,A1,T,W
    15                                                      LEAP SECONDS
                                                            END OF HEADER
31 10 10 15  2  0  0.0 -.724568963051E-06  .352429196937E-11  .000000000000E+00
     .810000000000E+02  .105937500000E+02  .427089218552E-08 -.148856857180E+01
     .571832060814E-06  .746127020102E-02  .472925603390E-05  .515378055573E+04
     .439200000000E+06 -.176951289177E-06  .679765366385E-02  .540167093277E-07
     .978380240916E+00  .300062500000E+03 -.105249752834E+01 -.819426989566E-08
     .142863093678E-10  .100000000000E+01  .160500000000E+04  .000000000000E+00
     .240000000000E+01  .000000000000E+00 -.130385160446E-07  .810000000000E+02
     .432006000000E+06  .000000000000E+00
 6 10 10 15  2  0  0.0  .455596484244E-03 -.140971678775E-10  .000000000000E+00
     .230000000000E+02 -.352500000000E+02  .500699427569E-08  .227090783348E+01
    -.185333192348E-05  .616293260828E-02  .853091478348E-05  .515365624428E+04
     .439200000000E+06  .104308128357E-06  .204411629865E+01  .353902578354E-07
     .934819176502E+00  .200625000000E+03 -.936257940341E+00 -.811783814054E-08
     .169649923743E-09  .100000000000E+01  .160500000000E+04  .000000000000E+00
     .240000000000E+01  .000000000000E+00 -.512227416039E-08  .230000000000E+02
     .432006000000E+06  .000000000000E+00
...
```

PRN Toc	SV_clock_bias	SV_clock_drift	SV_clock_drift_rate
IODE	Crs	Delta_n	M0
Cuc	e	Cus	sqrt(A)
Toe	Cic	OMEGA	Cis
i0	Crc	omega	OMEGA_DOT
IDOT	Codes_on_L2_ch	GPS_Week_#	L2_P_data_flag
SV_accuracy	SV_health	TGD	IODC
Trans_Time	Fit_interval	spare	spare

RINEX Support

Ver.	OBS						NAV						Met	CLK	GEO BRDC
	G	R	E	J	C	S	G	R	E	J	C	S			
2.10	O	O	O	O	O	O	N	G	N	N	–	H	–	–	–
2.11	O	O	O	O	O	O	N	G	N	N	–	H	–	–	–
2.12	O	O	O	O	O	O	N	G	N	N	–	H	–	–	–
3.00	O	O	O	O	O	O	N	N	N	N	N	N	–	C	–
3.01	O	O	O	O	O	O	N	N	N	N	N	N	–	C	–
3.02*	O	O	O	O	O	O	N	N	N	N	N	N	–	C	–

G: GPS, R: GLONASS, E: Galileo, J: QZSS, C: BeiDou, S: SBAS

* Based on draft (2012-12), O/N: RTKLIB Extension

RTCM SC-104

RTCM 2.3 Messages		RTCM 3.1 Messages	
Type	**Message**	**Type**	**Message**
1	Differential GPS Corrections	1001	L1-Only GPS RTK Observables
3	GPS Reference Station Parameters	1002	Extended L1-Only GPS RTK Observables
10	P-Code Differential Corrections	1003	L1&L2 GPS RTK Observables
11	C/A-Code L1, L2 Delta Corrections	1004	Extended L1&L2 GPS RTK Observables
17	GPS Ephemerides	1005	Stationary RTK Reference Station ARP
18	RTK Uncorrected Carrier Phase	1006	Stationary RTK Ref. Stn. ARP with Hgt.
19	RTK Uncorrected Pseudorange	1007	Antenna Descriptor
20	RTK Carrier Phase Corrections	1008	Antenna Descriptor & Serial Number
21	RTK Pseudorange Corrections	1013	System Parameters
22	Extended Reference Station Parameter	1014	Network Auxiliary Station Data
23	Antenna Type Definition Record	1015	GPS Ionospheric Correction Differences
24	Antenna Reference Point (ARP)	1016	GPS Geometric Correction Differences
59	Proprietary Messages	1019	GPS Ephemerides

RTCM: The Radio Technical Commission for Marine Service

RTCM 3 Support

Message		GPS	GLOASS	Galileo	QZSS	BeiDou	SBAS
OBS	Compact L1	1001~	1009~	-	-	-	-
	Full L1	1002	1010	-	-	-	-
	Compact L1/2	1003~	1011~	-	-	-	-
	Full L1/2	1004	1012	-	-	-	-
Ephemeris		1019	1020	1045/6*	1044*	-	-
MSM	1	1071~	1081~	1091~	1111*~	1121*~	1101*~
	2	1072~	1082~	1092~	1112*~	1122*~	1102*~
	3	1073~	1083~	1093~	1113*~	1123*~	1103*~
	4	1074	1084	1094	1114*	1124*	1104*
	5	1075	1085	1095	1115*	1125*	1105*
	6	1076	1086	1096	1116*	1126*	1106*
	7	1077	1087	1097	1117*	1127*	1107*
SSR	Orbit Corr.	1057	1063	1240*	1246*	-	-
	Clock Corr.	1058	1064	1241*	1247*	-	-
	Code Bias	1059	1065	1242*	1248*	-	-
	Combined	1060	1066	1243*	1249*	-	-
	URA	1061	1067	1244*	1250*	-	-
	HR-Clock	1062	1068	1245*	1251*	-	-
Antenna Info		1005 1006	1007 1008	1033			

* based on draft, ~ only encode

RTK vs. PPP

	RTK	Real-Time PPP
Coverage	Local/Regional (< 1000km)	Global
Typical Accuracy	1-3 cm HRMS	2-10 cm, much depending on orbit/clock quality
Effect of Ref Movement	Hard to separate ref and user movement	Less effect by distributed ref stations
System Complexity	Simple, at least one ref station	Complicated, need many ref stations
Latency of Corrections	~ 1 s	5 ~ 25 s
Biases	Basically cancelled by DD	Need careful handling

Which is better depends on AP requirement and technology level.
RTKLIB offers both. They are user-selectable by option settings.

PPP Models

	v.2.4.1	v.2.4.2
Satellites	GPS, GLO and QZS	GPS, GLO, QZS and **GAL**
Troposphere	Standard-Atmosphere NMF + Gradient	Standard or **GPT** NMF or **GMF** + Gradient
Ionosphere	Iono-Free LC (L1-L2)	Iono-Free LC (L1-L2**, L1-L5**) or **IONEX for single-freq**
Tidal Displacement	Solid Earth Tide: IERS 1996 Step 1 + Step 2 K1 radial only	Solid Earth Tide: **IERS DEHANTTIDEINEL.F** **Ocean Tide Loading:** **IERS 2010 with BLQ** **Pole Tide:** **IERS 2010 with IGS ERP**
Ambiguity Resolution	No (FLOAT)	**Yes with CNES Products (Experimental)**

B-2
RTKLIB Practice (1)

RTKLIB Practice (1)

- **Install RTKLIB**
- **Setup Receivers and Antennas**
- **Use RTKLIB in Post Processing Mode**
- **Use RTKLIB in Real-Time Mode**

Install RTKLIB

- **Copy the following directory and files in the USB memory to your laptop PC.**

  school

  ¥rtklib_2.4.2p9

  ¥sample1

  …

  ¥novatel

  ¥javad

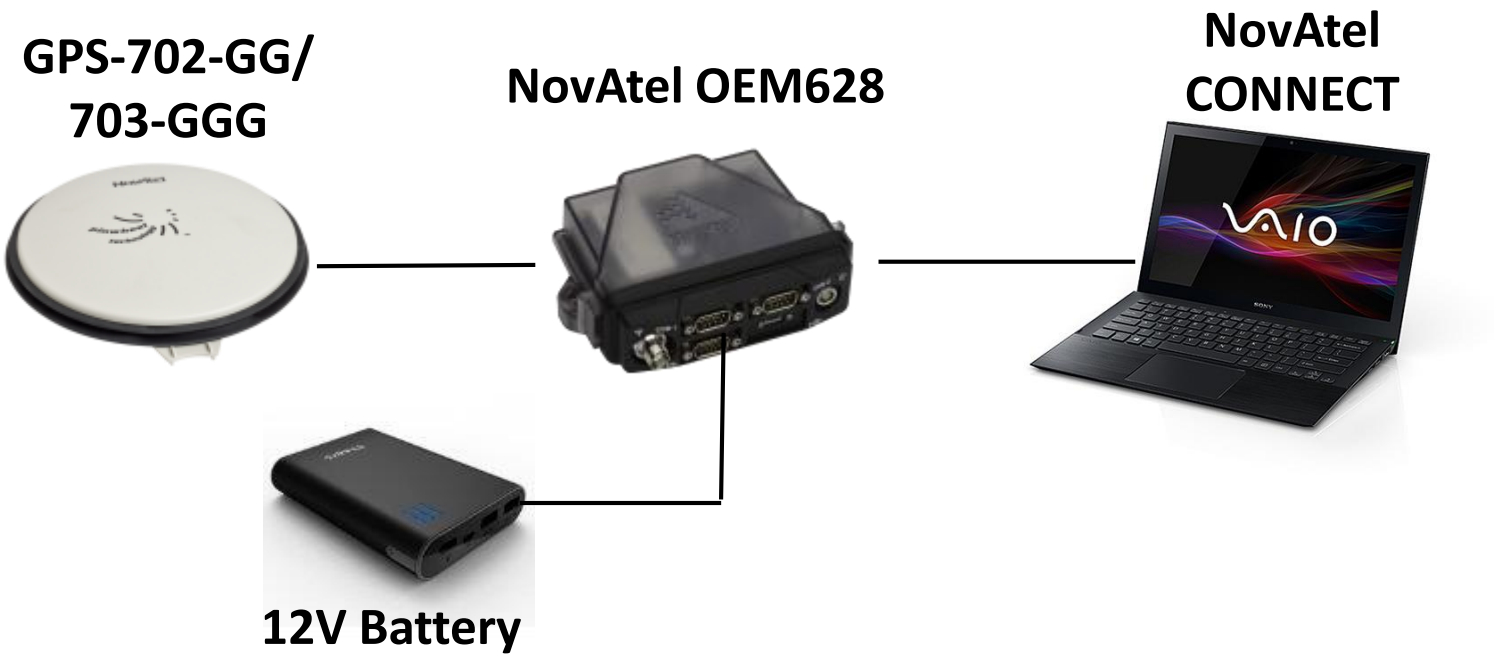
  ¥googleearth

Receivers and Antennas

- Receiver
  - NovAtel OEM628 (GPS, GLO, QZS, SBS, BDS) x 6
  - JAVAD Delta (GPS, GLO, QZS, SBS) x 2
- Antenna
  - NovAtel GPS-702-GG or 703-GGG (L1, L2, L5) x 6
  - JAVAD GrAnt-G3T (L1, L2, L5) x 2
- Others
  - 12V Battery, Cables (Antenna/Power/USB) x 8

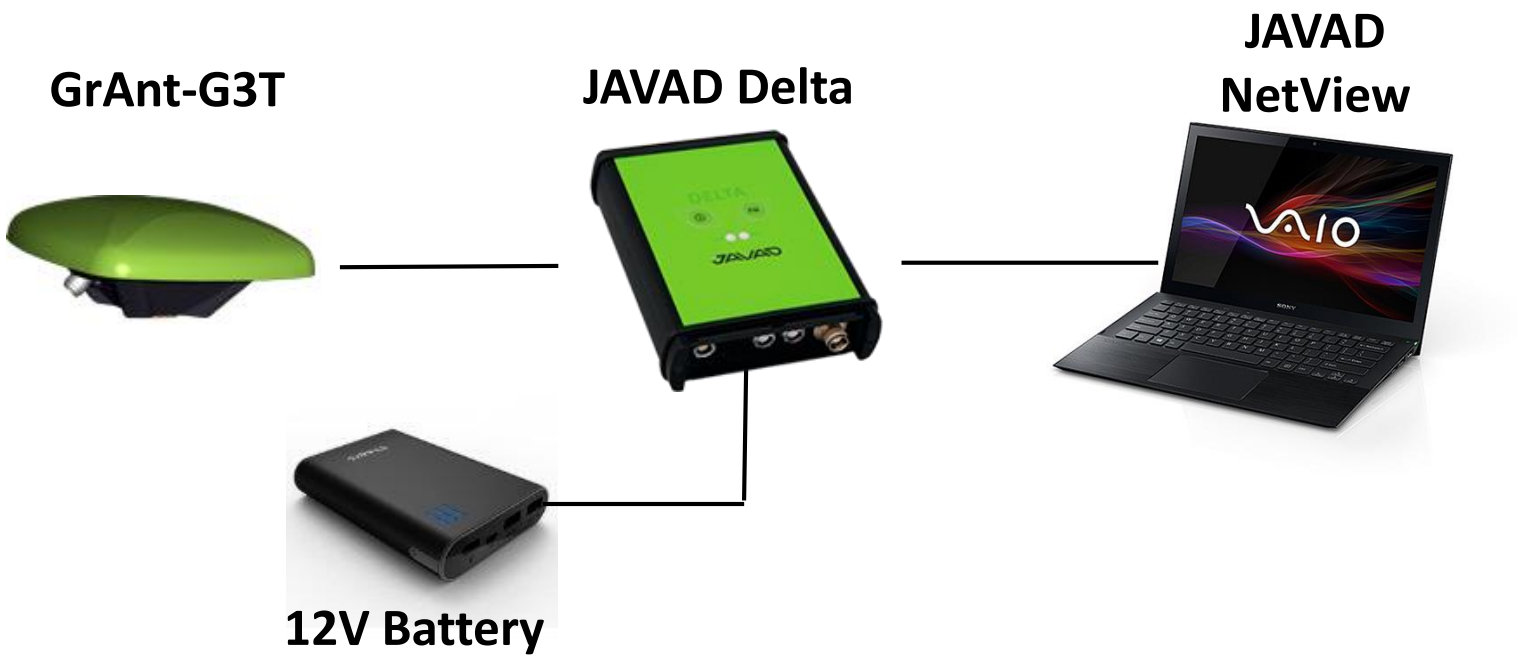
Setup NovAtel Receiver/Anntena

- **Install Support S/W to your laptop PC**
  - **NovAtel CONNECT PC Utilities 1.6.0**
    (school¥novatel¥NovAtelConnectSetup_1_6_0.zip)



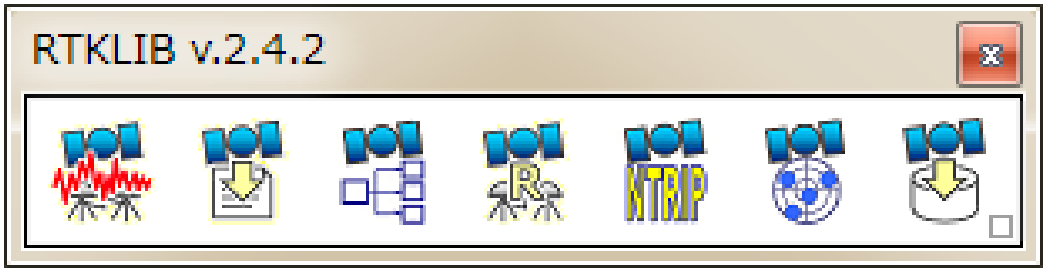
Setup JAVAD Receiver

- **Install Support S/W to your laptop PC.**
  - **JAVAD NetView 4.8.1**
    (school¥javad¥NetView_4_8_1_18.zip)



Use RTKLIB (1)

- **Execute RTKLAUNCH.**
  school¥rtklib_2.4.2p9¥bin¥rtklaunch.exe



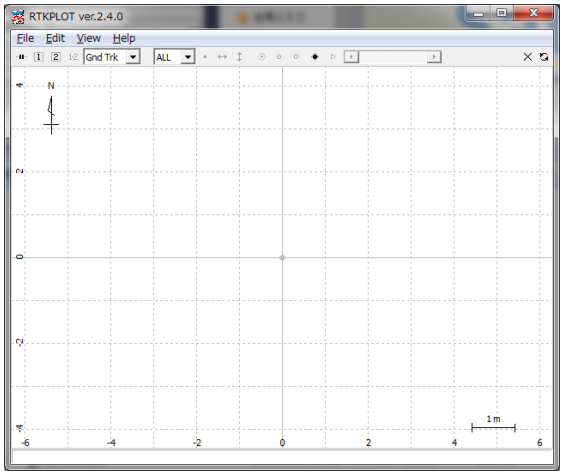
RTKPLOT STRSVR NTRIPBRS RTEGET

RTKCONV RTKPOST RTKNAVI

Use RTKLIB (2)

- **Execute RTKPLOT by RTKLAUNCH**
- **Execute Menu of RTKPLOT: File - Open Obs Data...**
  school¥sample1¥
  javad1_201102030000.obs

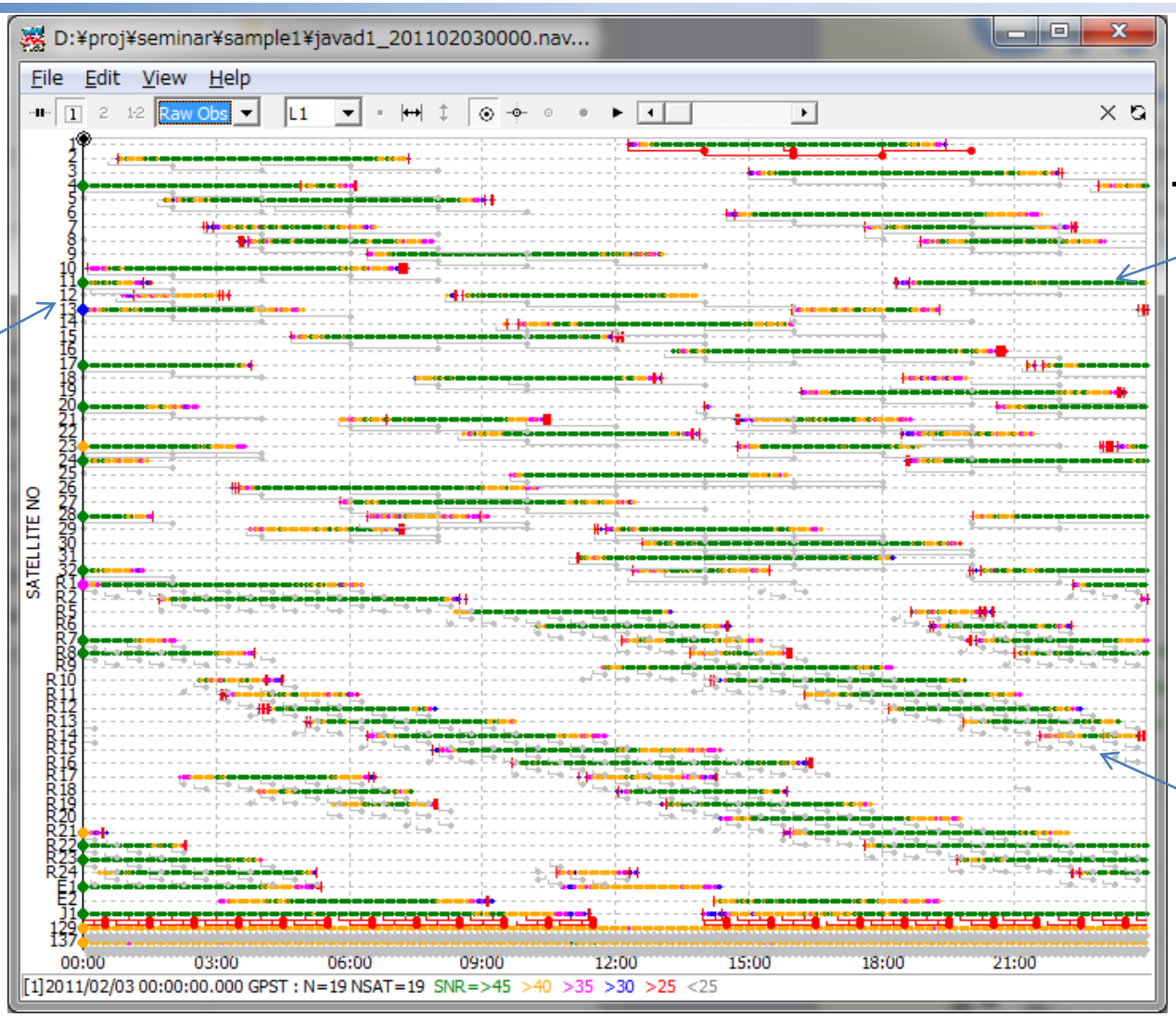
RTKLIB - RTKPLOT



JAVAD DELTA Receiver

Acknowledgment:
Sample data were captured by JAVAD DELTA receiver provided by JAXA

Use RTKLIB (3)



Satellite ID

Gnn: GPS
Rnn: GLO
Enn: GAL
Jnn: QZS
1nn: SBAS

Tracking Data

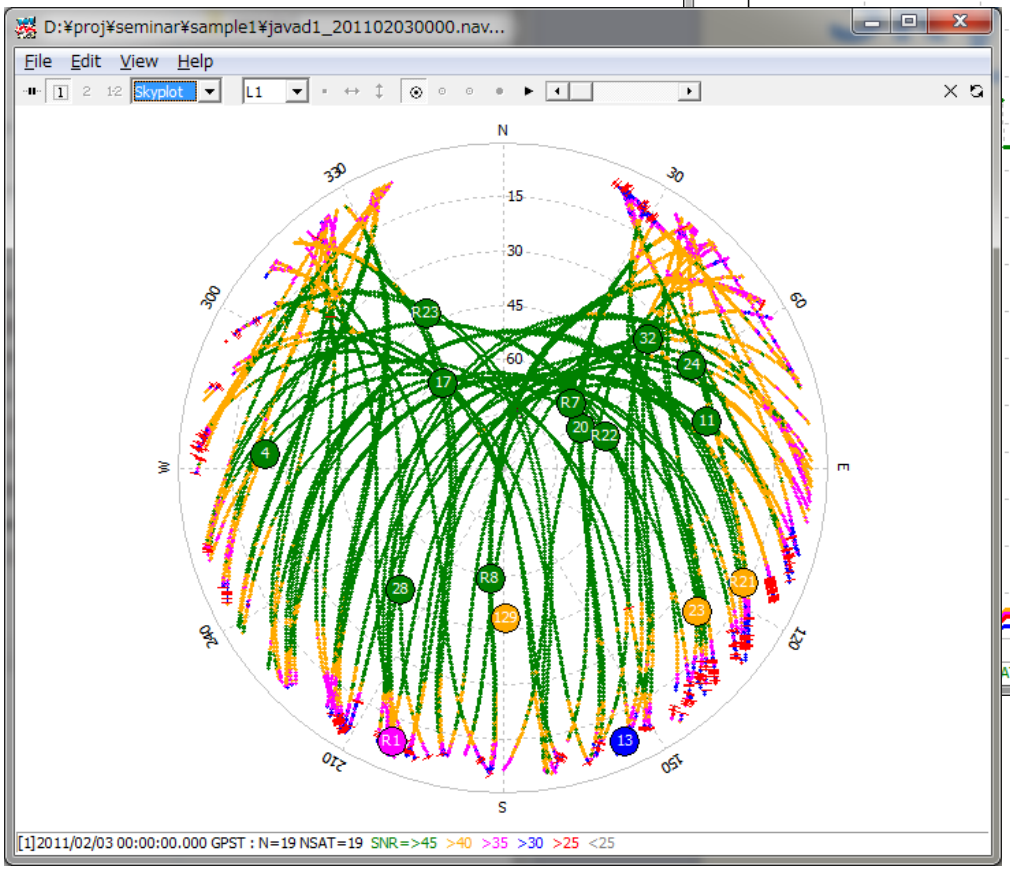
|: Cycle-Slip
|: Parity Unknown

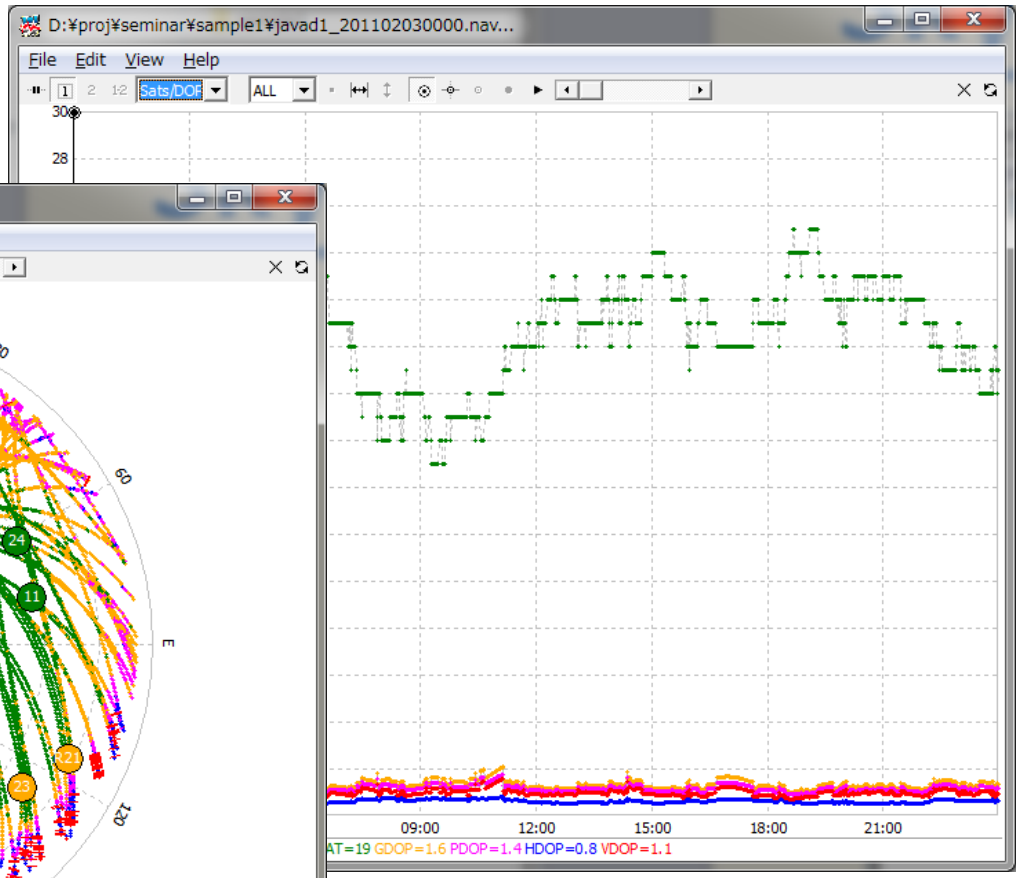
Ephemeris

● : Toe
Red: unhealthy

Use RTKLIB (4)

Skyplot

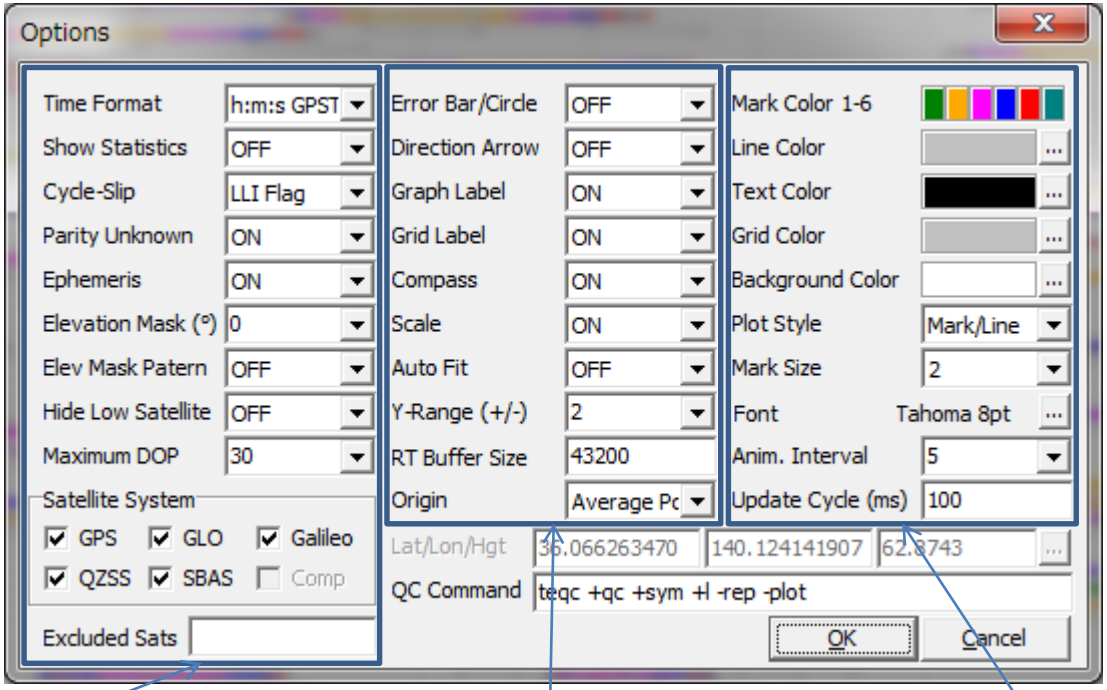




# of Visible Satellites and DOP

Use RTKLIB (5)

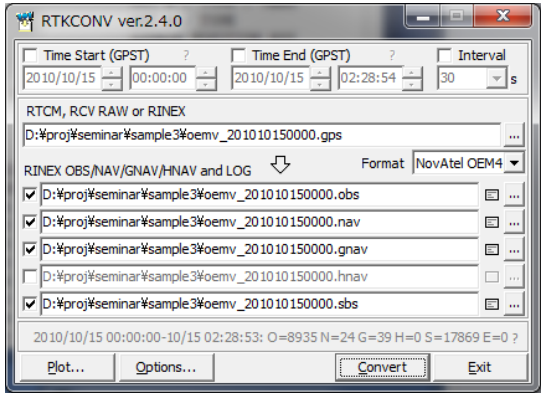
RTKPLOT - Options



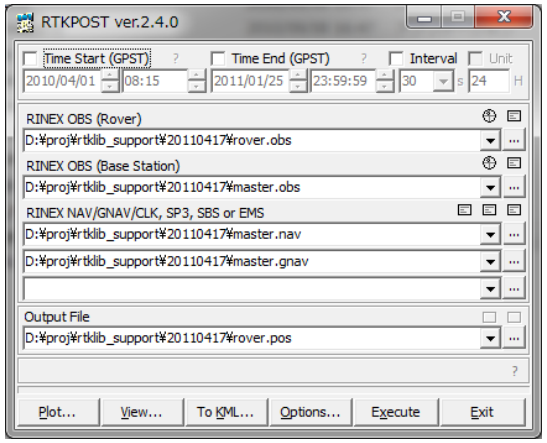
OBS Data Options **Solution Data Options** **Common Options**

Use RTKLIB (6)

- **Execute RTKCONV by RTKLAUNCH**
- **Set Input Data**
  school¥sample3¥
  oemv_201010150000.gps
- **Push Convert... Button**
- **Check RINEX Data**
- **Push Process... Button to Launch RTKPOST**



RTKCONV

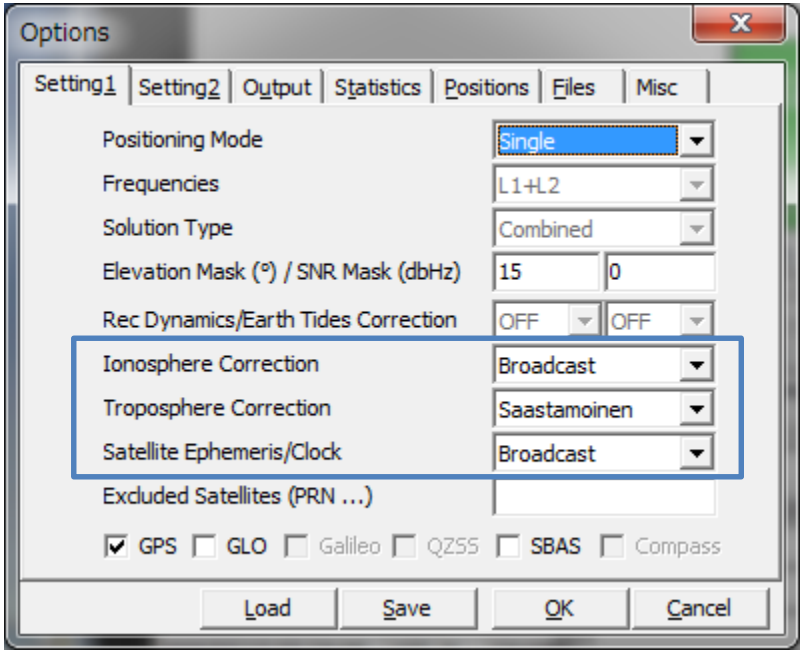


RTKPOST

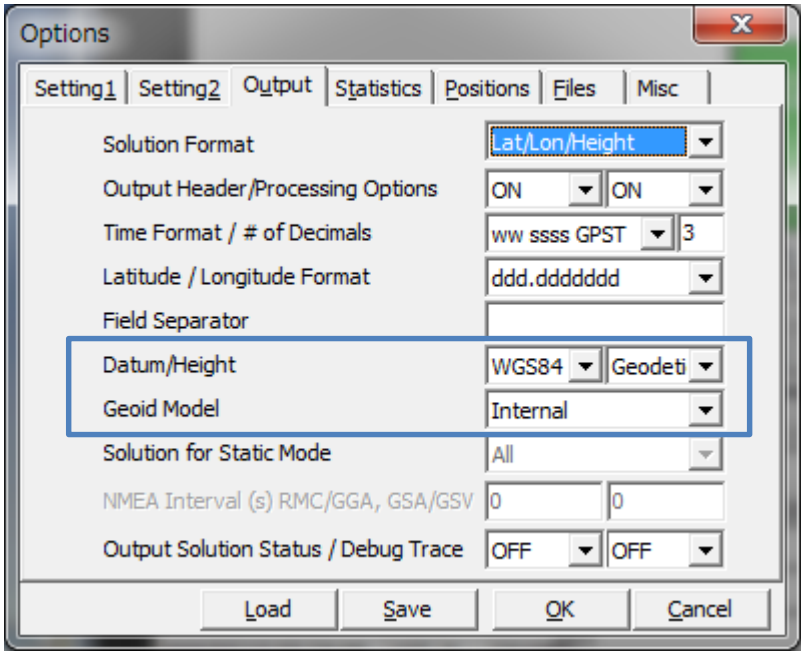
Use RTKLIB (7)

RTKPOST - Options

Setting1



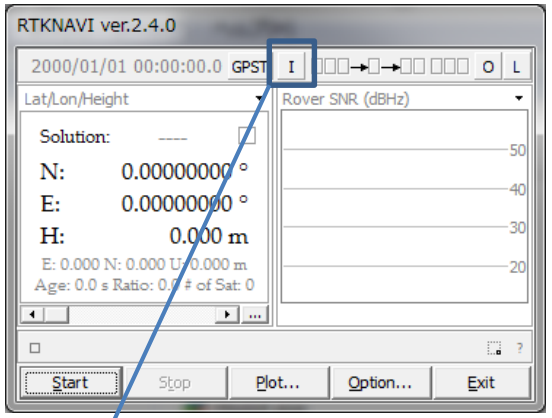
Output



Use RTKLIB in RT Mode (1)

- **Execute RTKNAVI by RTKLAUNCH**
- **Set Input Data Input Stream**
  Serial
- **Format**
  NovAtel OEM6 or Javad

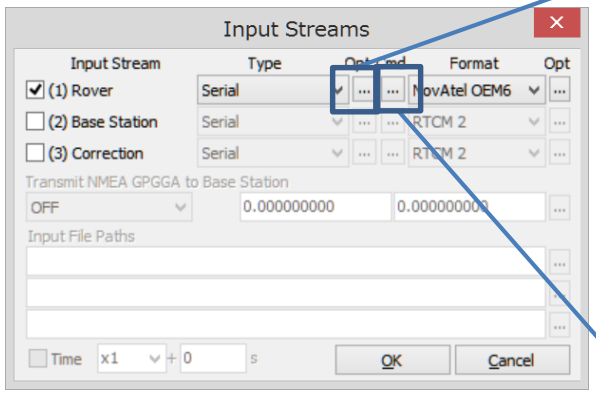
RTKLIB - RTKNAVI



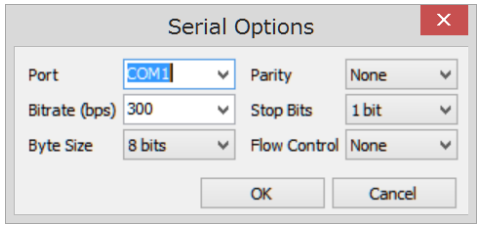
RTKLIB - RTKNAVI - Input Streams

Use RTKLIB in RT Mode (2)

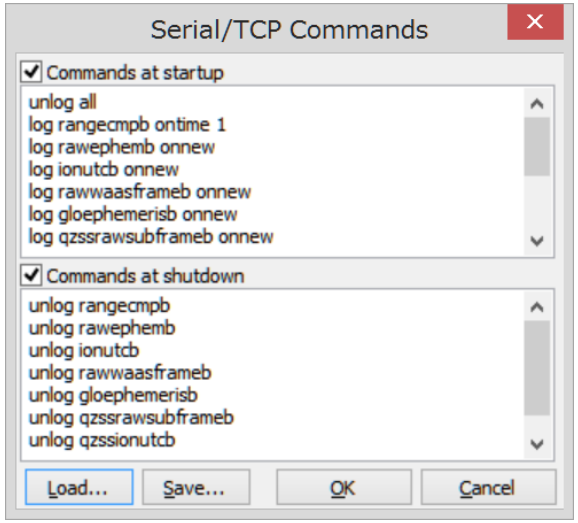
RTKLIB - RTKNAVI -
Input Streams



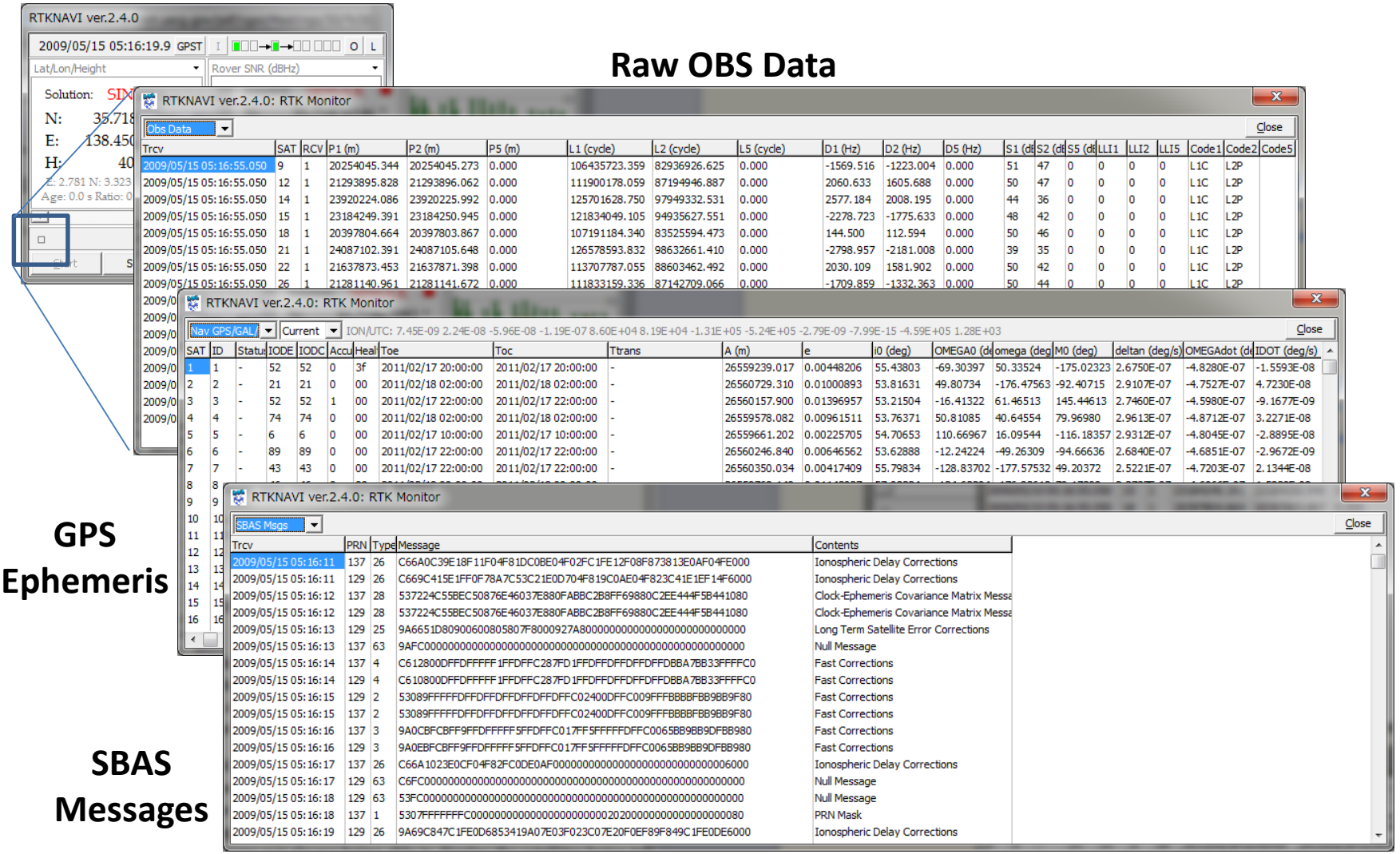
RTKLIB - RTKNAVI -
Input Streams - Serial Options



RTKLIB - RTKNAVI -
Input Streams - Serial/TCP Commands

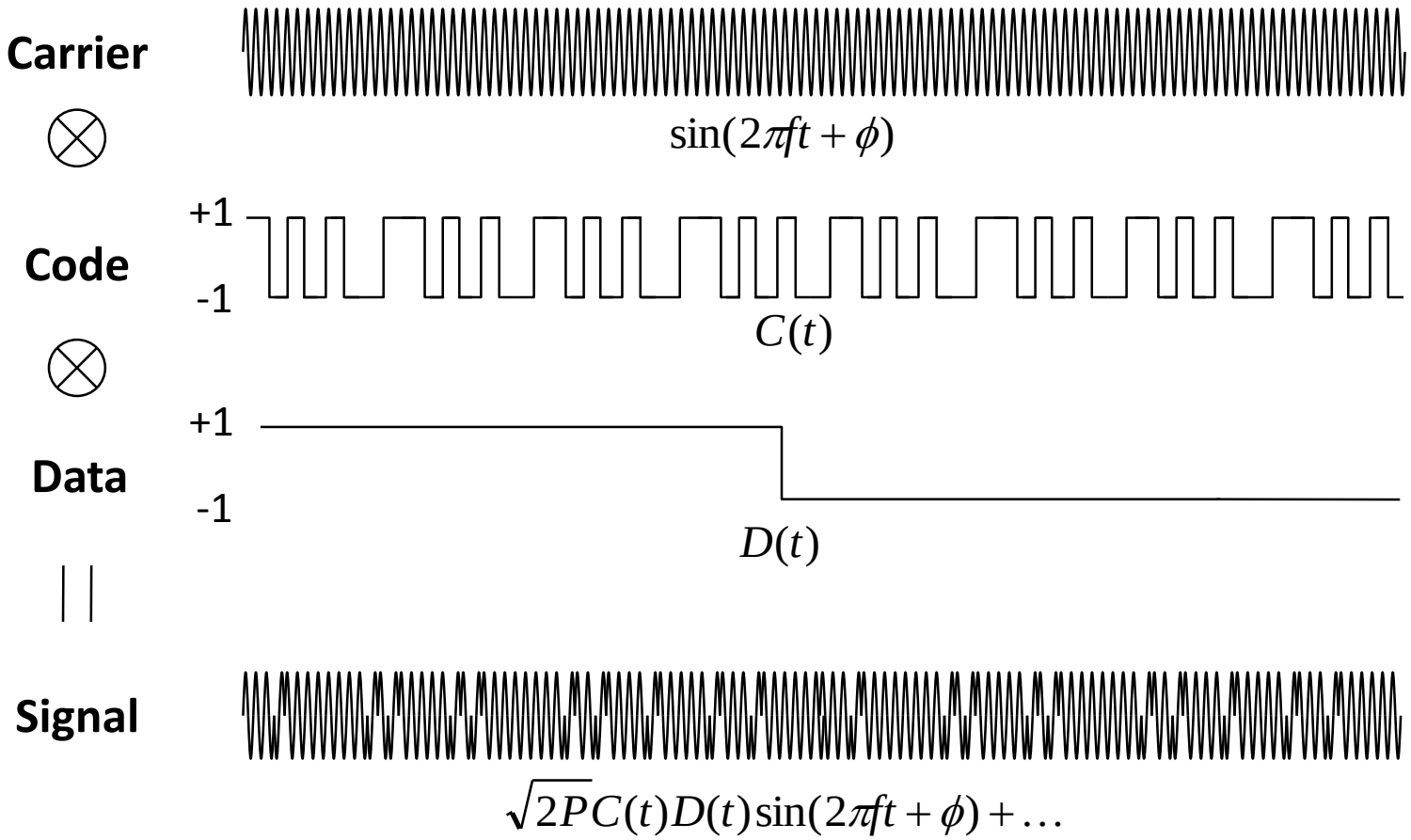


Use RTKLIB in RT Mode (3)



B-3
Theory of Precise Positioning (1)

GNSS Signal Structure

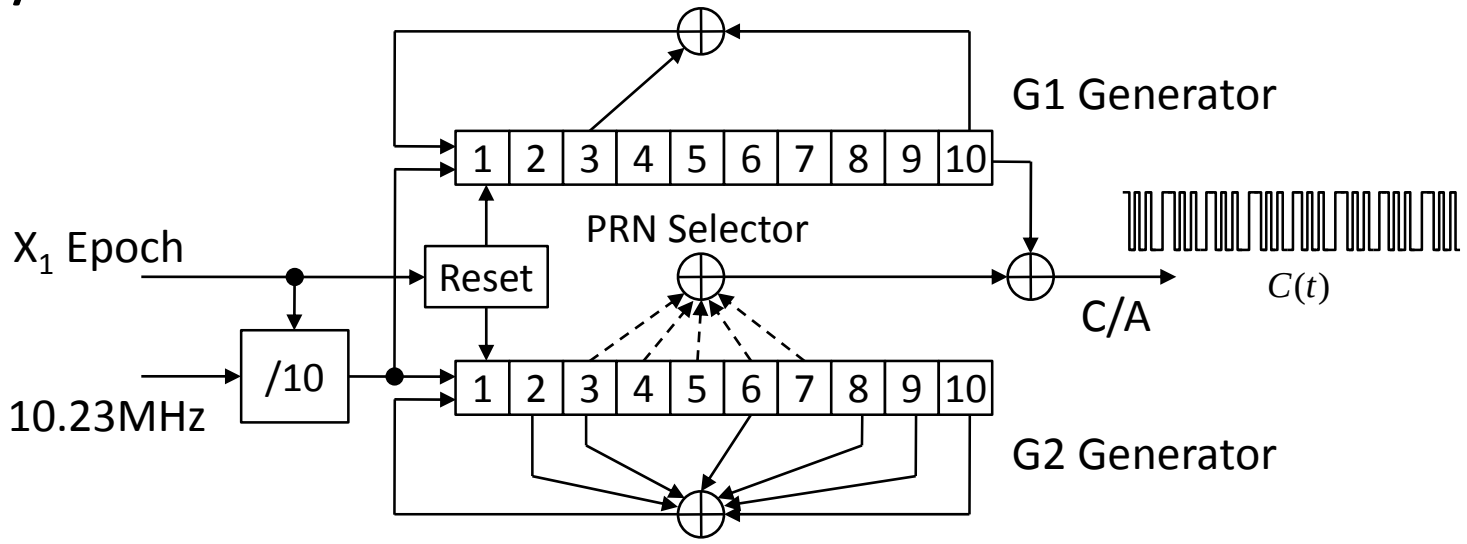


GNSS Signal Specifications

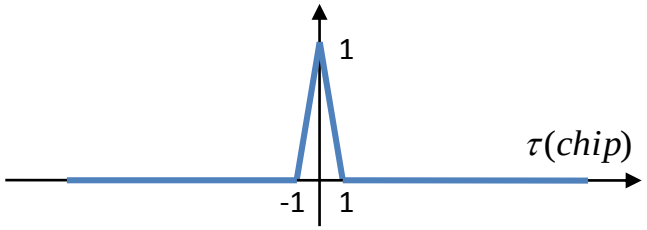
Carrier Freq (MHz)		Code	Modulation	Data Rate	GNSS
L1/E1	1575.42	C/A	BPSK (1)	50 bps	GPS, QZSS
				250 bps	QZSS (L1-SAIF), SBAS
		P(Y)	BPSK (10)	50 bps	GPS
		L1C-d/p	MBOC (6,1,1/11)	-/100 bps	GPS (III-), Galileo
		L1C-d/p	BOC (1,1)	-/100 bps	QZSS
L1	1602+0.5625K	C/A	BPSK	50 bps	GLONASS
L2	1227.60	P(Y)	BPSK (10)	50 bps	GPS
		L2C	BPSK (1)	25 bps	GPS (IIRM-), QZSS
L2	1246+0.4375K	C/A	BPSK	50 bps	GLONASS
L5/E5a	1176.45	L5-I/Q	BPSK (10)	-/100 bps	GPS (IIF-), QZSS
		E5a-I/Q	BPSK (10)	-/50 bps	Galileo
E5b	1207.14	E5b-I/Q	BPSK (10)	-/250 bps	Galileo
E6/LEX	1278.75	E6-I/Q	BPSK (5)	-/1000 bps	Galileo
		LEX	BPSK (5)	2000 bps	QZSS

Spreading (PRN) Code

GPS C/A Code Generator

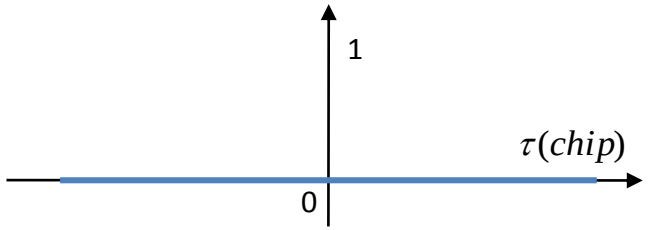


Auto-correlation function



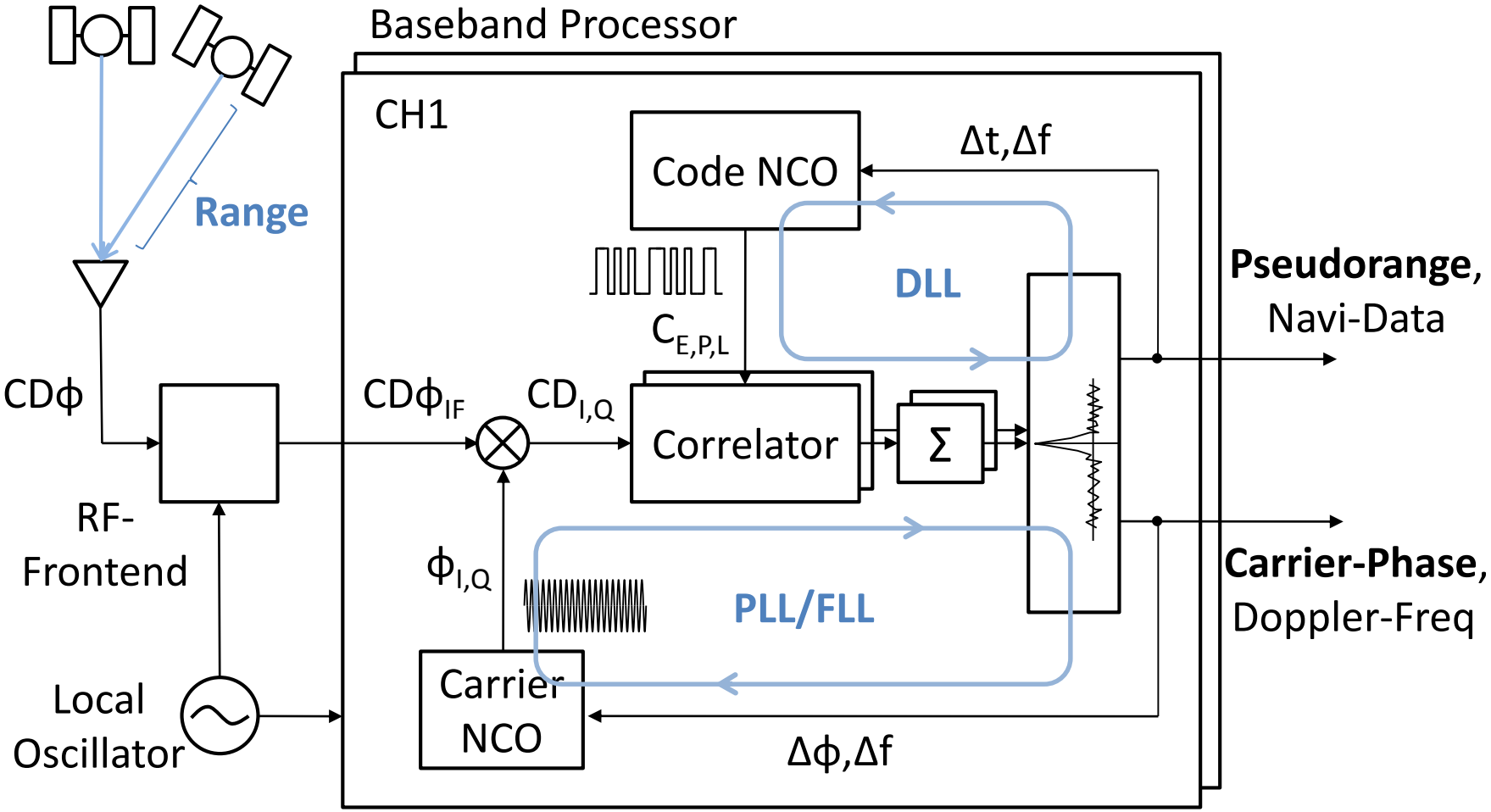
$$R(\tau) = \frac{1}{T}\int_0^T C^i(t)C^i(t-\tau)dt$$

Cross-correlation function



$$R(\tau) = \frac{1}{T}\int_0^T C^i(t)C^j(t-\tau)dt \quad (i \neq j)$$

Carrier/Code Tracking in Receiver



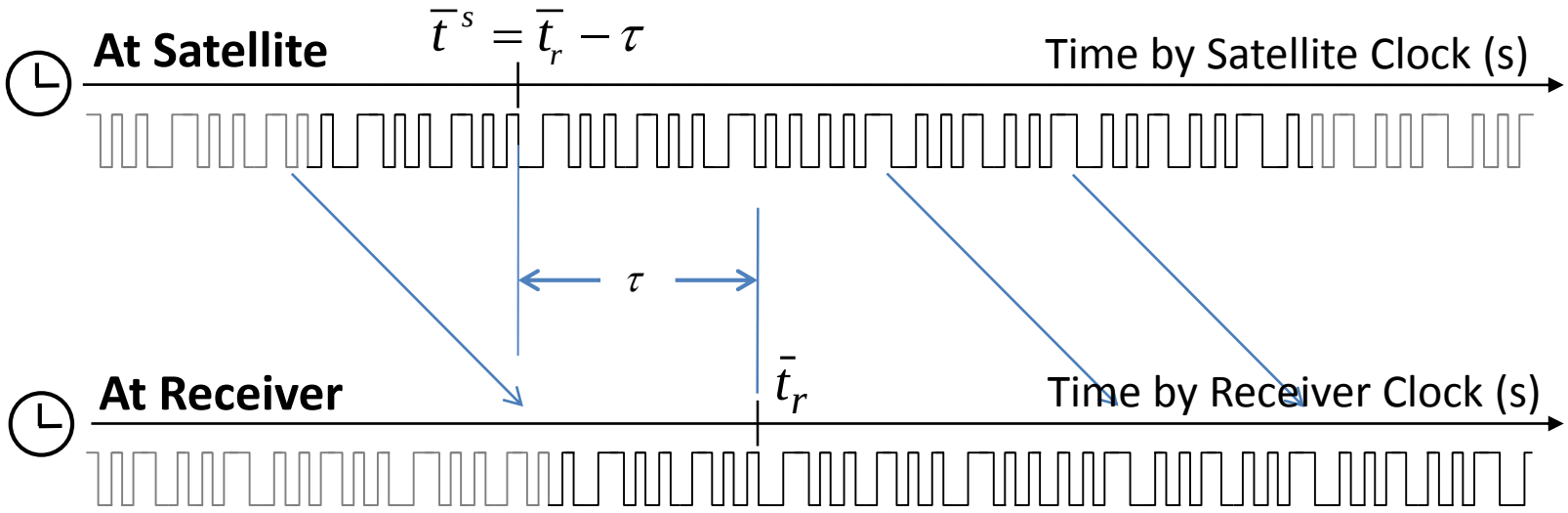
Pseudorange

Definition:

$$P_r^s \equiv c\tau = c(\bar{t}_r - \bar{t}^s)$$

(m)

The pseudo-range (PR) is the distance from the receiver antenna to the satellite antenna including receiver and satellite clock offsets (and other biases, such as atmospheric delays) *(RINEX 2.10)*



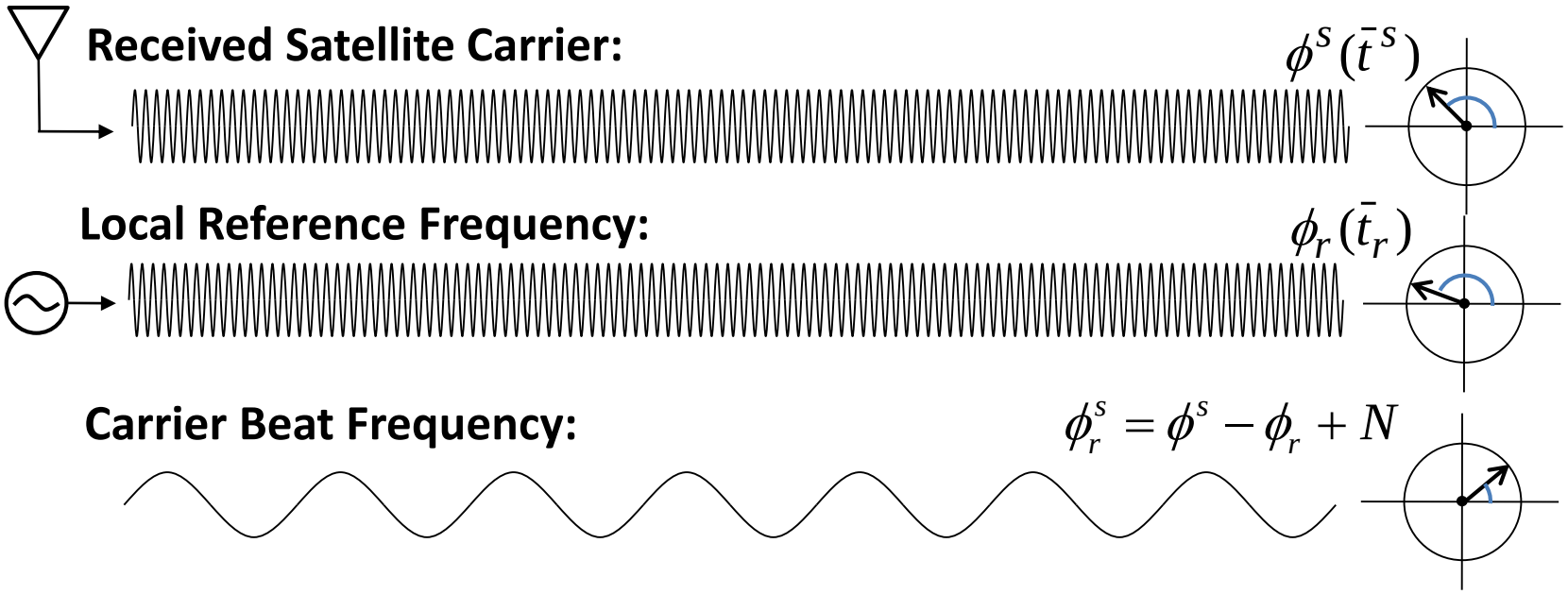
Carrier-Phase

Definition:

$$\phi_r^s = \phi^s - \phi_r + N$$

(cycle)

... actually being a measurement on the beat frequency between the received carrier of the satellite signal and a receiver-generated reference frequency. *(RINEX 2.10)*



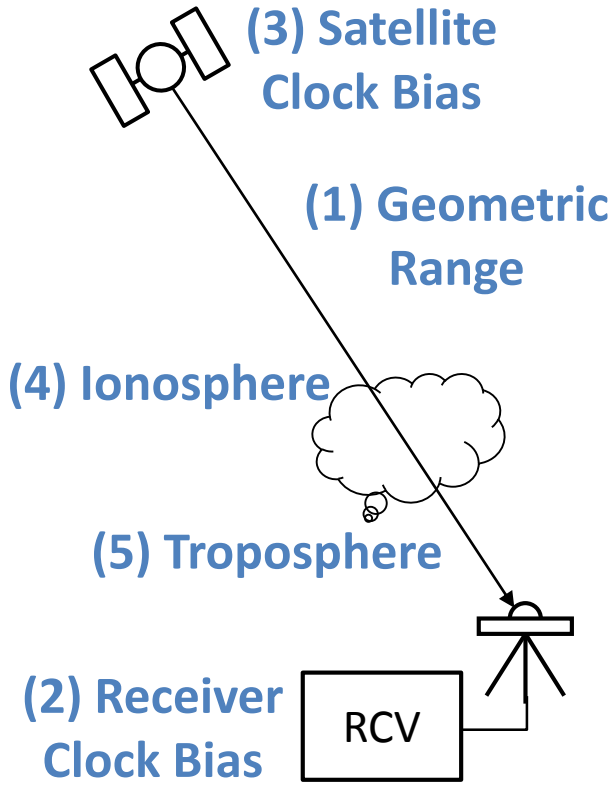
Code vs Carrier-Based Positioning

	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, ...

Pseudorange Model

$$
\begin{aligned}
P_r^s &\equiv c\tau \\
&= c(\bar{t}_r - \bar{t}^s) \\
&= c((t_r + dt) - (t^s + dT^s)) + \varepsilon_P \\
&= c(t_r - t^s) + c(dt_r - dT^s) + \varepsilon_P \\
&= (\rho_r^s + I_r^s + T_r^s) + c(dt_r - dT^s) + \varepsilon_P \\
&= \rho_r^s + c(dt_r - dT^s) + I_r^s + T_r^s + \varepsilon_P
\end{aligned}
$$

(1) (2) (3) (4) (5) (6)



Carrier-Phase Model (1)

Carrier-Phase:

$$\phi_r^s = \phi_r(t_r) - \phi^s(t^s) + N_r^s + \varepsilon_\varphi \qquad (\phi_{r,0} = \phi_r(t_0), \phi_0^S = \phi^S(t_0))$$

$$= (f(t_r + dt_r - t_0) + \phi_{r,0}) - (f(t^s + dT^s - t_0) + \phi_0^s) + N_r^s + \varepsilon_\varphi$$

$$= \frac{c}{\lambda}(t_r - t^s) + \frac{c}{\lambda}(dt_r - dT^s) + (\phi_{r,0} - \phi_0^s + N_r^s) + \varepsilon_\varphi \qquad \text{(cycle)}$$

$$\Phi_r^s \equiv \lambda\phi_r^s = c(t_r - t^s) + c(dt_r - dT^s) + \lambda(\phi_{r,0} - \phi_0^s + N_r^s) + \lambda\varepsilon_\varphi$$

$$= \rho_r^s + c(dt_r - dT^s) - I_r^s + T_r^s + \lambda B_r^s + d_r^s + \varepsilon_\Phi \qquad \text{(m)}$$

Carrier-Phase Bias Other Correction Terms

Pseudorange:

$$P_r^s = \rho_r^s + c(dt_r - dT^s) + I_r^s + T_r^s + \varepsilon_P$$

Carrier-Phase Model (2)

Carrier-Phase Bias:

$$B_r^s = \phi_{r,0} - \phi_0^s + N_r^s \qquad \text{(cycle)}$$

N_r^s : **Integer Ambiguity**

$\phi_{r,0}$: Receiver Initial Phase

ϕ_0^s : Satellite Initial Phase

Other Correction Terms:

$$d_r^s = -\boldsymbol{d}_{r,pco}{}^T \boldsymbol{e}_{r,enu}^s + \left(\boldsymbol{E}_{sat\to ecef}\,\boldsymbol{d}_{pco}^s\right)^T \boldsymbol{e}_r^s + d_{r,pcv} + d_{pcv}^s - \boldsymbol{d}_{disp}{}^T \boldsymbol{e}_{r,enu}^s + d_{pw} + d_{rel} \qquad \text{(m)}$$

$\boldsymbol{d}_{r,pco}$: Receiver Antenna Phase Center Offset

$d_{r,pcv}$: Receiver Antenna Phase Center Variation

$\boldsymbol{d}_{pco}^s$: Satellite Antenna Phase Center Offset

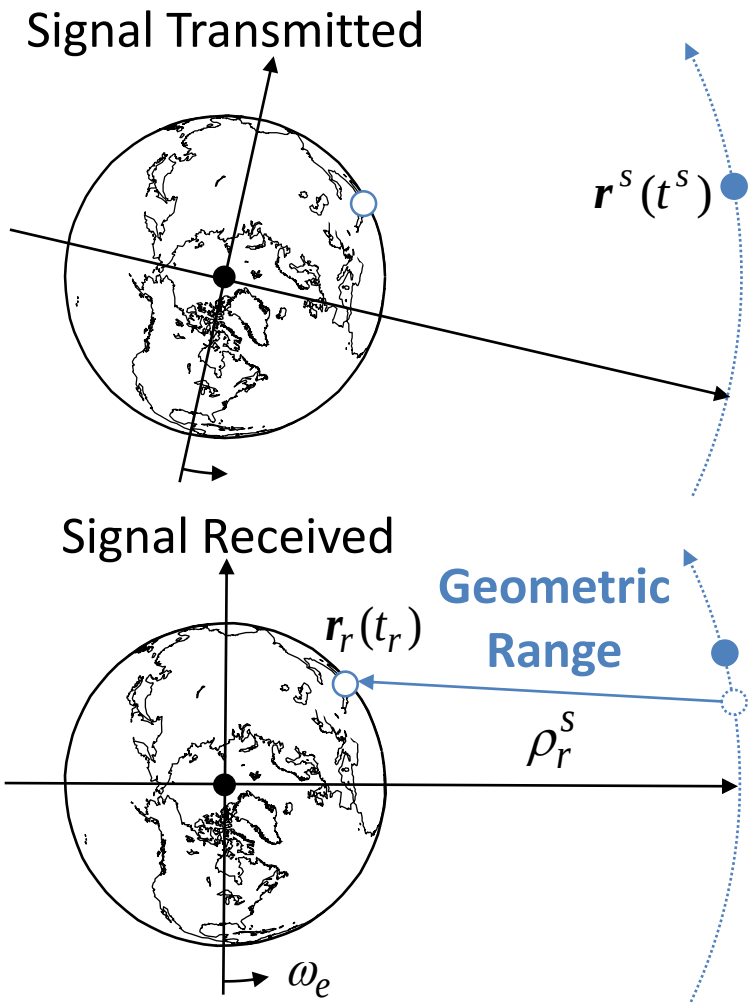
d_{pcv}^s : Satellite Antenna Phase Center Variation

$\boldsymbol{d}_{disp}$: Site Displacement

d_{pw} : Phase Wind-up Effect

d_{rel} : Relativistic Effect

Geometric Range



Signal Transmission Time

$$t^s = \bar{t}_r - P_r^s / c - dT(t^s)$$

(1)

$$\rho_r^s = \left\| \boldsymbol{U}(t_r)\boldsymbol{r}_r(t_r) - \boldsymbol{U}(t^s)\boldsymbol{r}^s(t^s) \right\|$$

(2)

$$\rho_r^s \approx \left\| \boldsymbol{r}_r(t_r) - \boldsymbol{R}_z(\omega_e(t_r - t^s))\boldsymbol{r}^s(t^s) \right\|$$

(3)

$$\rho_r^s \approx \left\| \boldsymbol{r}_r(t_r) - \boldsymbol{R}_z(\omega_e \rho_r^s / c)\boldsymbol{r}^s(t^s) \right\|$$

(4)

$$\rho_r^s \approx \left\| \boldsymbol{r}_r(t_r) - \boldsymbol{r}^s(t^s) \right\| + \frac{\omega_e(x^s y_r - y^s x_r)}{c}$$

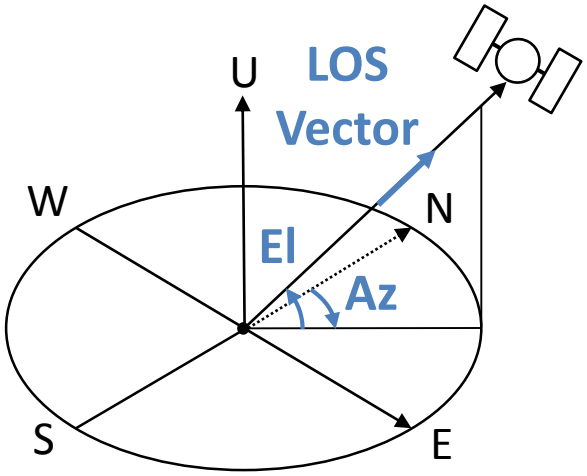
Sagnac Effect Correction

LOS (Line-of-Sight) Vector

LOS Vector:

$$\boldsymbol{e}_r^s = \frac{\boldsymbol{r}^s - \boldsymbol{r}_r}{\left\| \boldsymbol{r}^s - \boldsymbol{r}_r \right\|}, \quad \boldsymbol{e}_{r,enu}^s = \boldsymbol{E}_{ecef \to enu} \boldsymbol{e}_r^s = (e_e, e_n, e_u)^T$$

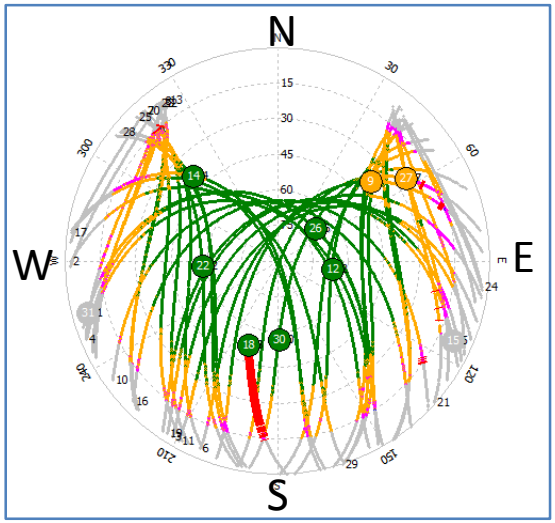
$$\boldsymbol{E}_{ecef \to enu} = \begin{pmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\phi\cos\lambda & -\sin\phi\sin\lambda & \cos\phi \\ \cos\phi\cos\lambda & \cos\phi\sin\lambda & \sin\phi \end{pmatrix}$$



Satellite Azimuth/Elevation Angle:

$$Az = \mathrm{ATAN2}(e_e, e_n)$$

$$El = \arcsin e_u$$

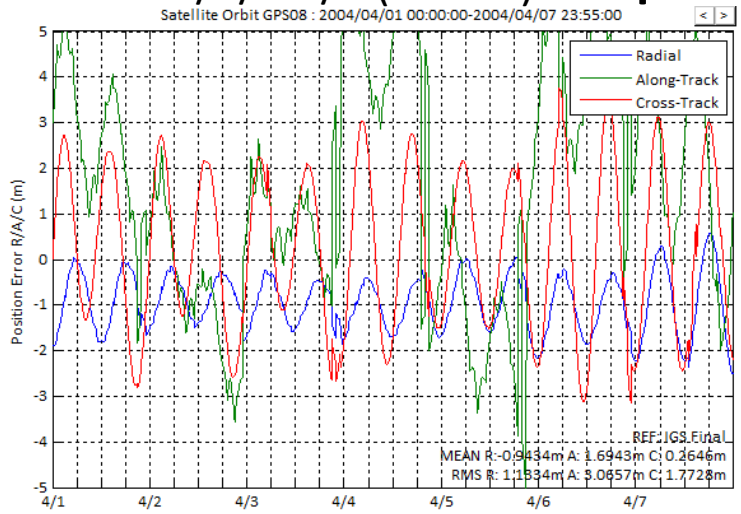


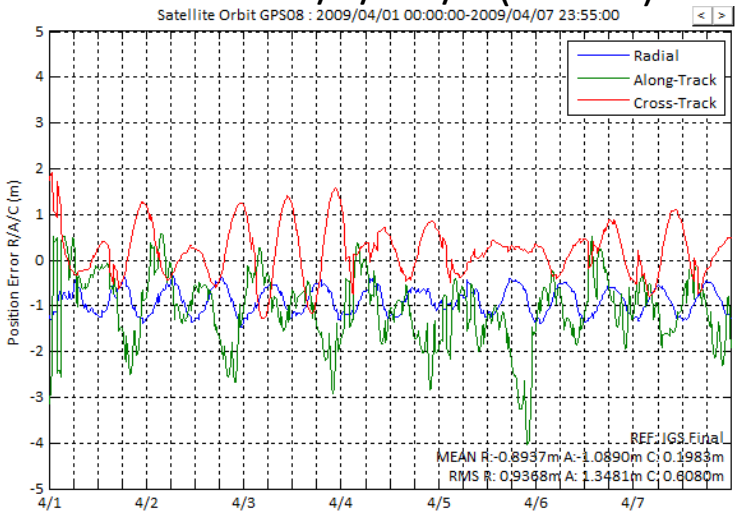
Error Sources and DOP

- **Error sources of Standard positioning**
  - Ephemeris/SV Clock Error
  - Ionospheric Model Error
  - Tropospheric Model Error
  - Multipath
  - Receiver Noise
  - Other Errors
  - S/A (Selective Availability)
- **Satellites-Receiver Geometry**
  - DOP (Dilution of Precision)

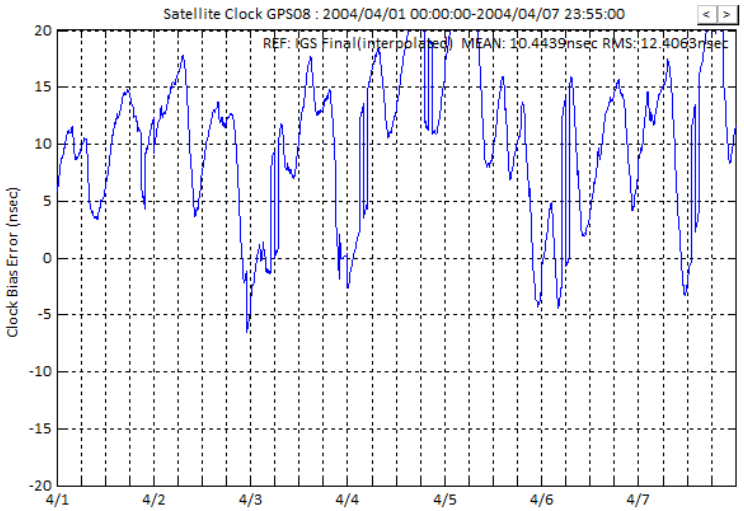
Ephemeris/SV Clock Error

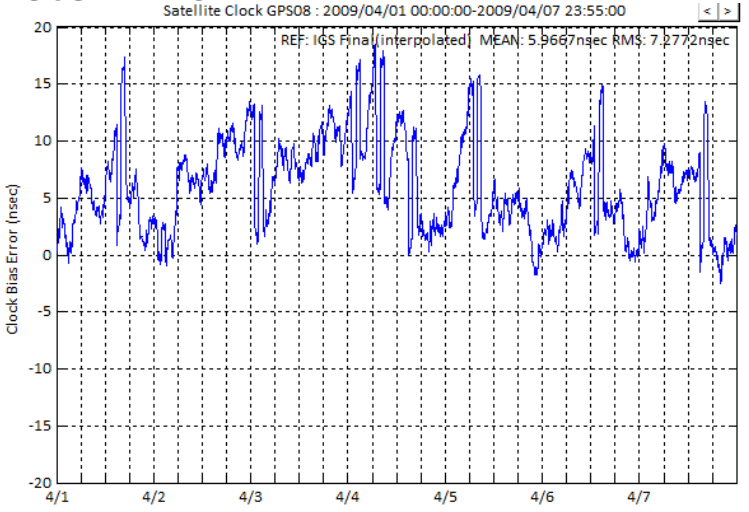
2004/4/1-4/7 (PRN08) **Ephemeris Error** 2009/4/1-4/7 (PRN08)



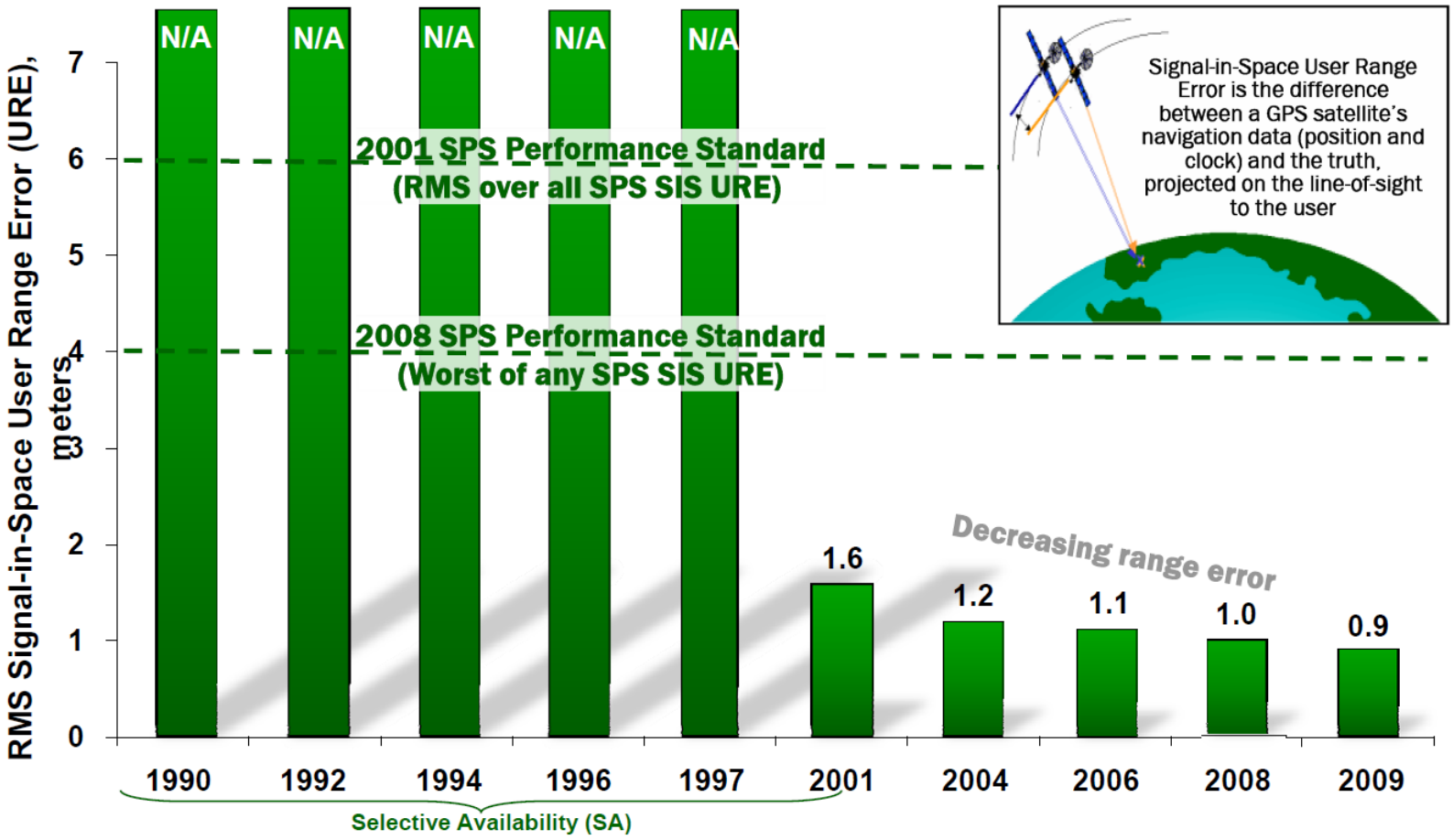


SV Clock Parameter Error



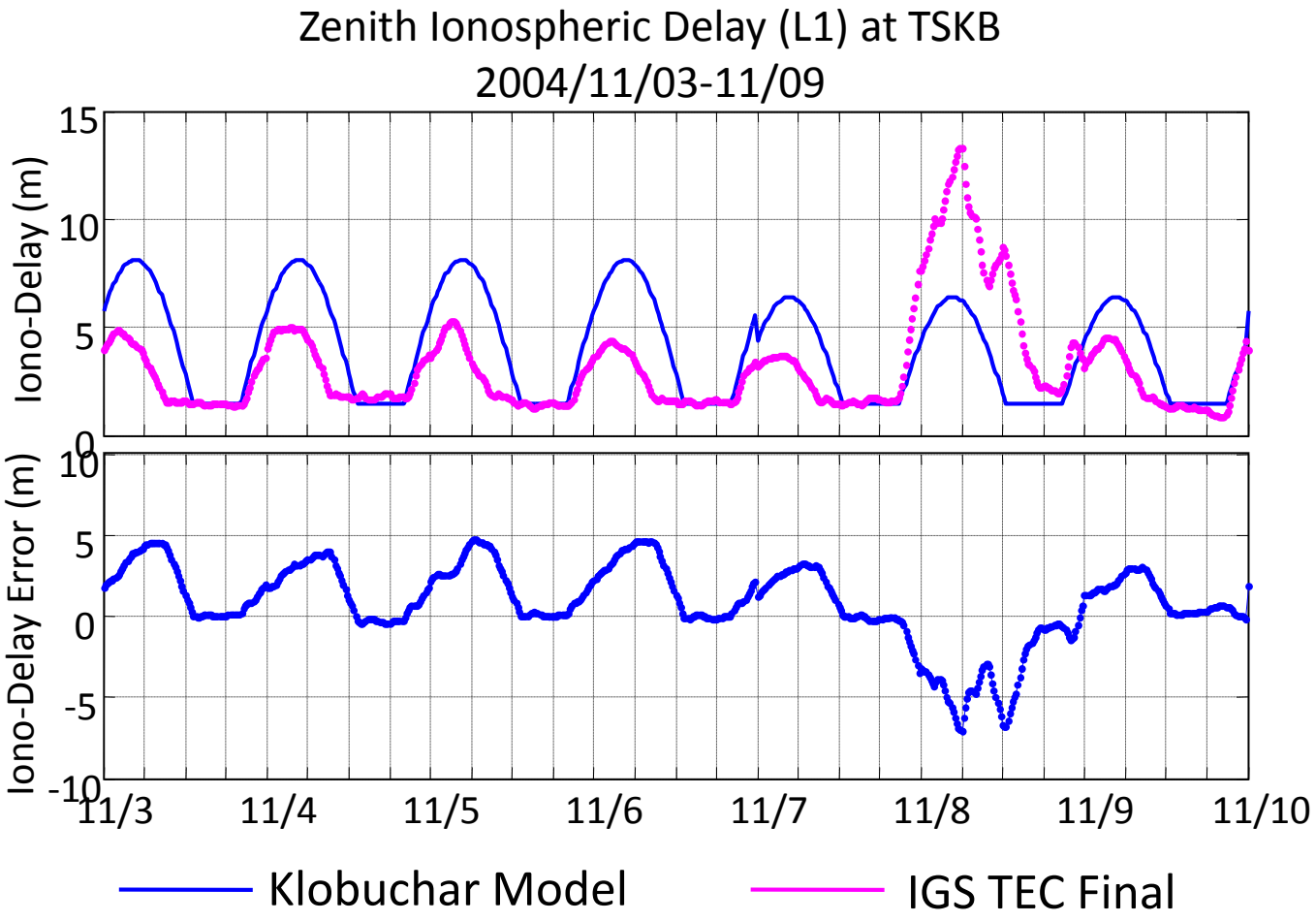


GPS SIS-URE



L.S.Steiner, GPS Program Update to CGSIC 2010, Sep 21, 2010

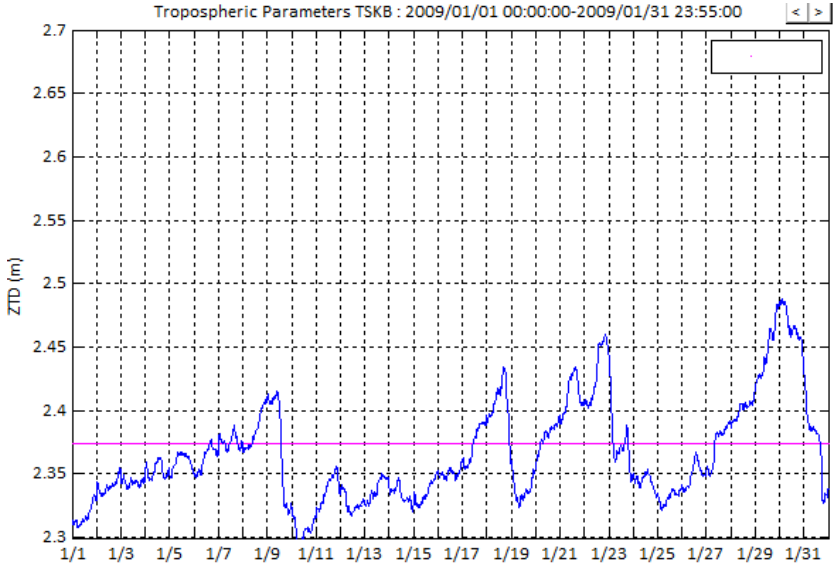
Ionospheric Model Error



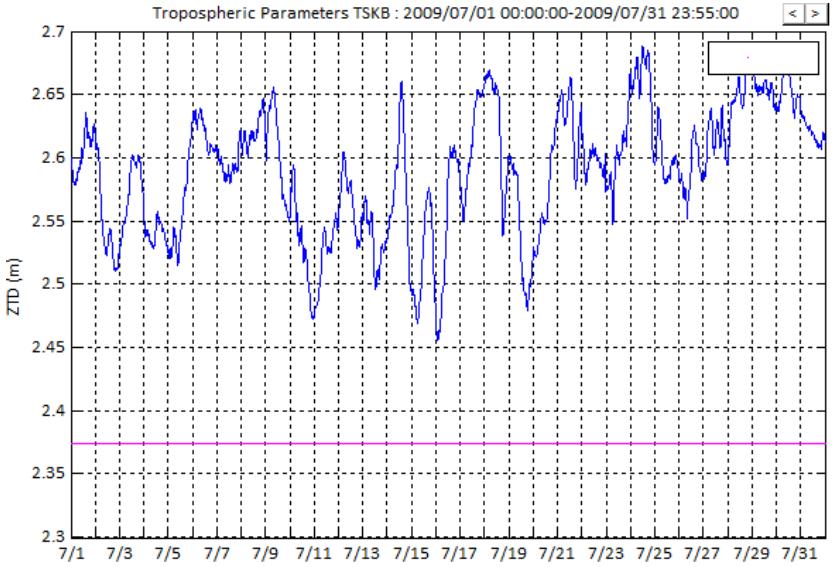
Tropospheric Model Error

ZTD (Zenith Total Delay) at TSKB

2009/1/1-2009/1/31



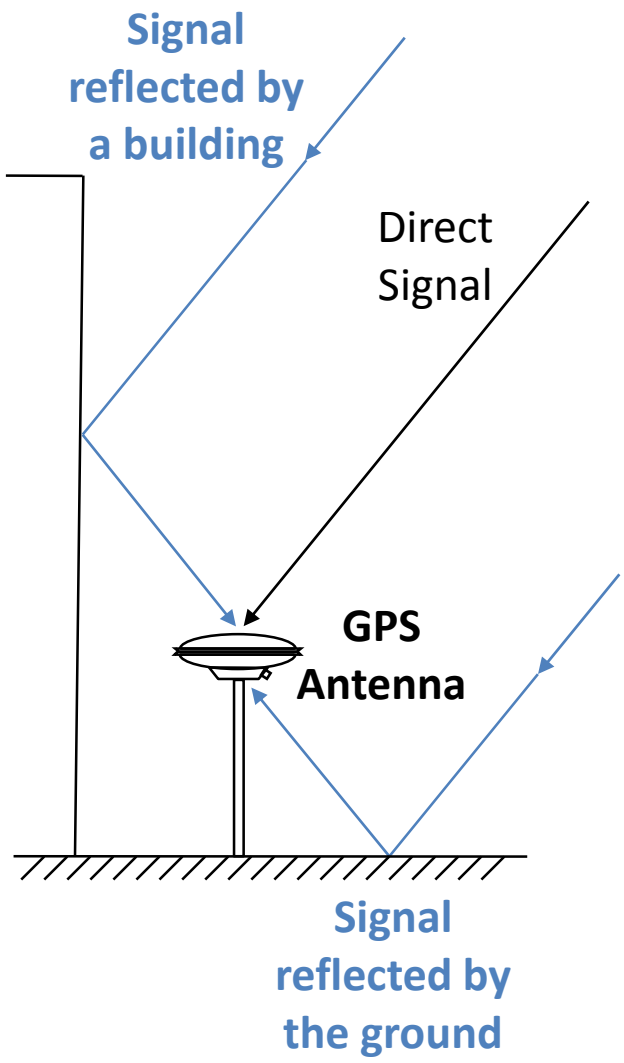
2009/7/1-2009/7/31



Saastamoinen Model

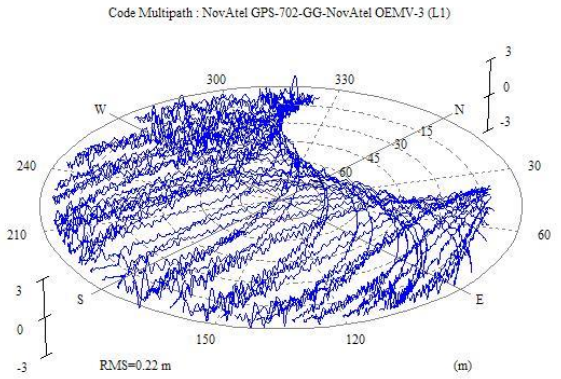
Estimated by PPP

Multipath

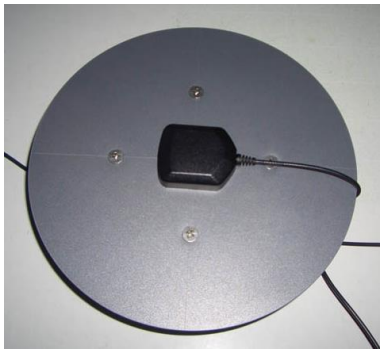


Geodetic-Grade Antenna

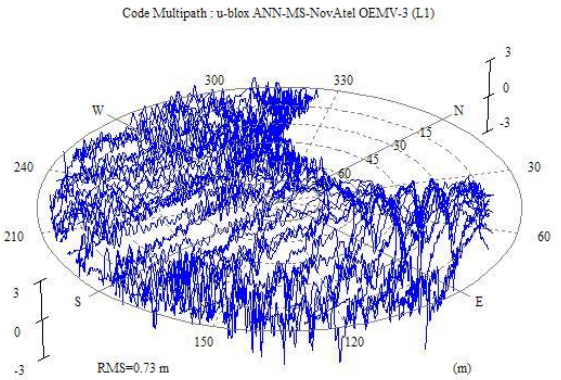
NovAtel GPS-702-GG



Consumer-Grade Antenna



u-blox ANN-MS



DOP

GDOP, PDOP, HDOP, VDOP

$$GDOP = \sqrt{q_{ee} + q_{nn} + q_{uu} + q_{tt}}$$

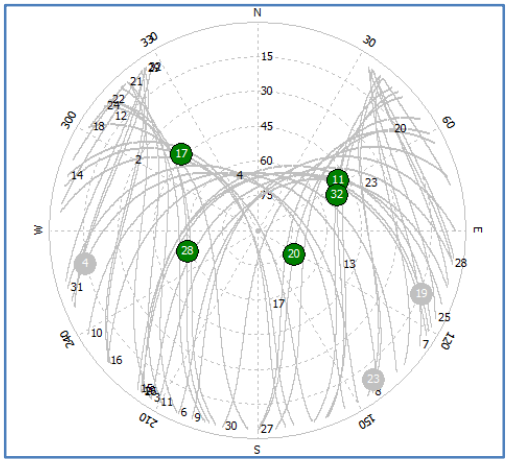
$$PDOP = \sqrt{q_{ee} + q_{nn} + q_{uu}}$$

$$HDOP = \sqrt{q_{ee} + q_{nn}}$$

$$VDOP = \sqrt{q_{uu}}$$

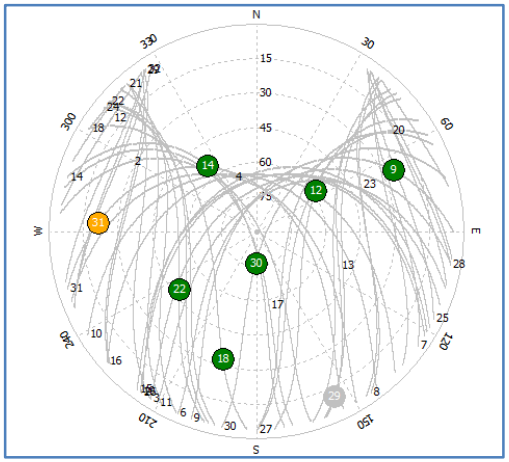
$$\boldsymbol{Q} = (\boldsymbol{H}^T \boldsymbol{H})^{-1} = \begin{pmatrix} q_{ee} & q_{en} & q_{eu} & q_{et} \\ q_{ne} & q_{nn} & q_{nu} & q_{nt} \\ q_{ue} & q_{un} & q_{uu} & q_{ut} \\ q_{te} & q_{tn} & q_{tu} & q_{tt} \end{pmatrix} \quad \boldsymbol{H} = \begin{pmatrix} -\boldsymbol{e}_{r,enu}^{s_1\,T} & 1 \\ -\boldsymbol{e}_{r,enu}^{s_2\,T} & 1 \\ \vdots & \vdots \\ -\boldsymbol{e}_{r,enu}^{s_m\,T} & 1 \end{pmatrix}$$

# of satellites = 5



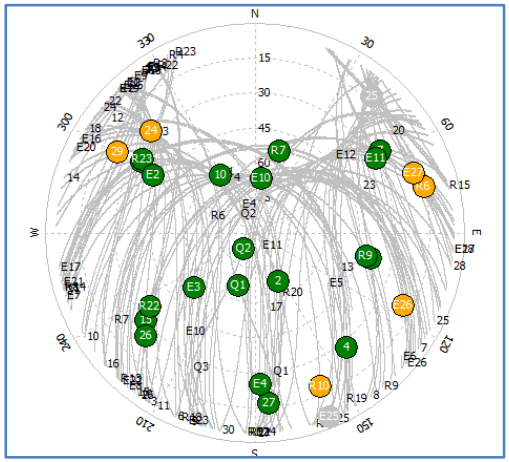
GDOP=33.4 PDOP=25.9
HDOP=8.1 VDOP=24.7

# of satellites = 7



GDOP=2.5 PDOP=2.1
HDOP=1.2 VDOP=1.8

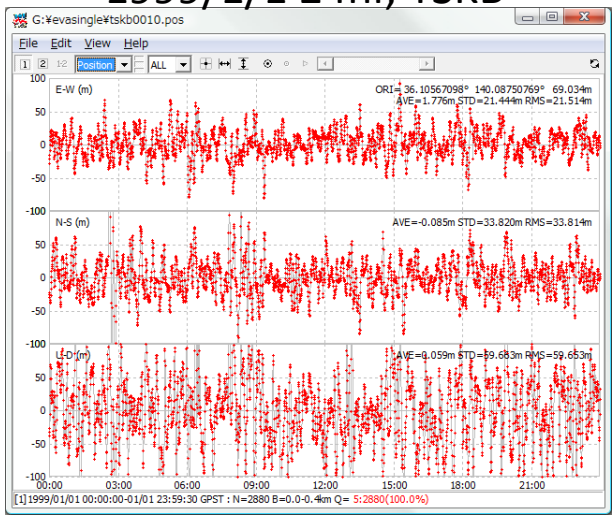
# of satellites = 27



GDOP=1.2 PDOP=1.0
HDOP=0.5 VDOP=0.9

SPP (Single Point Positioning)

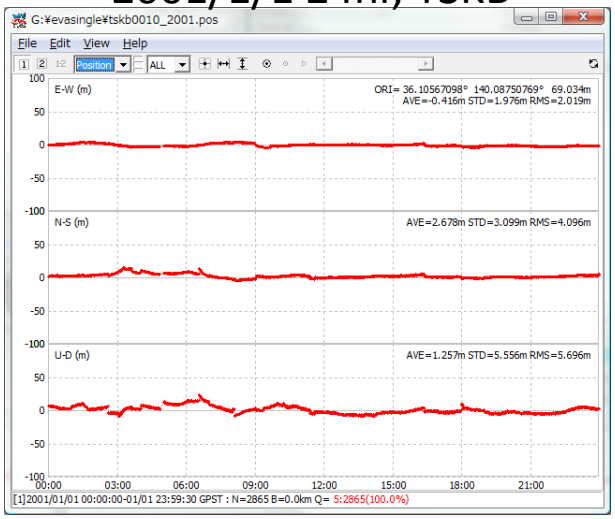
1999/1/1 24hr, TSKB



RMS Error:
E: 21.51m
N: 33.81m
U: 59.65m

100m

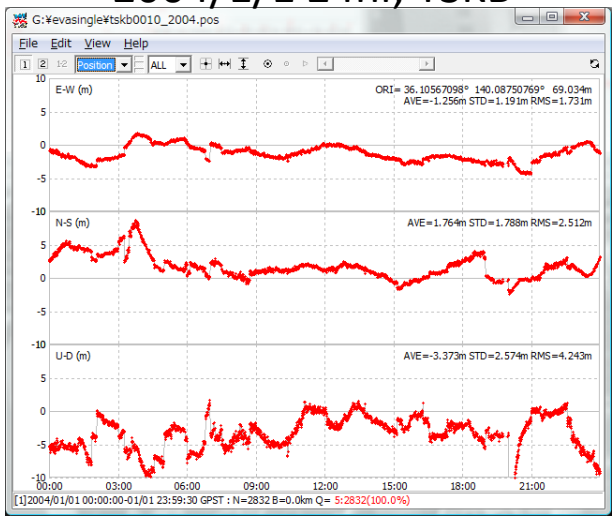
2001/1/1 24hr, TSKB



RMS Error:
E: 2.02m
N: 4.10m
U: 5.70m

100m

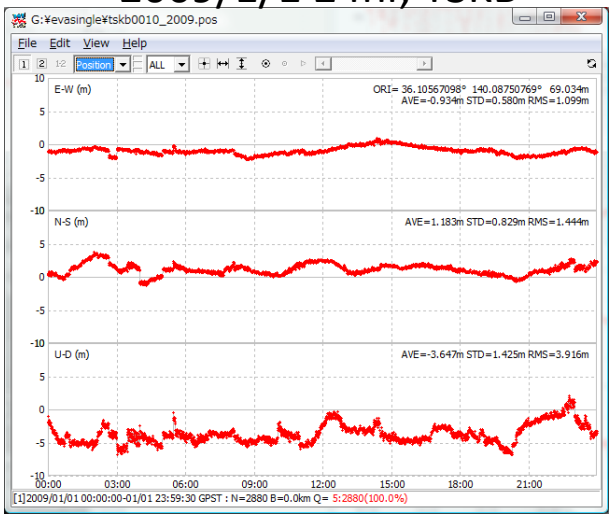
2004/1/1 24hr, TSKB



RMS Error:
E: 1.73m
N: 2.51m
U: 4.24m

10m

2009/1/1 24hr, TSKB



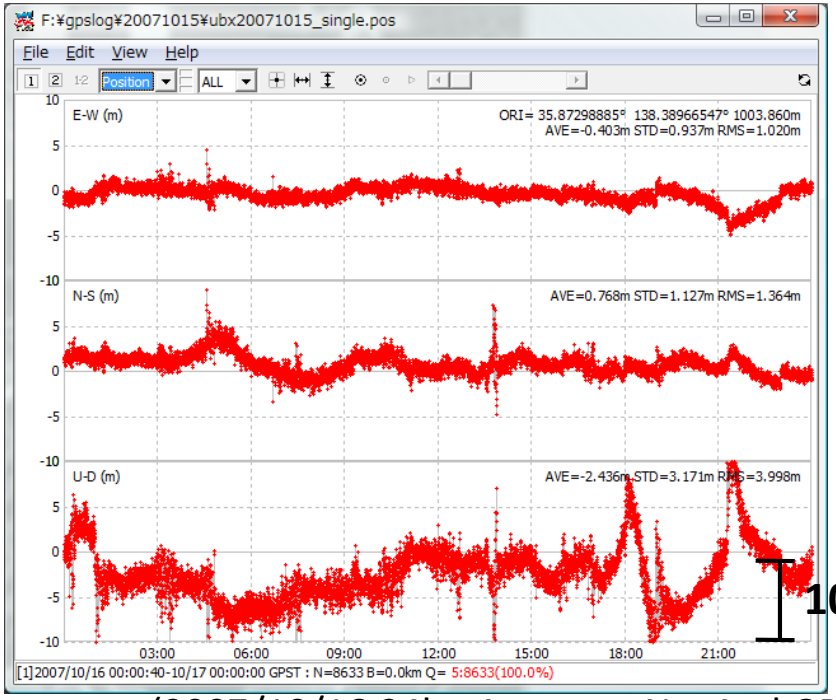
RMS Error:
E: 1.10m
N: 1.44m
U: 3.92m

10m

DGPS Positioning (SBAS)

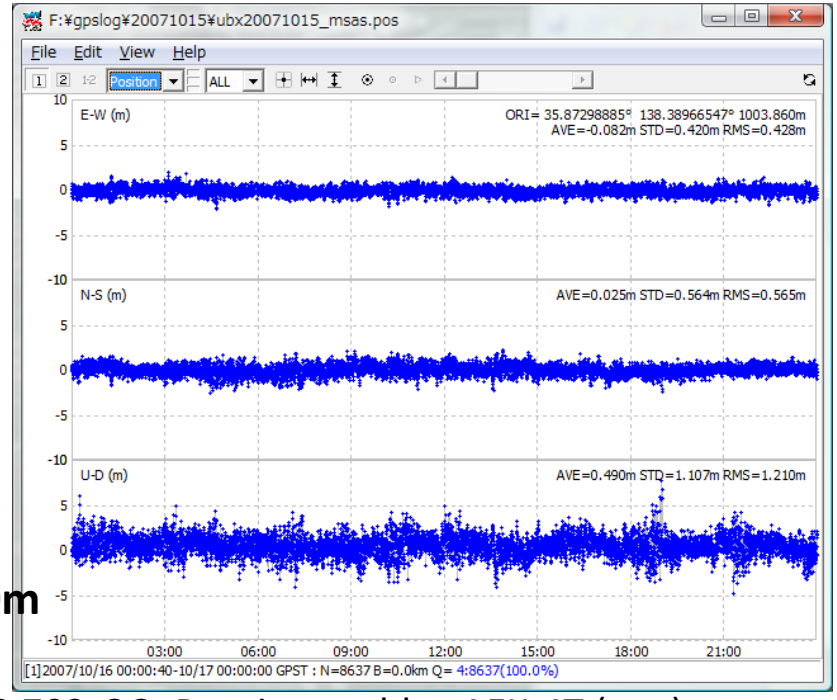
SPP

RMS Error:
E: 1.02m N: 1.36m U: 4.00m



SBAS DGPS (MSAS)

RMS Error:
E: 0.43m N: 0.57m U: 1.21m



(2007/10/16 24hr, Antenna: NovAtel GPS-702-GG, Receiver: u-blox AEK-4T (raw),
Processing S/W: RTKLIB 2.1.0, All Corrections=ON, Ranging=ON)

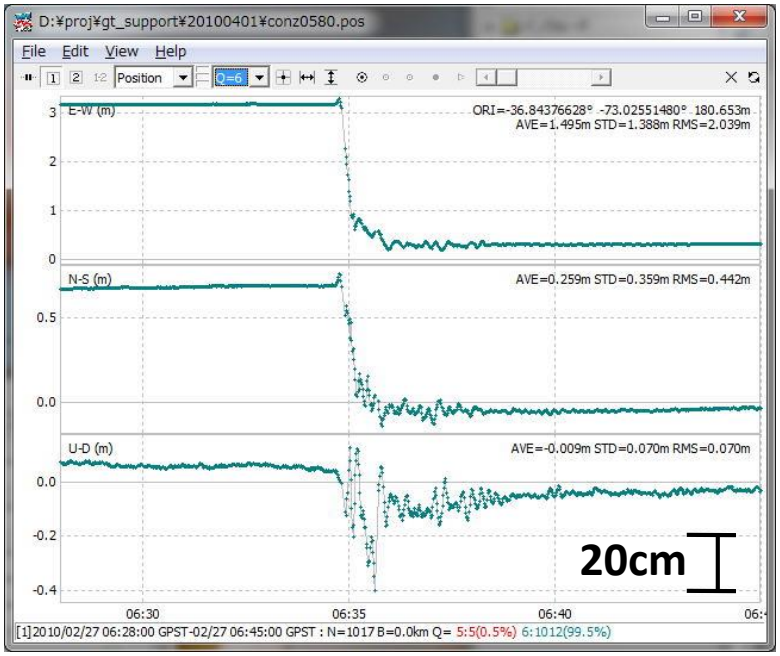
PPP (Precise Point Positioning)

- **Feature**
  - with Single Receiver (No Reference Station)
  - Efficient Analysis for Many Receivers
  - Precise Ephemeris
  - Conventionally Post-Processing
- **Applications**
  - GPS Seismometer
  - GPS Meteorology
  - POD (Precise Orbit Determination) of LEO Satellite
  - Precise Time Transfer

Static PPP vs Kinematic PPP

Kinematic PPP

Station: IGS CONZ

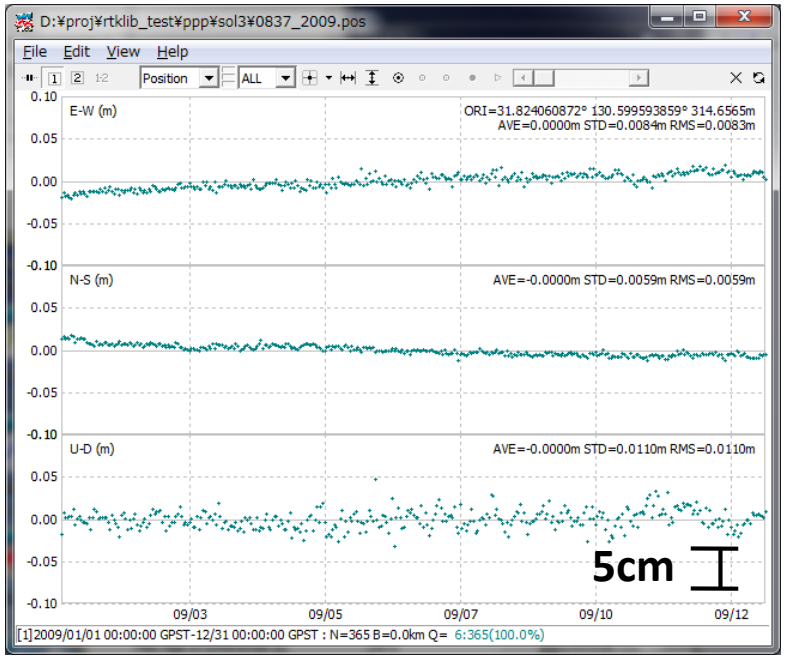


2010/2/27 6:28-6:45 GPST

Interval: 1 s

Static PPP

Station: GEONET 0837



2009/1/1-2009/12/31

Interval: 1day

PPP Applications

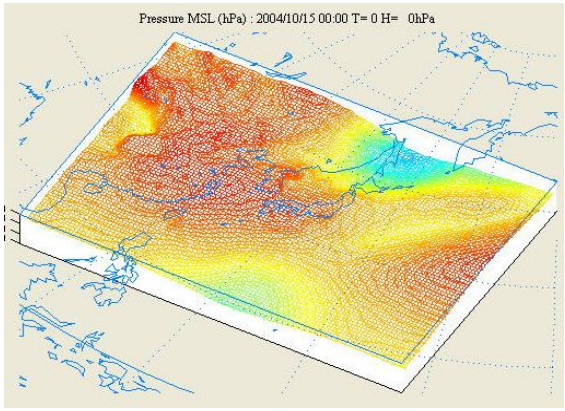
Automated Farming

Tsunami Warning

Mining Machine Control

Offshore Construction

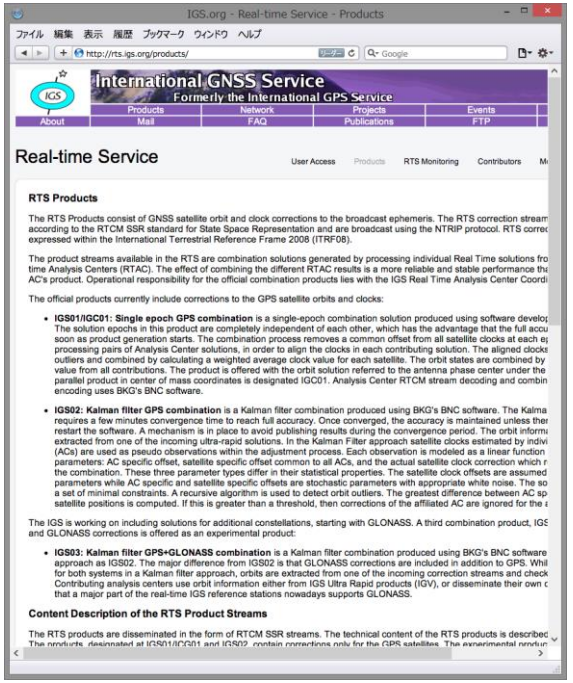
Autonomous Driving



Weather Forecast

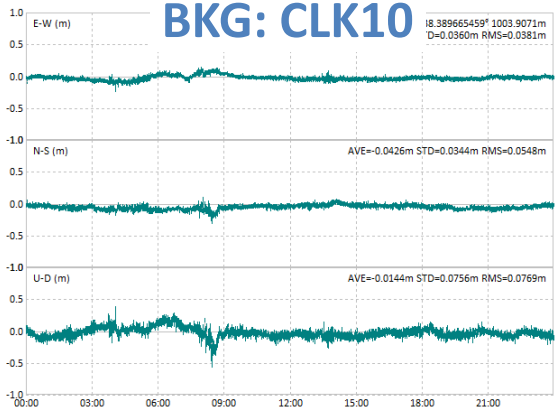
IGS Real-time Service

- **Developed by IGS-RTPP**
  - RTCM v.3 MT1057-1068 (SSR)
  - Corrections to broadcast ephemeris
  - Real-time NTRIP stream
  - Interval: 10 s, Latency: 5 - 10 s
  - GPS and GLONASS
- **Analysis Strategy**
  - Orbit: fixed to IGU or estimated
  - Clock: estimated with IGS real-time tracking network

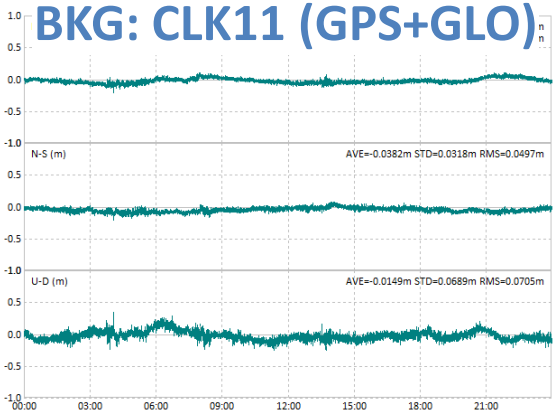


http://rts.igs.org

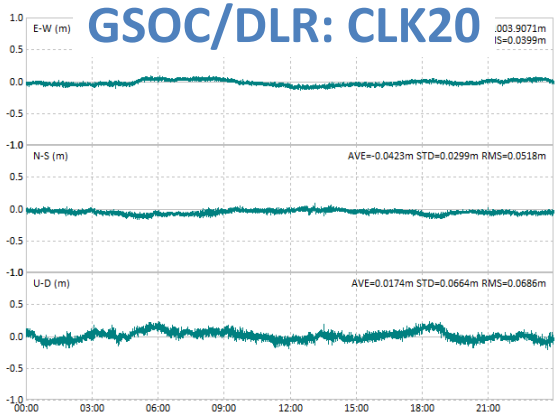
RT-PPP Performance with IGS



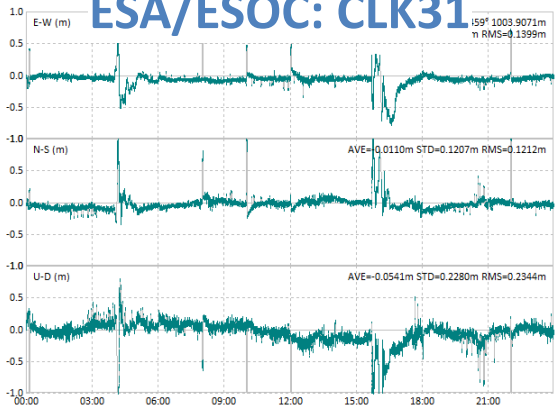
RMS: 3.8, 5.5, 7.7cm



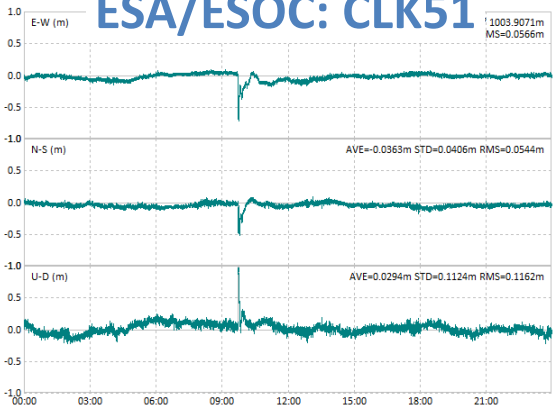
RMS: 3.8, 5.0, 7.1cm



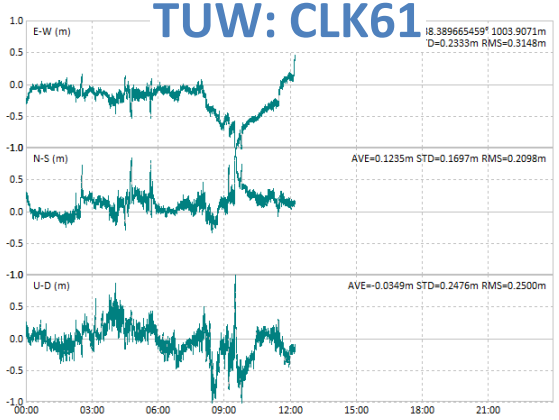
RMS: 4.0, 5.2, 6.9cm



RMS: 14.0, 12.1, 23.4cm



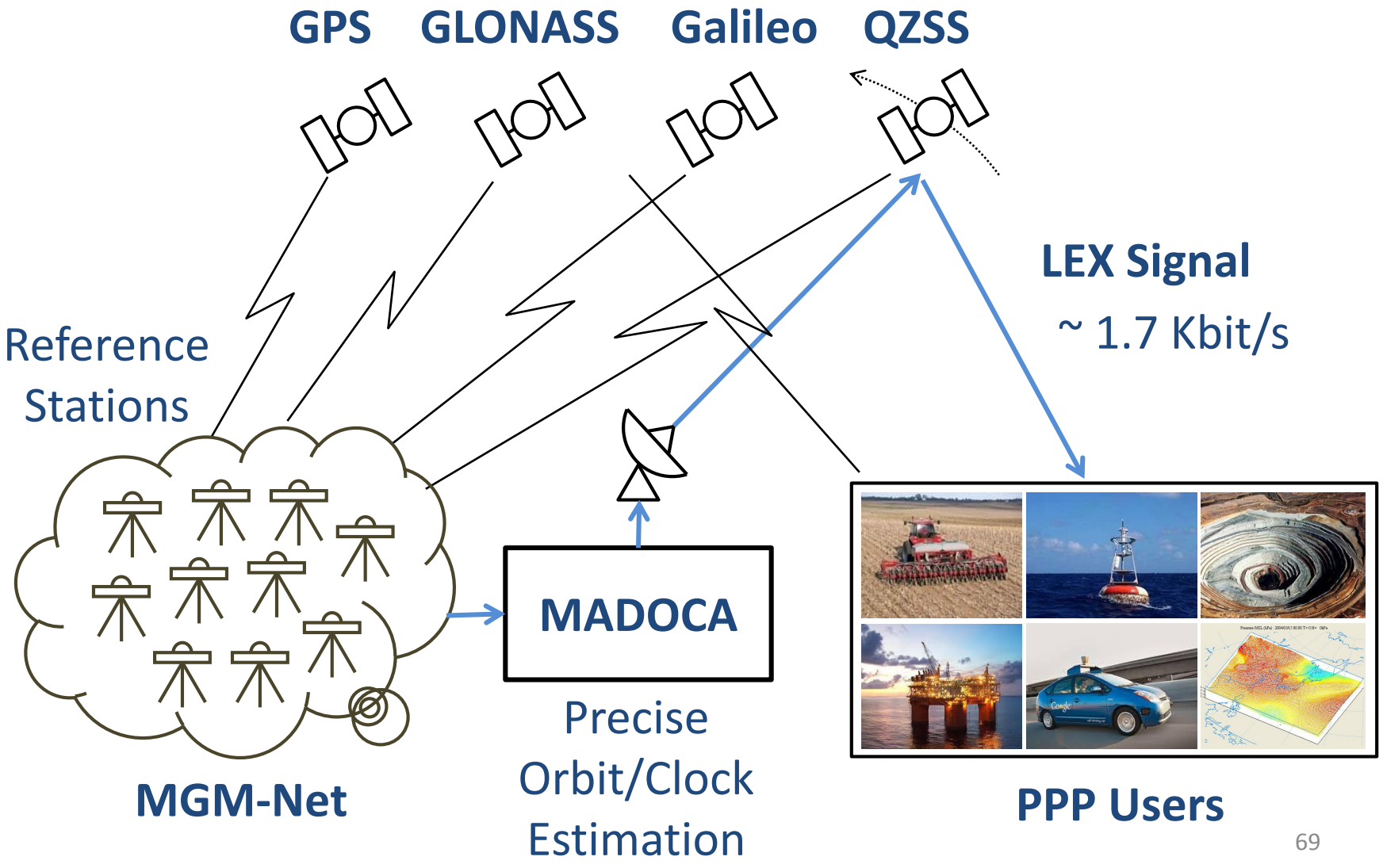
RMS: 5.7, 5.4, 11.6cm



RMS: 23.3, 21.0, 25.0cm

2010/9/18 0:00-23:59, 1Hz, Kinematic PPP, NovAtel OEMV-3+GPS-702, RTKLIB 2.4.1

Real-Time PPP via QZSS LEX

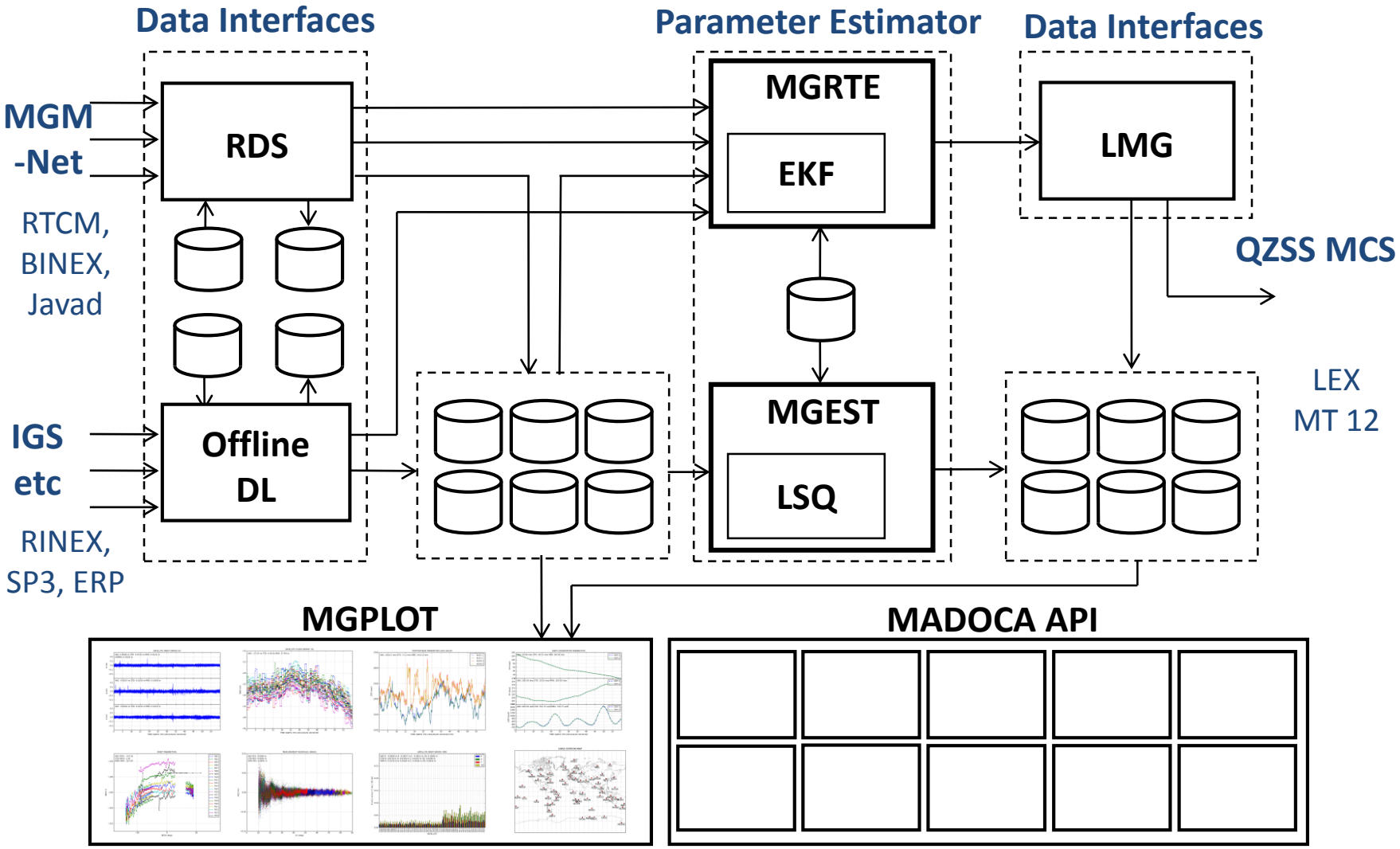


MADOCA (1)

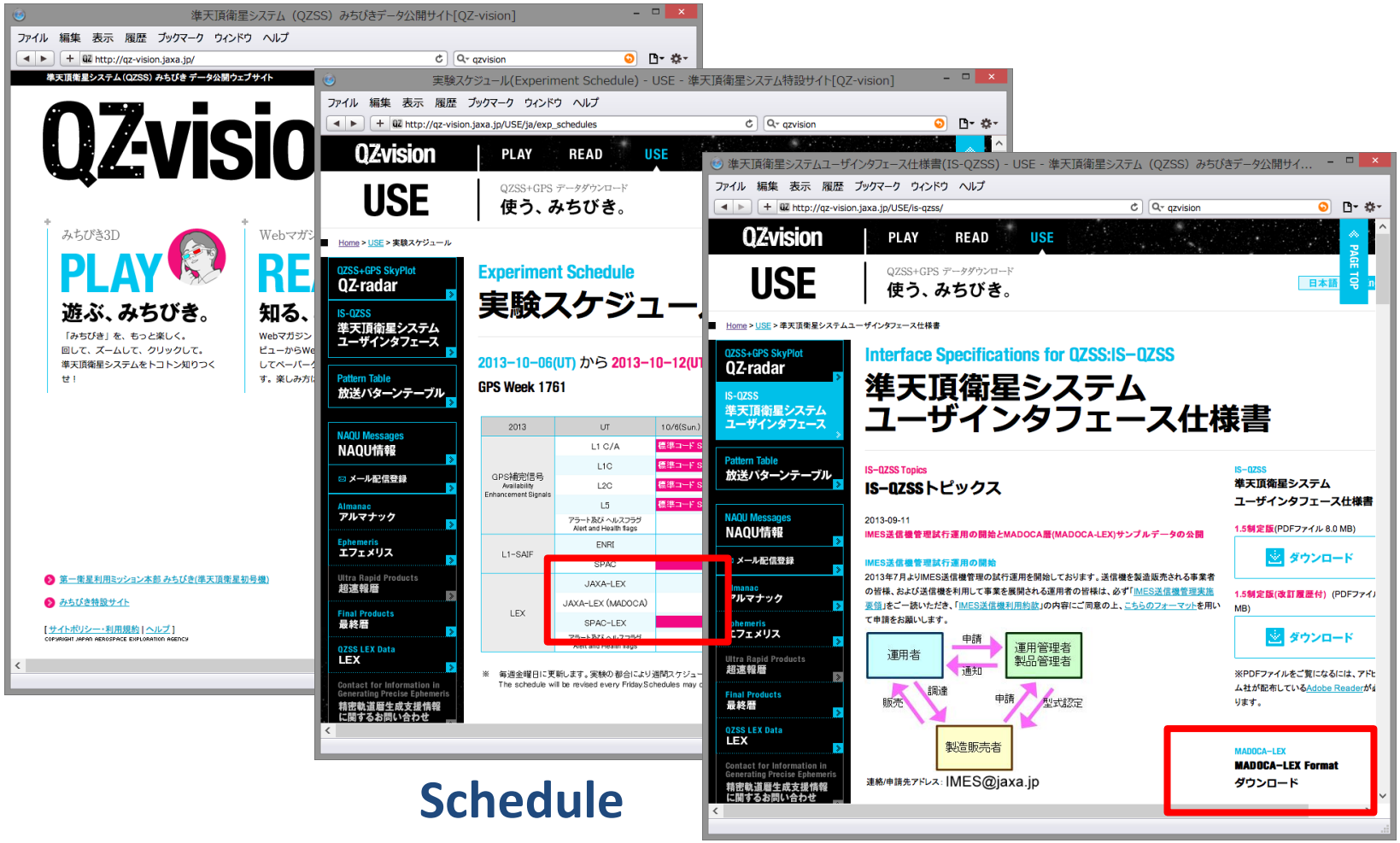
Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

- **For real-time PPP service via QZSS LEX**
  - Many (potential) applications over global area
- **Precise orbit/clock for multi-GNSS constellation**
  - Key-technology for future cm-class positioning
- **Brand-new codes developed from scratch**
  - Optimized multi-threading design for recent CPU
  - As basis of future model improvements

MADOCA (2)


Data Interfaces
Parameter Estimator
Data Interfaces
MGM
-Net
RTCM,
BINEX,
Javad
RDS
MGRTE
EKF
LMG
QZSS MCS
LEX
MT 12
IGS
etc
RINEX,
SP3, ERP
Offline
DL
MGEST
LSQ
MGPLOT
MADOCA API

MADOCA-PPP



Schedule

LEX Data Format

LEX MT12 Format

■メッセージタイプ　　：JAXA実験用信号としてメッセージタイプ 12 で放送予定

■メッセージフォーマット　：PPPユーザ向けのRTCM(*1) SSR(State Space Representation)フォーマットに基づき、MADOCAにより生成したプロダクトを格納する。
LEXメッセージのデータ部には、RTCMメッセージの“Variable Length Data Message”のみを先頭から詰めて格納する。
LEXメッセージとRTCMメッセージの関係は、下記のとおり。
(*1)RTCM (Radio Technical Commission for Maritime services)

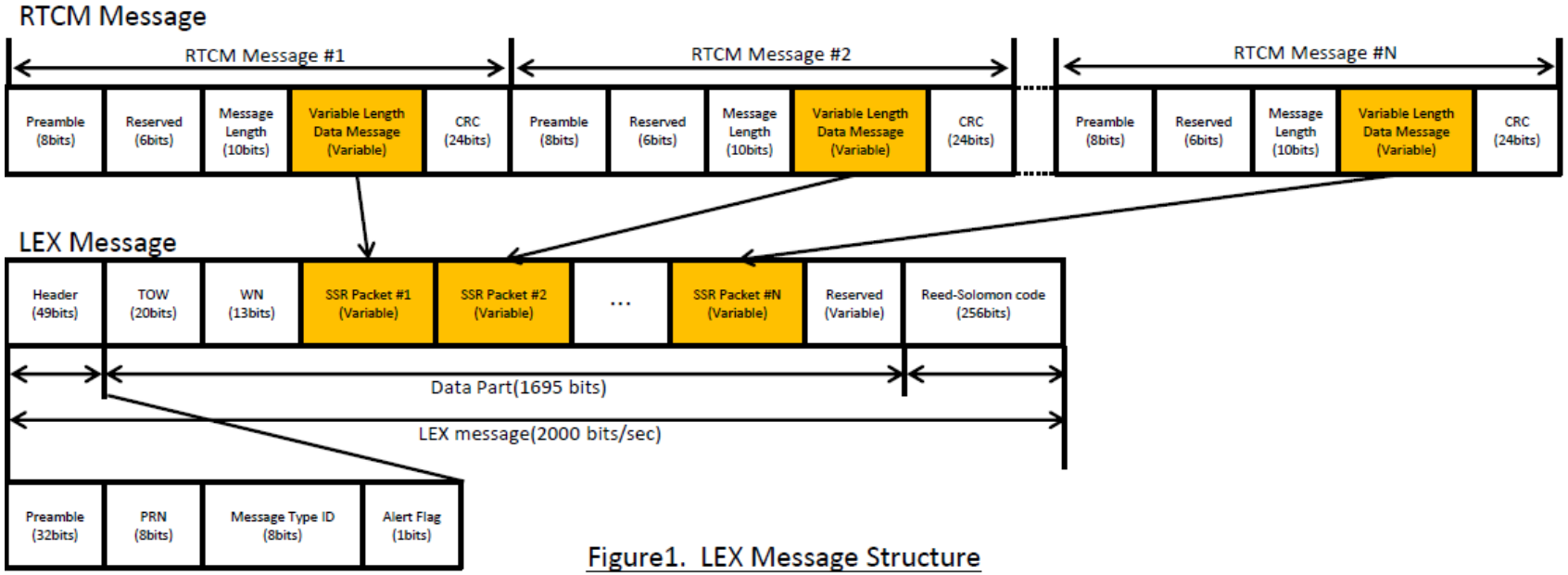


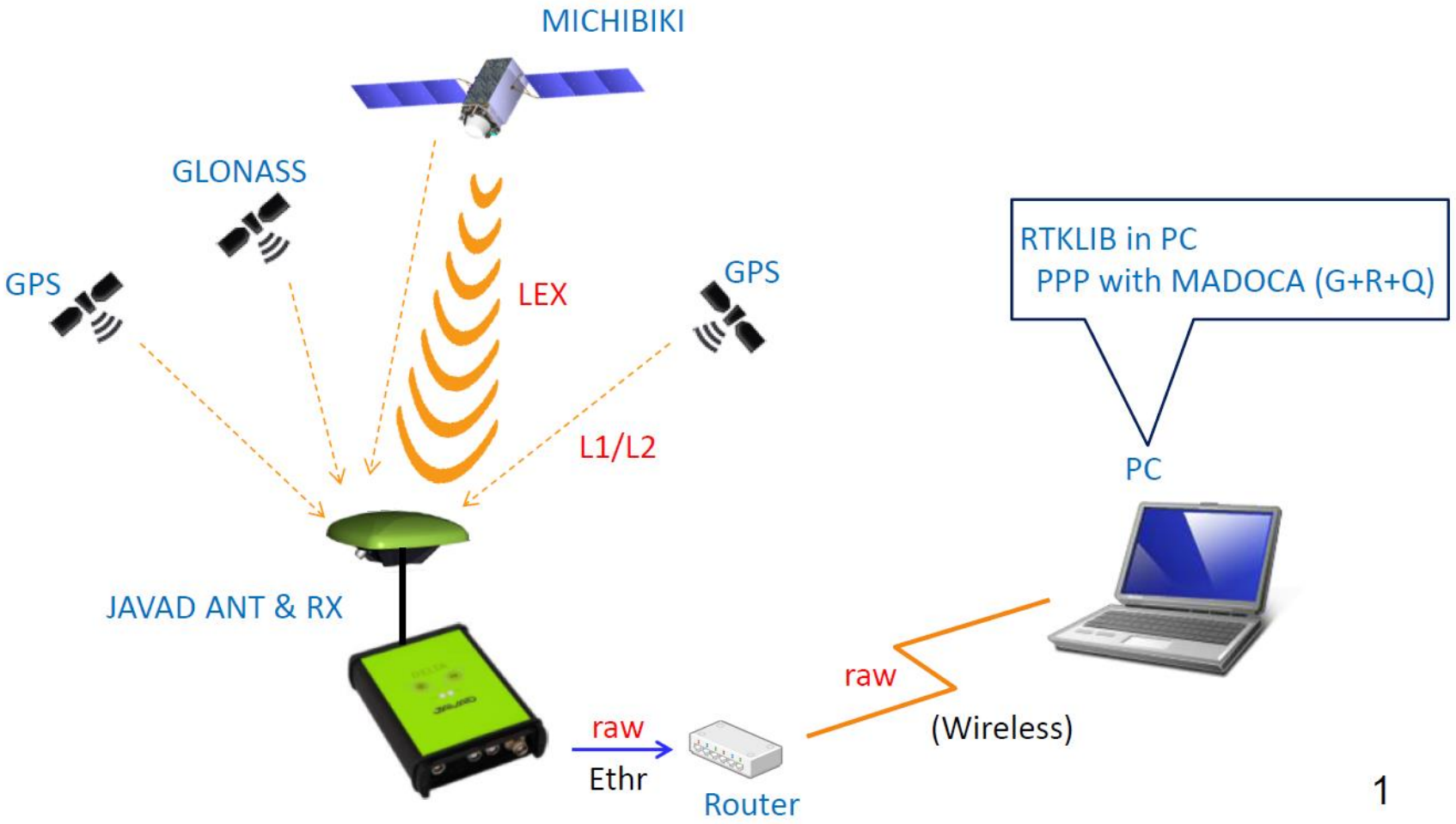
Figure1. LEX Message Structure

JAXA Activities and QZSS Intro by JAXA

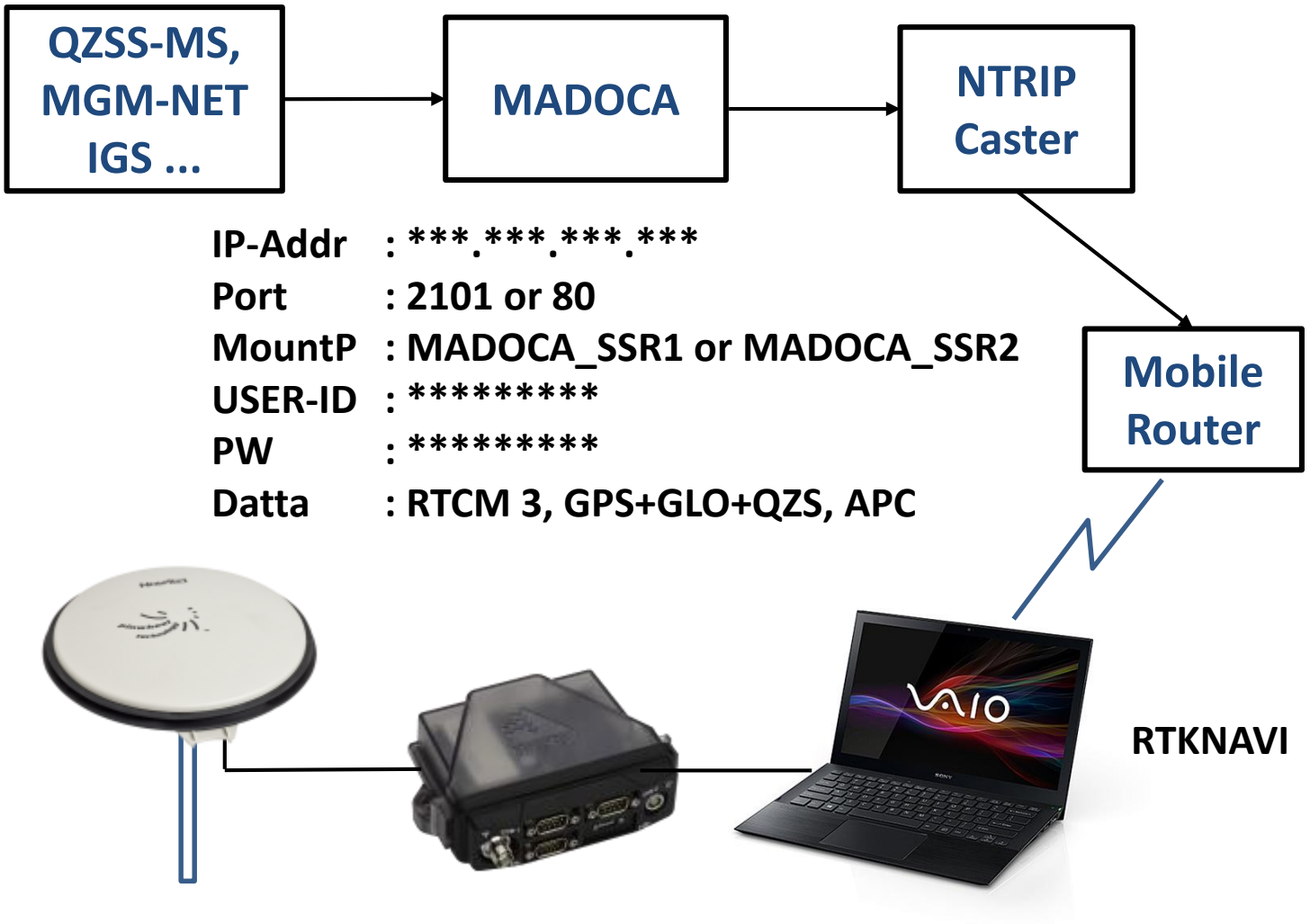
QZSS-Demo & RTKLIB Practice (2)

Demonstration of MADOCA-LEX-PPP

- ✓ **Demonstration of real time LEX-PPP with MADOCA**
- ✓ **Moving point tracking (“MADOCA ART”)**

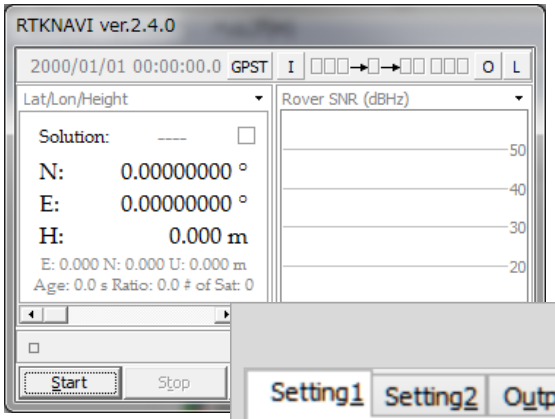


PPP Setup (1)

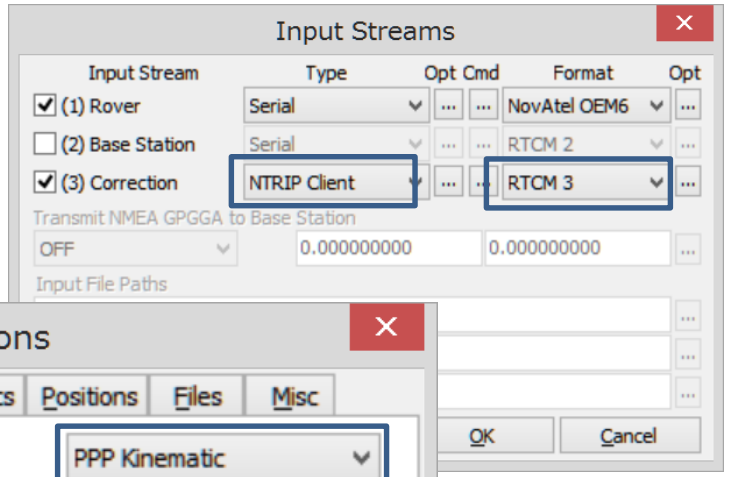

QZSS-MS,
MGM-NET
IGS ...
MADOCA
NTRIP
Caster
IP-Addr : ***.***.***.***
Port : 2101 or 80
MountP : MADOCA_SSR1 or MADOCA_SSR2
USER-ID : *********
PW : *********
Datta : RTCM 3, GPS+GLO+QZS, APC
Mobile
Router
RTKNAVI

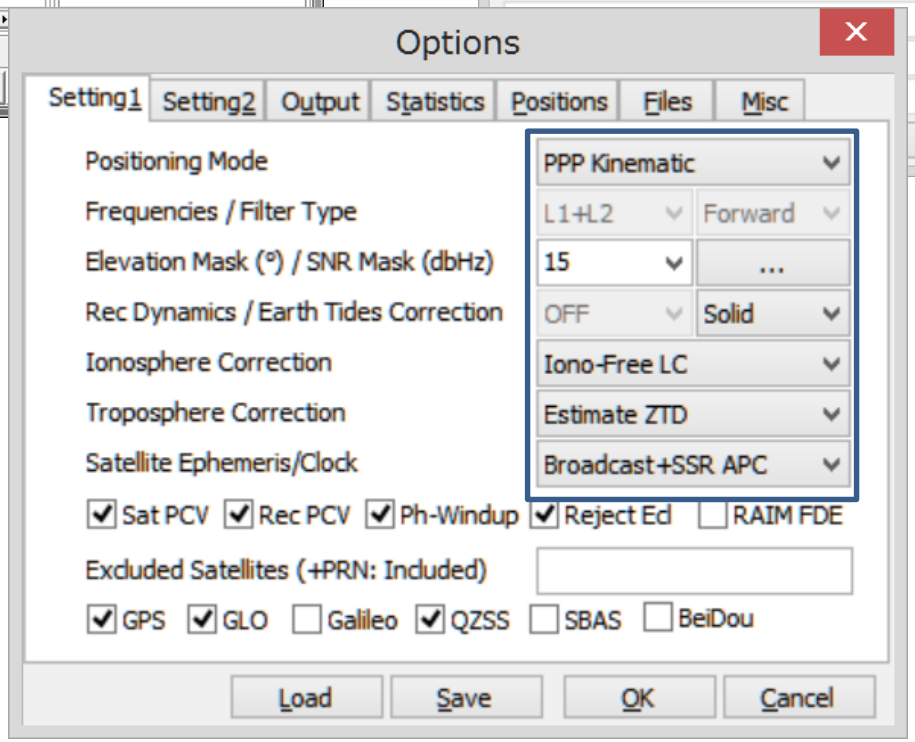
PPP Setup (2)

RTKNAVI



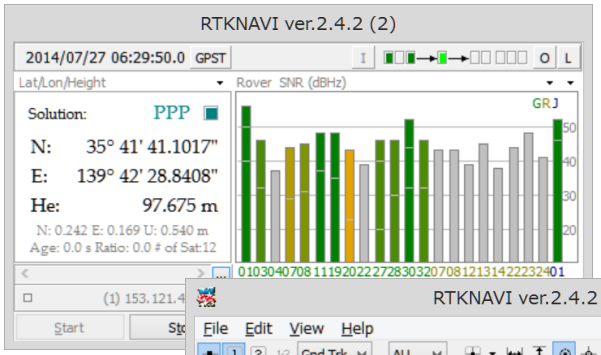
RTKNAVI - Input Streams





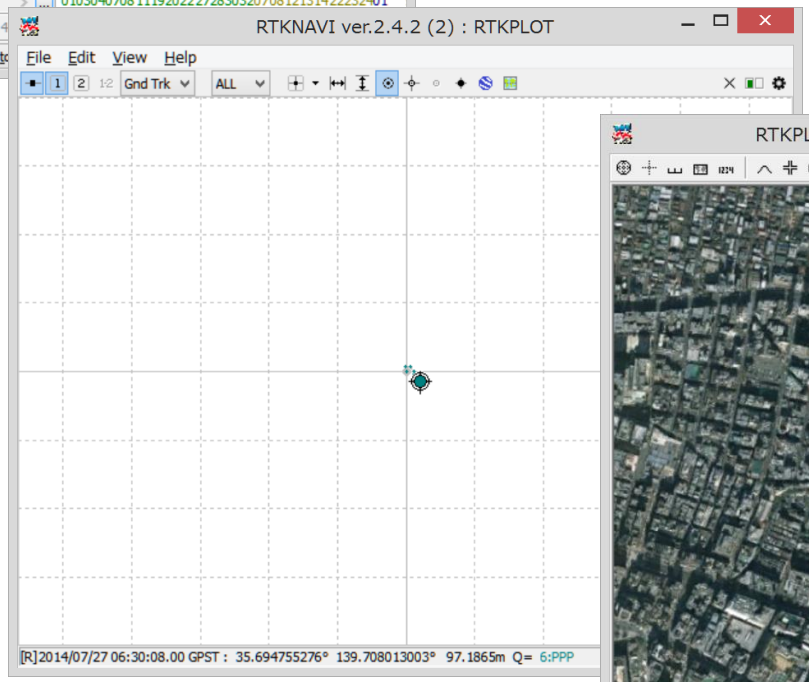
RTKNAVI - Options

PPP Setup (3)

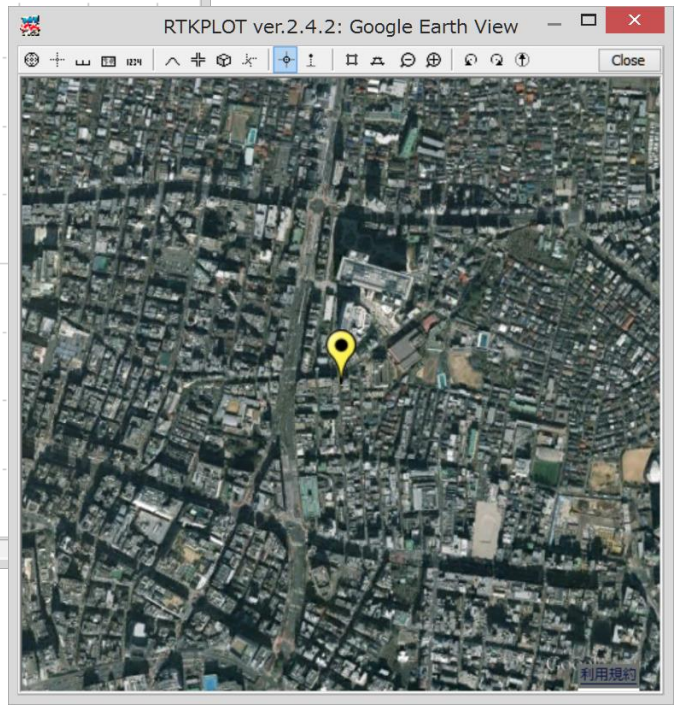


RTKNAVI

RTKPLOT



RTKPLOT - GE View



RTKLIB Practice (2)

Draw A Figure on the Ground by using PPP