測位航法学会 平成23年度全国大会 セミナー②

GNSS Precise Positioning with RTKLIB Part I

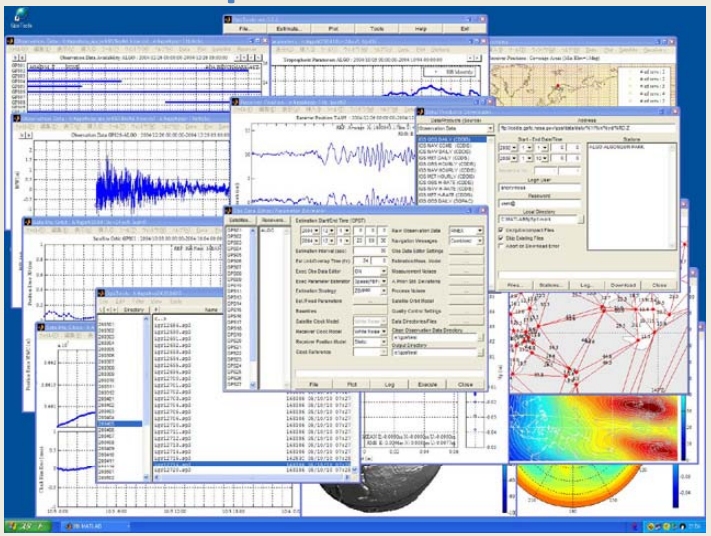
2011-4-25,26 @東京海洋大学品川 楽水会館

東京海洋大学　高須 知二

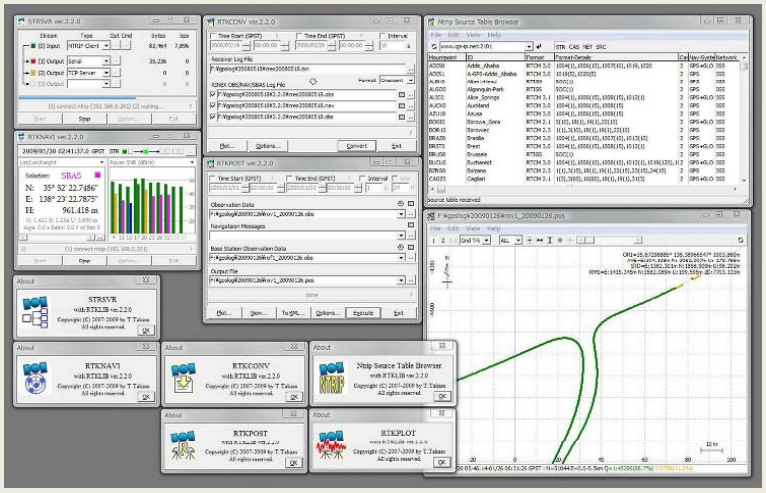
Self Introduction

?

GpsTools 0.6.4



RTKLIB 2.4.0



Timetable

1. GPS/GNSS	April 25	9:30-10:40
2. Signal and Receiver		10:50-12:00
3. Standard Positioning		13:00-15:10
4. RTKLIB		15:30-16:40
5. RTK	April 26	9:30-10:40
6. PPP		10:50-12:00
7. RTK System		13:00-15:10
8. Advanced Topics		15:20-16:20

0.Preparation

WiFi Connection:

SSID: ipntj_2011, PW: xxxxxxxx

RTKLIB Package:

http://www.rtklib.com/prog/rtklib_2.4.0.zip

http://www.rtklib.com/prog/xxxxxxxxxx.zip

(23.0 MB, 26.1 MB)

Sample Data:

http://www.rtklib.com/prog/xxxxxxxx.zip

(18.9MB)

1. GPS/GNSS

GPS (Global Positioning System)

- **NAVSTAR GPS**
  - Satellite navigation system developed by US DoD
  - Operated by US Air Force GPS Directorate (GPS Wing, JPO)
- **History**
  - 1978/2 First satellite launch
  - 1983 Freely available for civilian use
  - 1993 Fully operational (FOC)
  - 2000/5 S/A Termination
  - 2011/4 31 operational satellites (Test: PRN1=SVN49)

GNSS (Global Navigation Satellite System)

- **GNSS (Global Navigation Satellite System)**
  - **GPS** (US)
  - **GLONASS** (Russia)
  - **Galileo** (EU)
  - **Compass** (China)
- **RNSS (Regional Navigation Satellite System)**
  - **QZSS** (Japan)
  - **IRNSS** (India)
- **SBAS (Satellite Based Augmentation System)**
  - **WAAS, EGNOS, MSAS, SDCM, GAGAN**

GPS/GNSS Applications

Military Applications: ...

Civil Applications:

Air Navigation
- Nonprecision approach and landing
- Domestic en route
- Oceanic en route
- Terminal
- Remote areas
- Helicopter operations
- Aircraft attitude
- Collision avoidance
- Air Traffic Control

Land Navigation
- Vehicle monitoring
- Schedule improvement
- Minimal routing
- Law enforcement

Marine navigation
- Oceanic
- Coastal
- Harbor/approach
- Inland waterways

Static positioning and timing
- Offshore resource exploration
- Hydrographic surveying
- Aids to navigation
- Time transfer
- Land surveying
- Geographical information systems

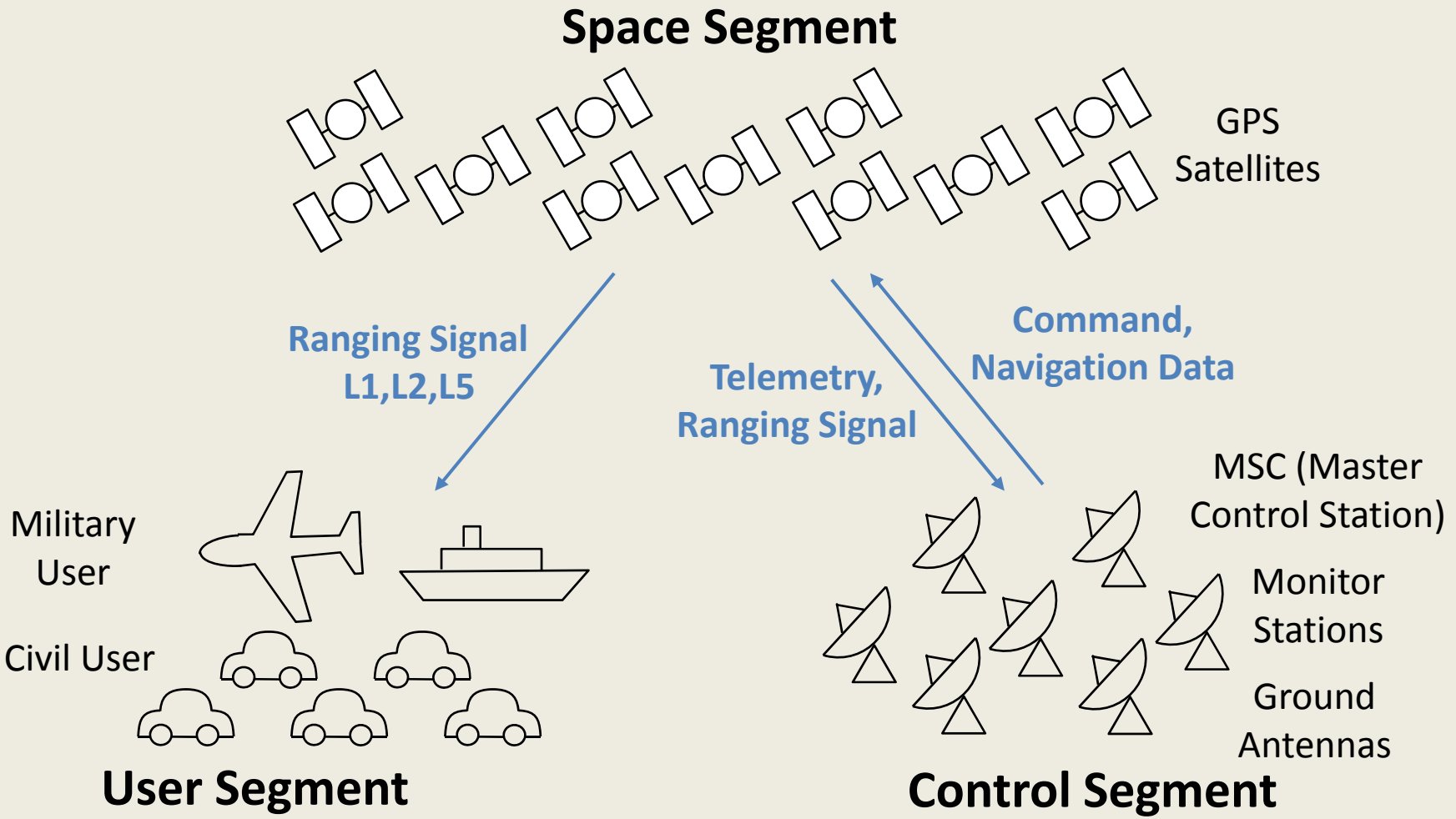
Space
- Launch
- In-flight/orbit
- Reentry/landing
- Attitude measurement

Search and Rescue
- Position reporting and monitoring
- Rendezvous
- Coordinated search
- Collision avoidance

...

(B.W.Parkinson, Introduction and Heritage of NAVSTAR, the Global Positioning System, 1994)

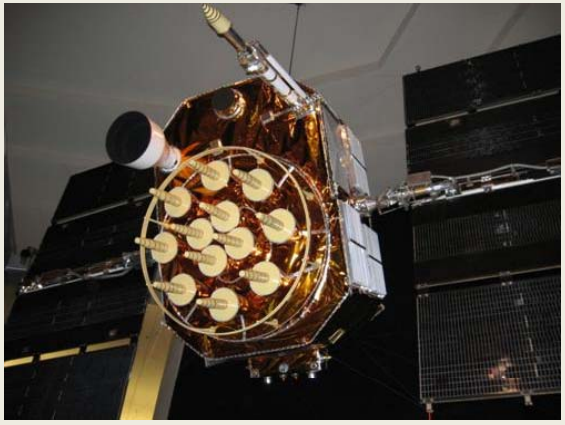
GPS System


Space Segment
GPS Satellites
Ranging Signal L1,L2,L5
Telemetry, Ranging Signal
Command, Navigation Data
Military User
Civil User
MSC (Master Control Station)
Monitor Stations
Ground Antennas
User Segment
Control Segment

GPS Space Segment

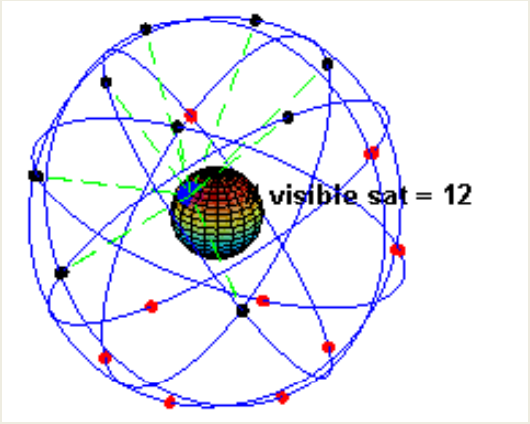
- **Satellite Constellation**
  - 6 Plane x 4 = 24 Satellites (Nominal)
  - Altitude: 20,100km
  - Inclination: 55°
  - Period: 1/2 Sidereal Day (11h 58' 2")

GPS Block II



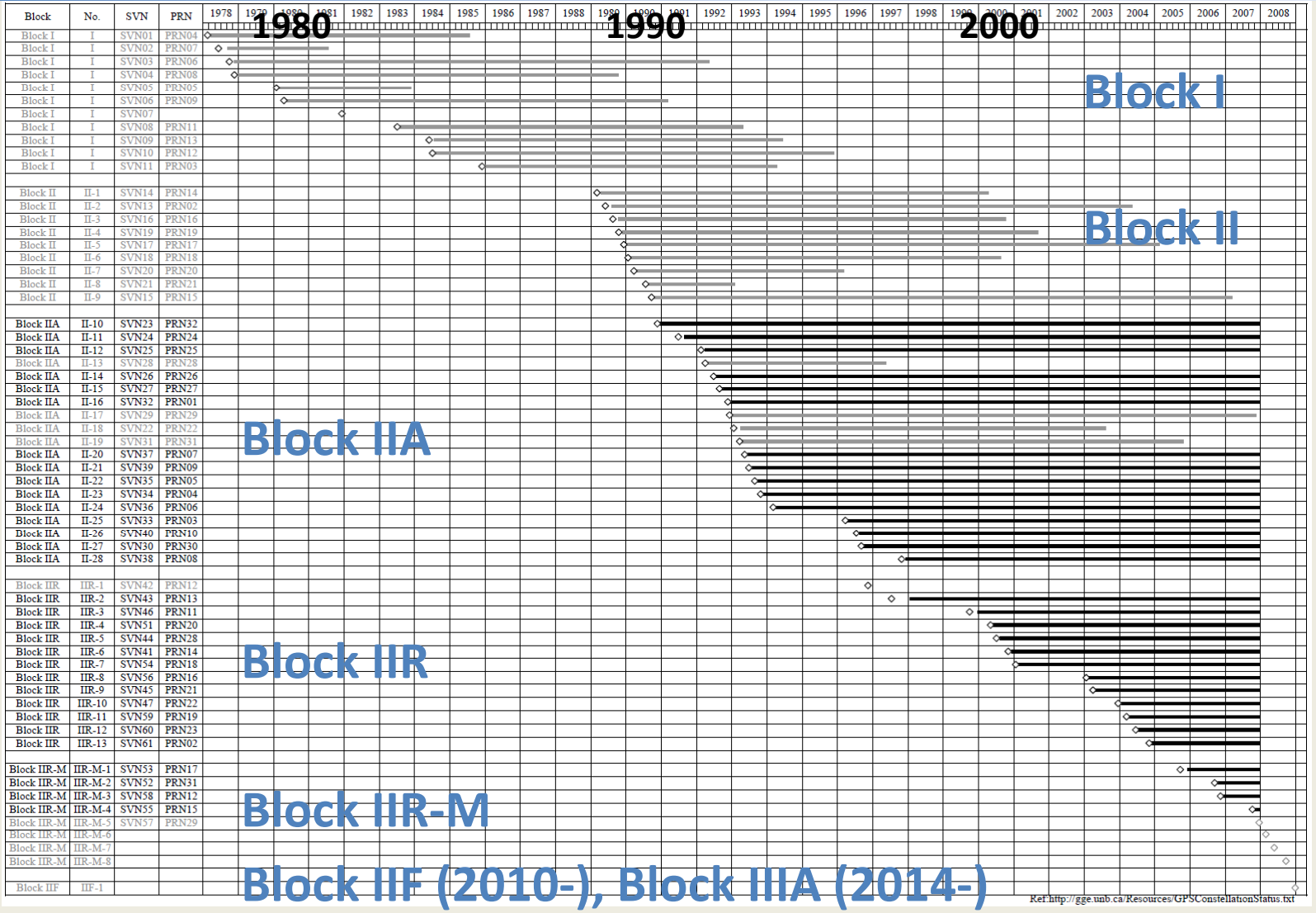
(http://www.ion.org/museum)

Satellite Orbit Planes



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

GPS Satellites

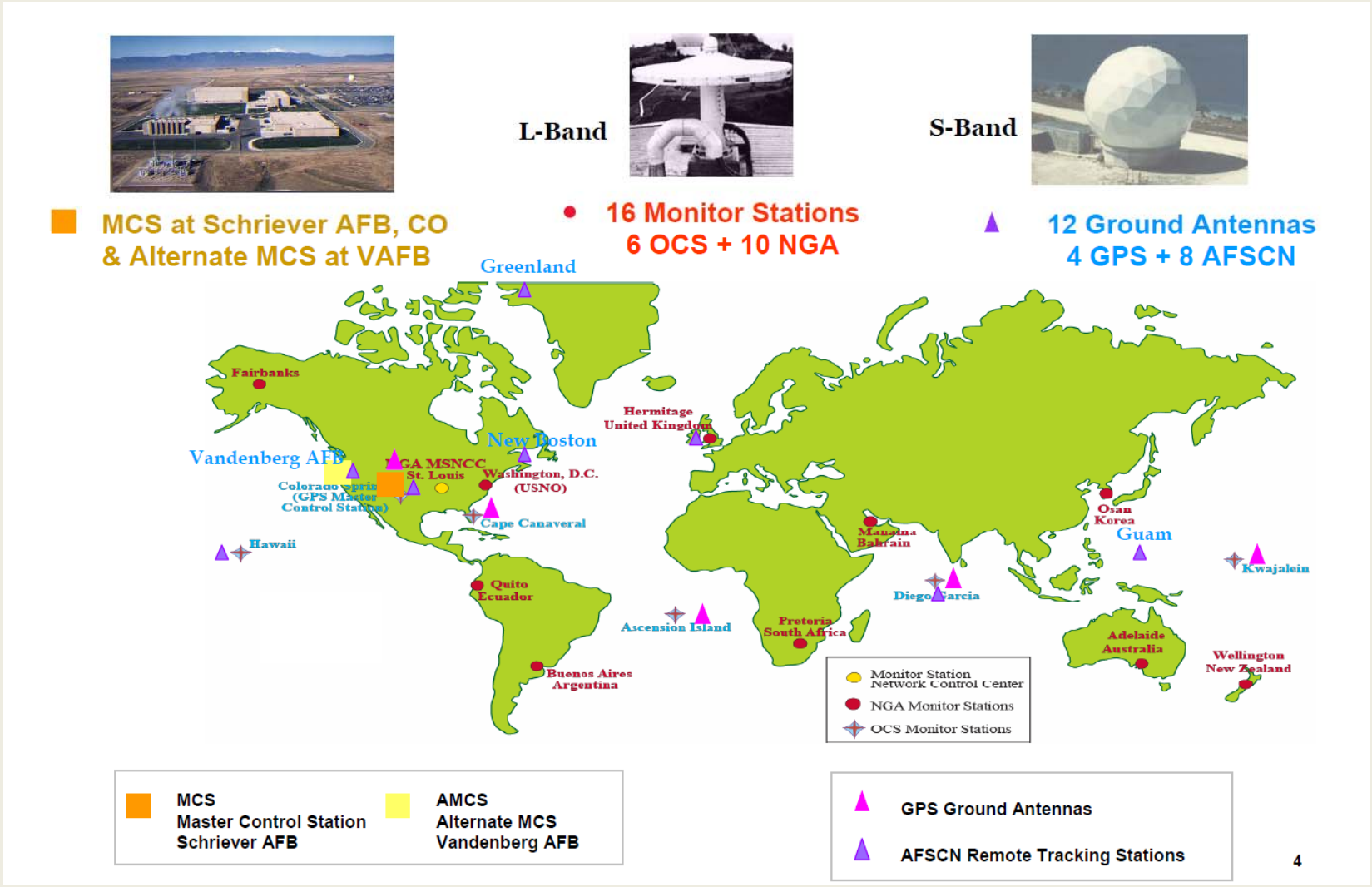


Block	No.	SVN	PRN
Block I	I	SVN01	PRN04
Block I	I	SVN02	PRN07
Block I	I	SVN03	PRN06
Block I	I	SVN04	PRN08
Block I	I	SVN05	PRN05
Block I	I	SVN06	PRN09
Block I	I	SVN07	
Block I	I	SVN08	PRN11
Block I	I	SVN09	PRN13
Block I	I	SVN10	PRN12
Block I	I	SVN11	PRN03
Block II	II-1	SVN14	PRN14
Block II	II-2	SVN13	PRN02
Block II	II-3	SVN16	PRN16
Block II	II-4	SVN19	PRN19
Block II	II-5	SVN17	PRN17
Block II	II-6	SVN18	PRN18
Block II	II-7	SVN20	PRN20
Block II	II-8	SVN21	PRN21
Block II	II-9	SVN15	PRN15
Block IIA	II-10	SVN23	PRN32
Block IIA	II-11	SVN24	PRN24
Block IIA	II-12	SVN25	PRN25
Block IIA	II-13	SVN28	PRN28
Block IIA	II-14	SVN26	PRN26
Block IIA	II-15	SVN27	PRN27
Block IIA	II-16	SVN32	PRN01
Block IIA	II-17	SVN29	PRN29
Block IIA	II-18	SVN22	PRN22
Block IIA	II-19	SVN31	PRN31
Block IIA	II-20	SVN37	PRN07
Block IIA	II-21	SVN39	PRN09
Block IIA	II-22	SVN35	PRN05
Block IIA	II-23	SVN34	PRN04
Block IIA	II-24	SVN36	PRN06
Block IIA	II-25	SVN33	PRN03
Block IIA	II-26	SVN40	PRN10
Block IIA	II-27	SVN30	PRN30
Block IIA	II-28	SVN38	PRN08
Block IIR	IIR-1	SVN42	PRN13
Block IIR	IIR-2	SVN43	PRN13
Block IIR	IIR-3	SVN46	PRN11
Block IIR	IIR-4	SVN51	PRN20
Block IIR	IIR-5	SVN44	PRN28
Block IIR	IIR-6	SVN41	PRN14
Block IIR	IIR-7	SVN54	PRN18
Block IIR	IIR-8	SVN56	PRN16
Block IIR	IIR-9	SVN45	PRN21
Block IIR	IIR-10	SVN47	PRN22
Block IIR	IIR-11	SVN59	PRN19
Block IIR	IIR-12	SVN60	PRN23
Block IIR	IIR-13	SVN61	PRN02
Block IIR-M	IIR-M-1	SVN53	PRN17
Block IIR-M	IIR-M-2	SVN52	PRN31
Block IIR-M	IIR-M-3	SVN58	PRN12
Block IIR-M	IIR-M-4	SVN55	PRN15
Block IIR-M	IIR-M-5	SVN57	PRN29
Block IIR-M	IIR-M-6		
Block IIR-M	IIR-M-7		
Block IIR-M	IIR-M-8		
Block IIF	IIF-1		

GPS Signals

- **Signals**
  - L1C/A : Block IIA, IIR
  - L1C : Block IIIA -
  - L1P(Y), L2P(Y) (military) : Block IIA, IIR, (-2020)
  - L2C : Block IIR-M -
  - L1M, L2M (military) : Block IIR-M -
  - L5 : Block IIF -
- **Multiplexing**
  - CDMA (Code Division Multiple Access)

GPS Ground Segment



(L.C.P.Harrington, GPS Status and Modernization, 2009)

GLONASS (ГЛОНАСС)

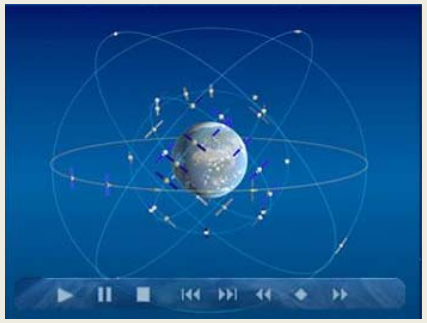
- **Development**
  - USSR and Russia
- **Satellite Constellation**
  - 3 Plane x 8 = 24 Sats + 3 Spare (FOC)
  - Altitude: 19,100 km, Inclination: 64.5°
  - GLONASS, GLONASS-M (2003-), GLONASS-K (2011-)
- **Signals**
  - L1C/A, L1P (FDMA: 1602+n x 0.5625 MHz)
  - L2C/A, L2P (FDMA: 1246+n x 0.4375 MHz)
  - L3 CDMA (GLONASS-K-)

Galileo

- **Development**
  - EU and ESA
- **Satellite Constellation**
  - 3 Plane x 9 = 27 Sats + 3 Spare (FOC)
  - Altitude: 23,200km, Inclination: 56°
  - Test Sats: GIOVE-A (2005), GIOVE-B (2007)
  - 2012 4 Sats (IOV), 2014/15 18 Sats, 2016/17 FOC
- **Signals**
  - E5a (OS,CS), E5b (OS, SoL, CS)
  - E6a (PRS), E6b/c (CS), E1a (PRS), E1b/c (OS, SoL, CS)

Compass (Beidou-2, 北斗)

- **Development**
  - China
- **Satellite Constellation**
  - Phase I (-2012): 3 Sats (GEO)
  - Phase II (-2020): 14 Sats (5 GEO, 5 IGSO, 4 MEO)
  - Phase III (2020-): 35 Sats (5 GEO, 3 IGSO, 27 MEO)
  - 2011/4: 8 Sats (4 GEO, 3 IGSO, 1 MEO), No ICD
- **Signals**
  - Phase II: B1, B2, B3 (?)
  - Phase III: B1, B2, B3 (L1C, L5 GPS Compatible?)

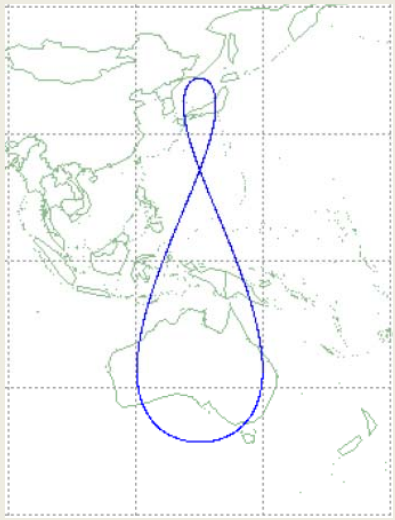


http://www.beidou.gov.cn

QZSS (Quasi Zenith Satellite System)

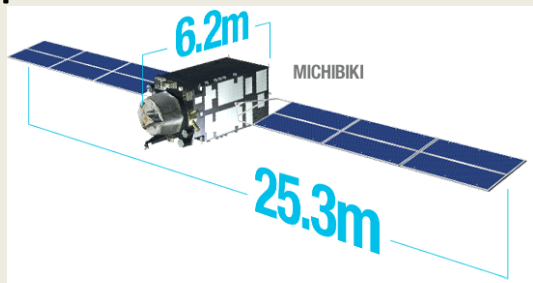
- **Development**
  - Japan, JAXA
- **Satellite Constellation**
  - 1 Sat (IOC), 4 or 7 Sats (FOC)
  - Altitude: ~36,000km, Inclination: 43°
  - Eccentricity: 0.075
  - 2010/9/11 First Sat "Michibiki" Launch
- **Signals**
  - L1C/A, L1C, L2C, L5: GPS Compatible
  - L1-SAIF, LEX: Augmentation

QZSS Ground Track



(IS-QZSS 1.2)

"Michibiki"

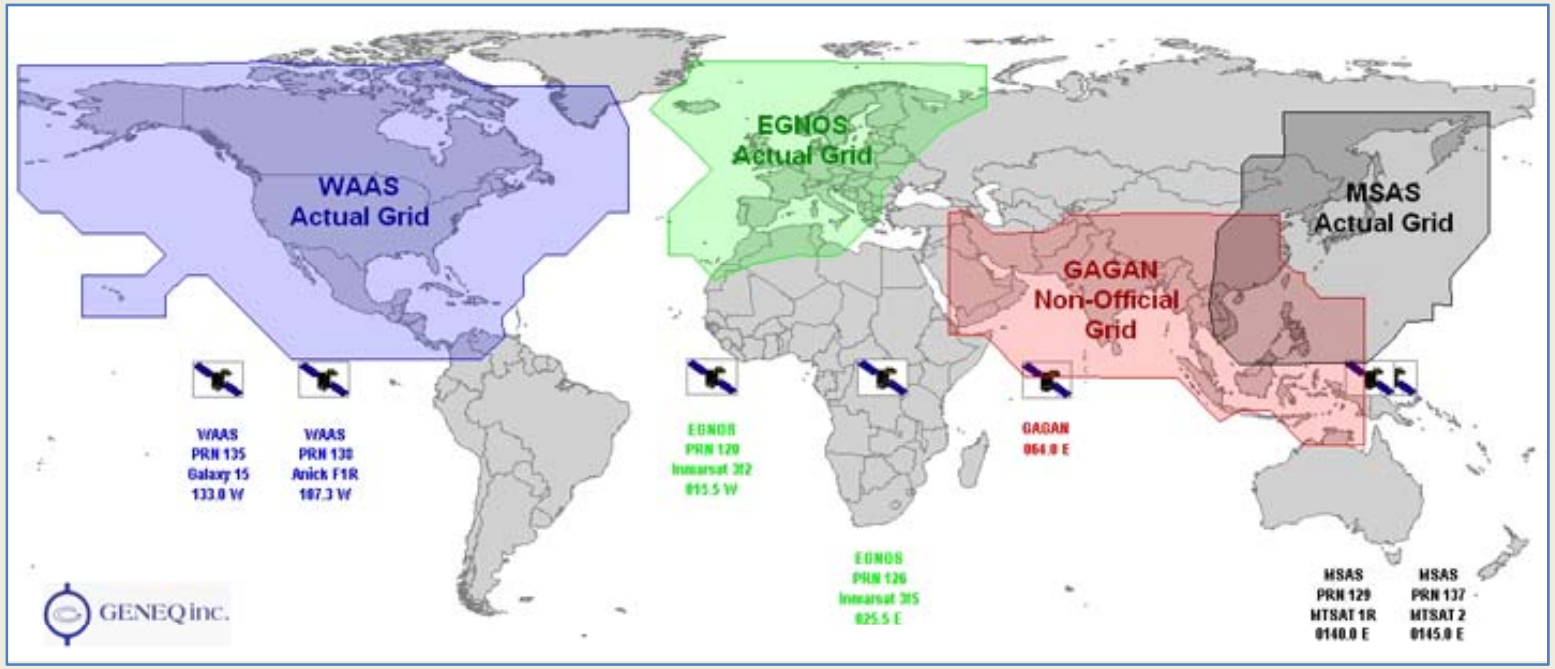


(http://qz-vision.jaxa.jp)

SBAS (Satellite Based Augmentation System)

System	Development	Operation	GEO Satellite		
			PRN	Name	Location
WAAS	US, DOT, FAA	2003/7-	135	Galaxy 15	133W
			138	Anik F1R	107.3W
EGNOS	ESA, EC, Eurocontrol	2009/10,-2011/3-(SoL)	120	Inmarsat-3 AOR-E	15.5W
			124	Artemis	21.5E
			126	Inmarsat-3 IOR-W	25E
MSAS	Japan, JCAB	2007/9-	129	MTSAT-IR	140E
			137	MTSAT-II	145E
SDCM	Russia	2014-	?	Luch-5A	16E
			?	Luch-5B	95E
			?	Luch-4	167E
GAGAN	India, AAI, ISRO	2011-	127	GSAT-12	?

SBAS Coverage Map



(by GENEQ Inc.)

Satellite Launch (2010-2011)

Date/Time (UTC)	Satellite	Orbit	Launcher	Launch Site	Notes
2010/01/16 16:12	Compass (Beidou-2) G2	GEO	Long March 3C	Xichang, China	
2010/03/01 21:19	GLONASS-M x 3	MEO	Proton-M	Baikonur, Kazakhstan	
2010/04/15 10:57	GSAT-4 (GAGAN)	GEO	GSLV	Satlsh Dhawan, India	Failed
2010/05/28 03:00	GPS Block IIF-1	MEO	Delta-IV	Cape Canaveral, USA	
2010/06/02 15:53	Compass (Beidou-2) G3	GEO	Long March 3C	Xichang, China	
2010/07/31 21:30	Compass (Beidou-2) I1	IGSO	Long March 3A	Xichang, China	
2010/09/02 00:53	GLONASS-M x 3	MEO	Proton-M	Baikonur, Kazakhstan	
2010/09/11 11:17	QZSS-1 "Michibiki"	IGSO	H-IIA	Tanegashima, Japan	
2010/10/31 16:26	Compass (Beidou-2) G4	GEO	Long March 3C	Xichang, China	
2010/12/05 10:25	GLONASS-M x 3	MEO	Proton-M	Baikonur, Kazakhstan	Failed
2010/12/17 20:20	Compass (Beidou-2) I2	IGSO	Long March 3A	Xichang, China	
2011/02/26 03:07	GLONASS-K1	MEO	Soyuz	Pleasetsk, Russia	
2011/04/09 20:47	Compass (Beidou-2) I3	IGSO	Long March 3A	Xichang, China	

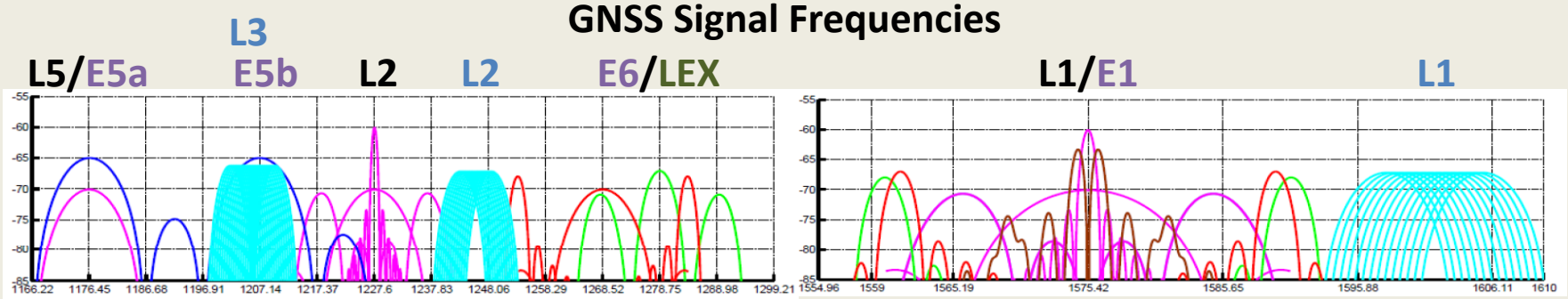
Planned: 2011/5 GSAT-12, 2011/6 **GPS Block IIF-2**, 2011/7 GLONASS-M x 3, 2011/8 Galileo IOV x 2

GNSS Constellation

Number of Planned GNSS Satellites

System	2010	2013	2016	2019
GPS	31	32	32	32
GLONASS	23 (+2)	24 (+3)	24 (+3)	24 (+3)
Galileo	0	4	18	27 (+3)
Compass	6	12	30	32 (+3)
QZSS	1	1	7	7
IRNSS	0	7	7	7
SBAS	7	8	11	11
Total	68	88	129	140

GNSS Signal Frequencies



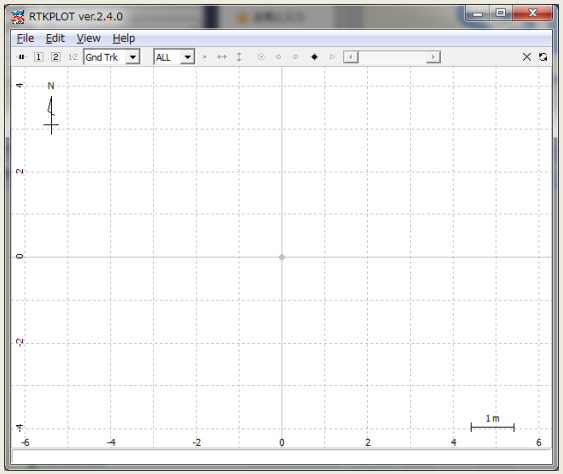
(Y.Yang, COMPASS: View on Compatibility and Interoperability, 2009)

1. GPS/GNSS: Exercise

Check Visible GNSS Satellites

- **Objective**
  check visible GNSS satellites
- **Program**
  …¥rtklib_2.4.0¥bin¥rtkplot.exe
  …¥rtklib_2.4.1b¥bin¥rtkplot.exe
- **Data**
  …¥seminar¥sample1¥
  javad1_201102030000.obs
  javad1_201102030000.nav

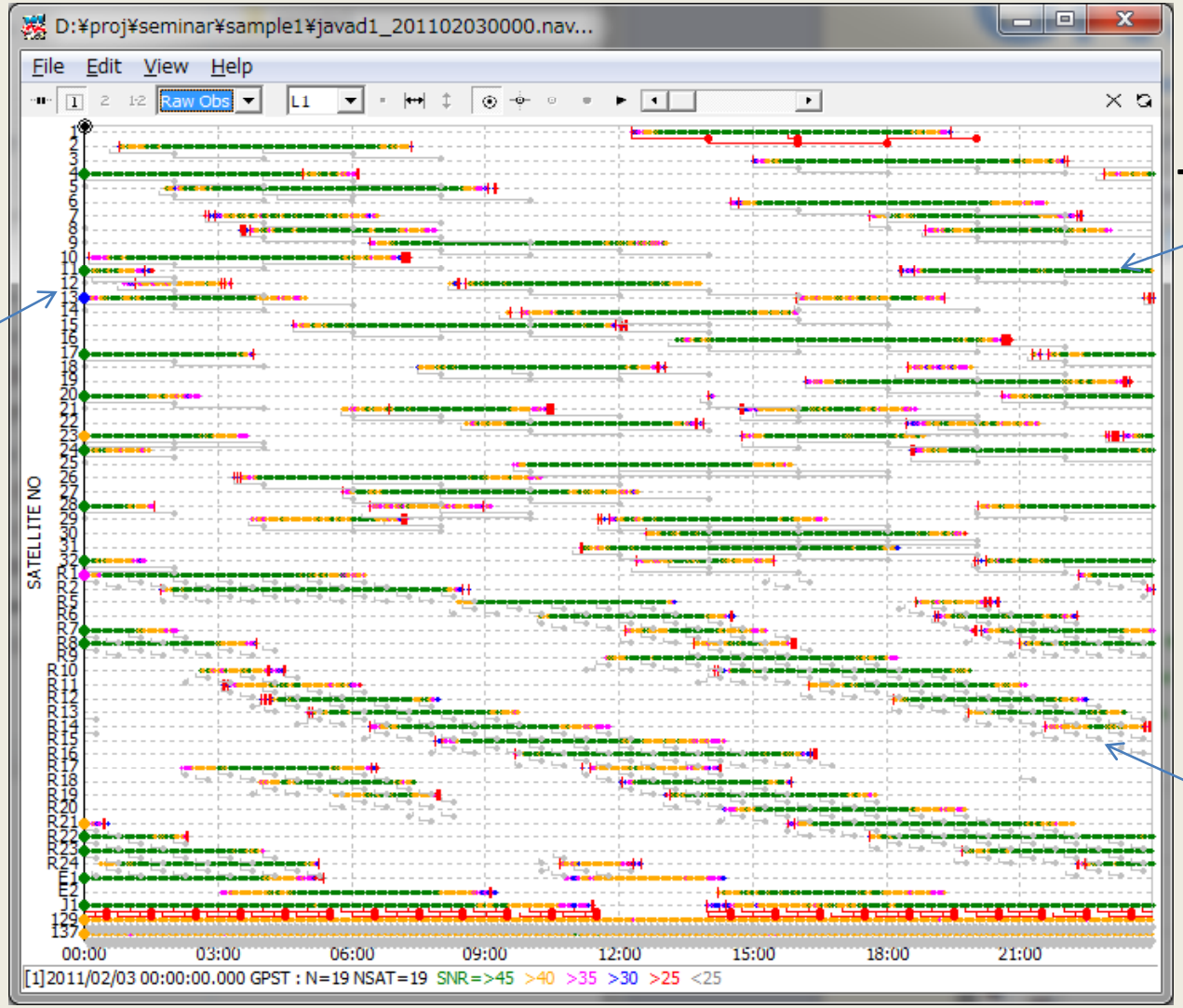
RTKLIB - RTKPLOT



JAVAD DELTA Receiver

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

Satellite Visibility



Satellite ID

Gnn: GPS

Rnn: GLO

Enn: GAL

Jnn: QZS

1nn: SBAS

Tracking Data

|: Cycle-Slip

|: Parity Unknown

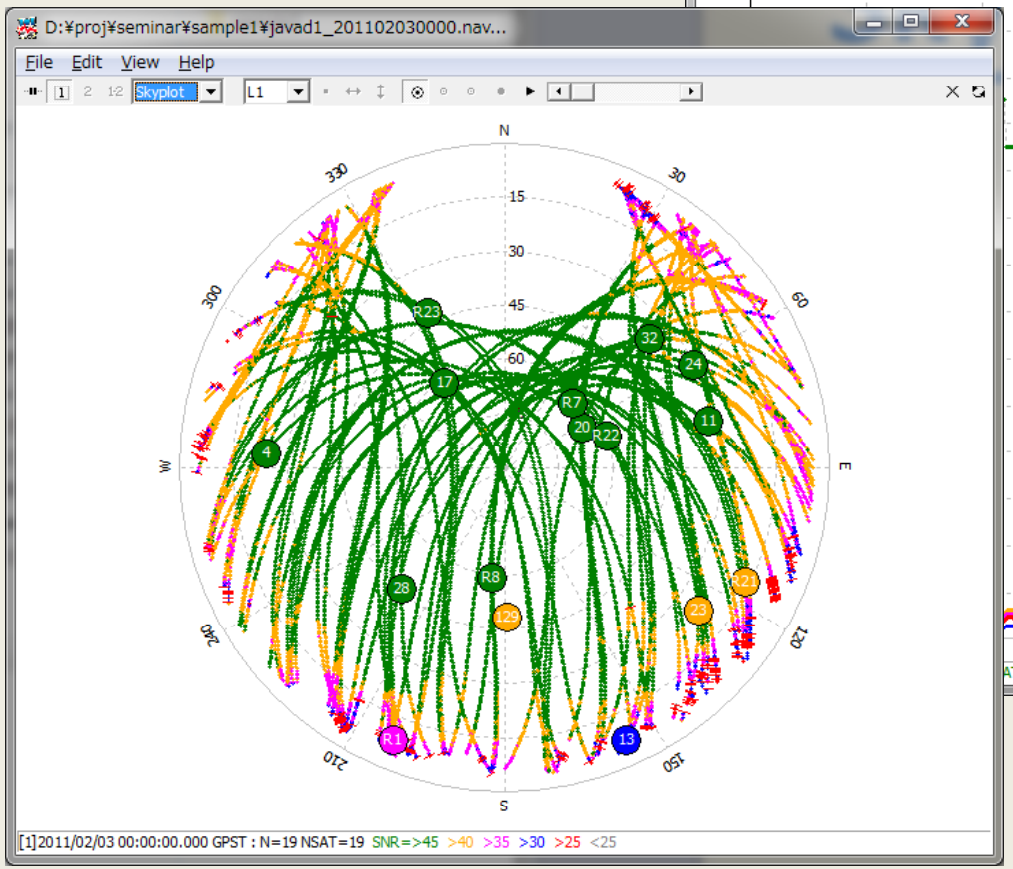
Ephemeris

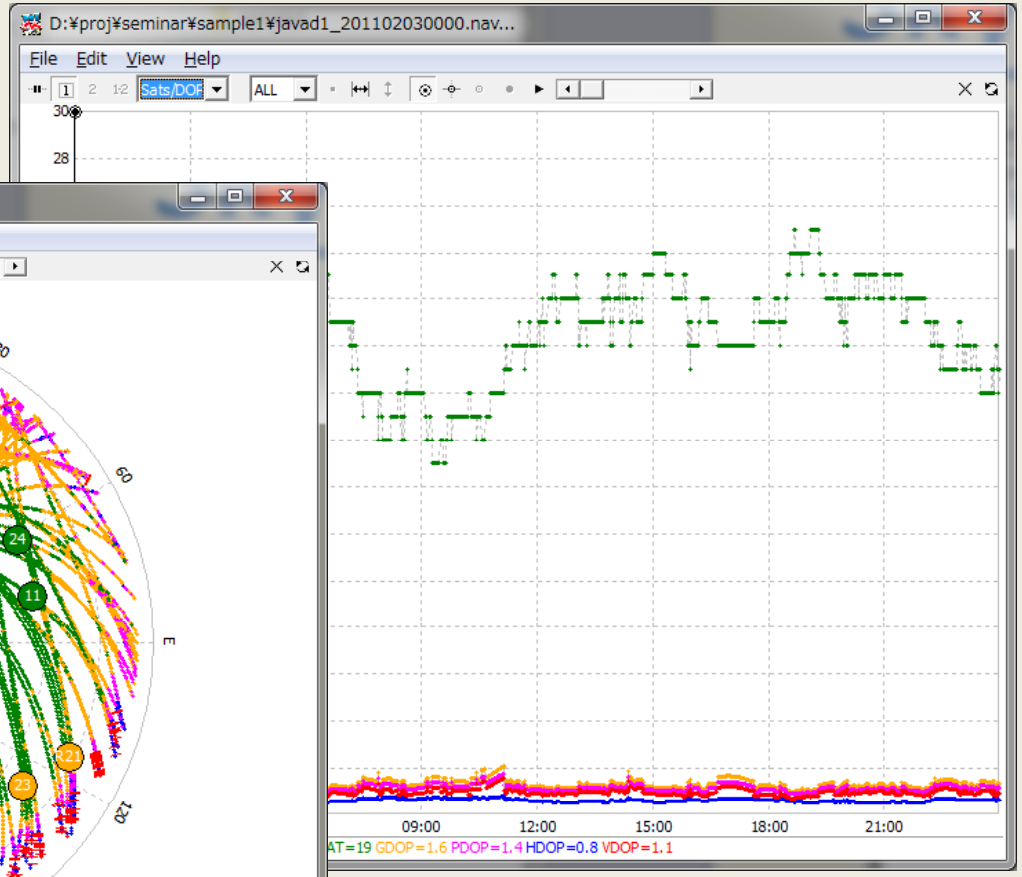
●: Toe

Red: unhealthy

Skyplot or # of Sats/DOP

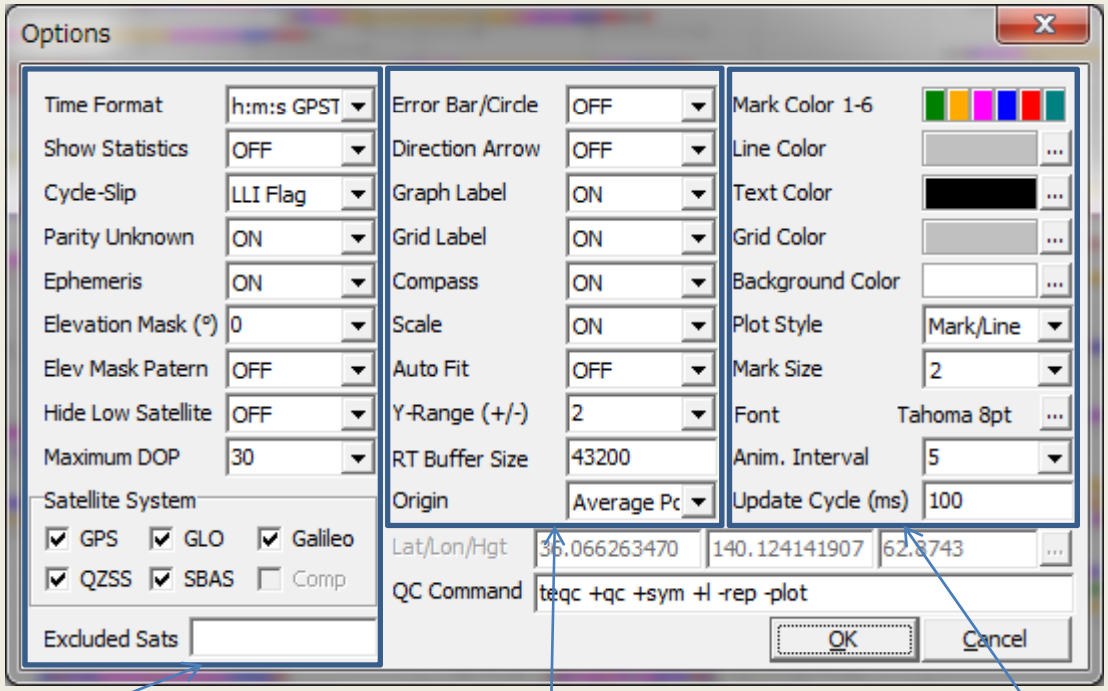
Skyplot





# of Visible Satellites and DOP

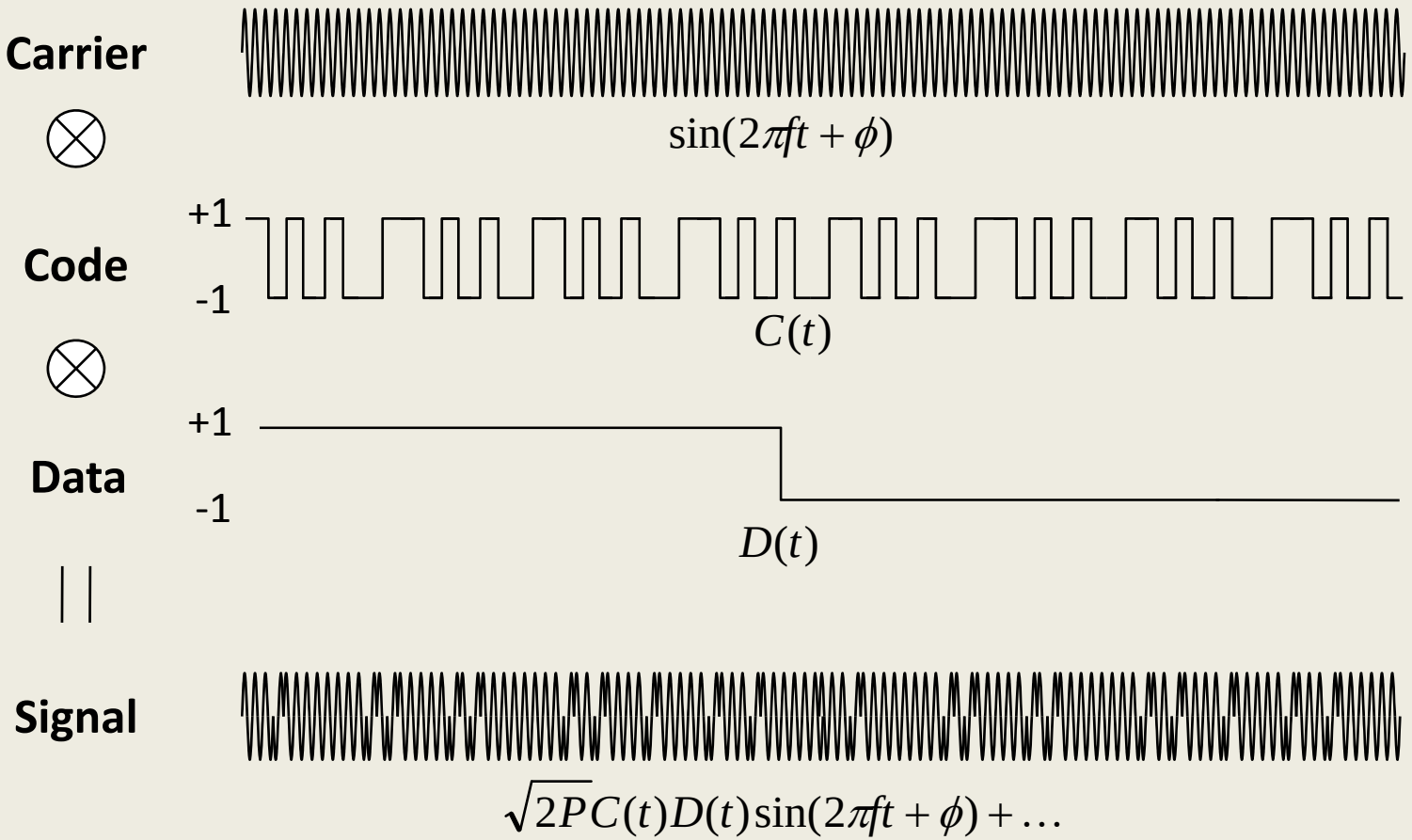
RTKPLOT: Edit - Options



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

2. Signal and Receiver

GNSS Signal Structure

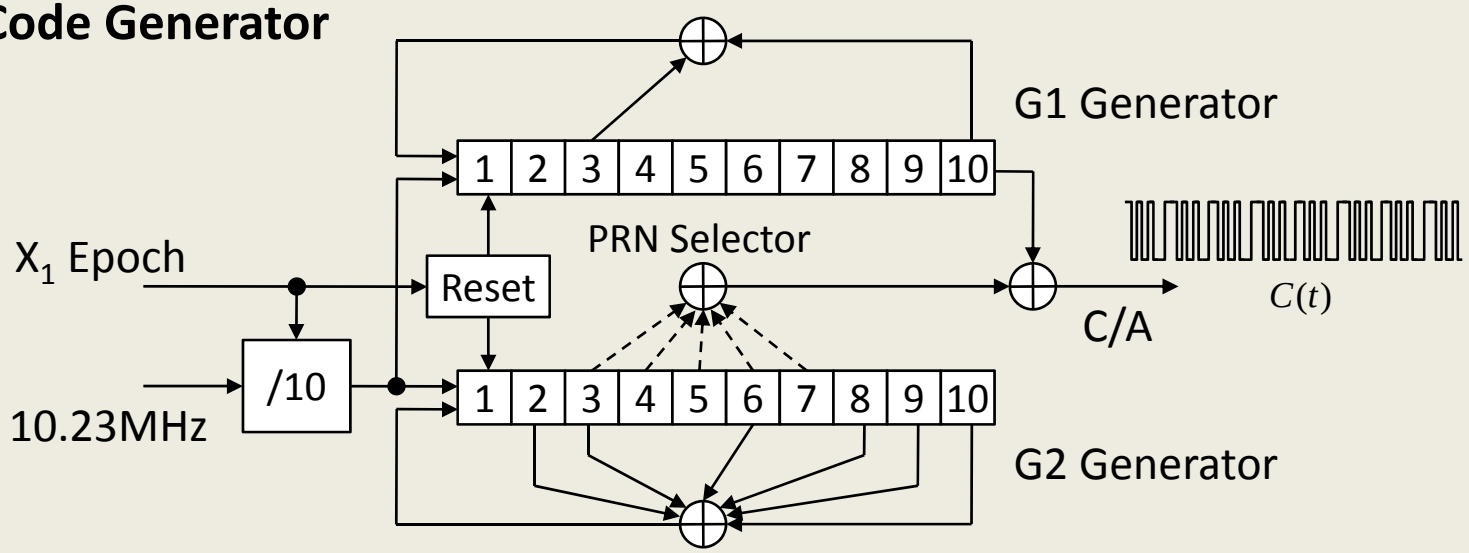


GNSS Signal Specifications

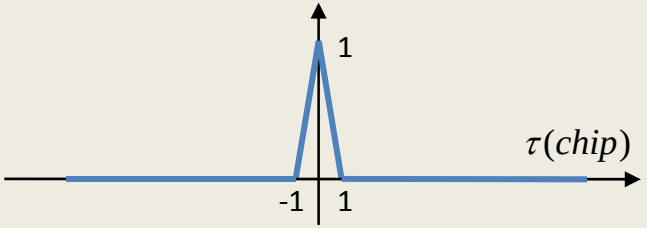
Carrier Freq (MHz)		Code	Modulation	Data Rate	GNSS
L1/E1	1575.42	C/A	BPSK (1)	50 bps	**GPS, QZSS**
				250 bps	**QZSS (L1-SAIF), SBAS**
		P(Y)	BPSK (10)	50 bps	**GPS**
		L1C-d/p	MBOC (6,1,1/11)	-/100 bps	**GPS (IIIA-), Galileo**
		L1C-d/p	BOC (1,1)	-/100 bps	**QZSS**
L1	1602+0.5625K	C/A	BPSK	50 bps	**GLONASS**
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**

PRN (Pseudo-Random Noise) Code

C/A Code Generator

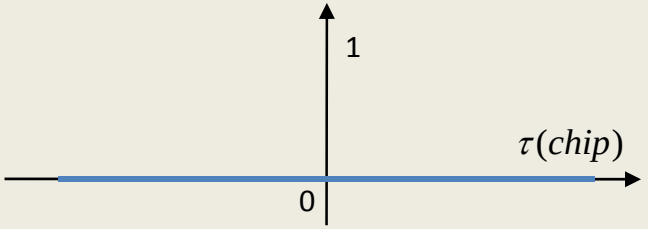


Auto-correlation function



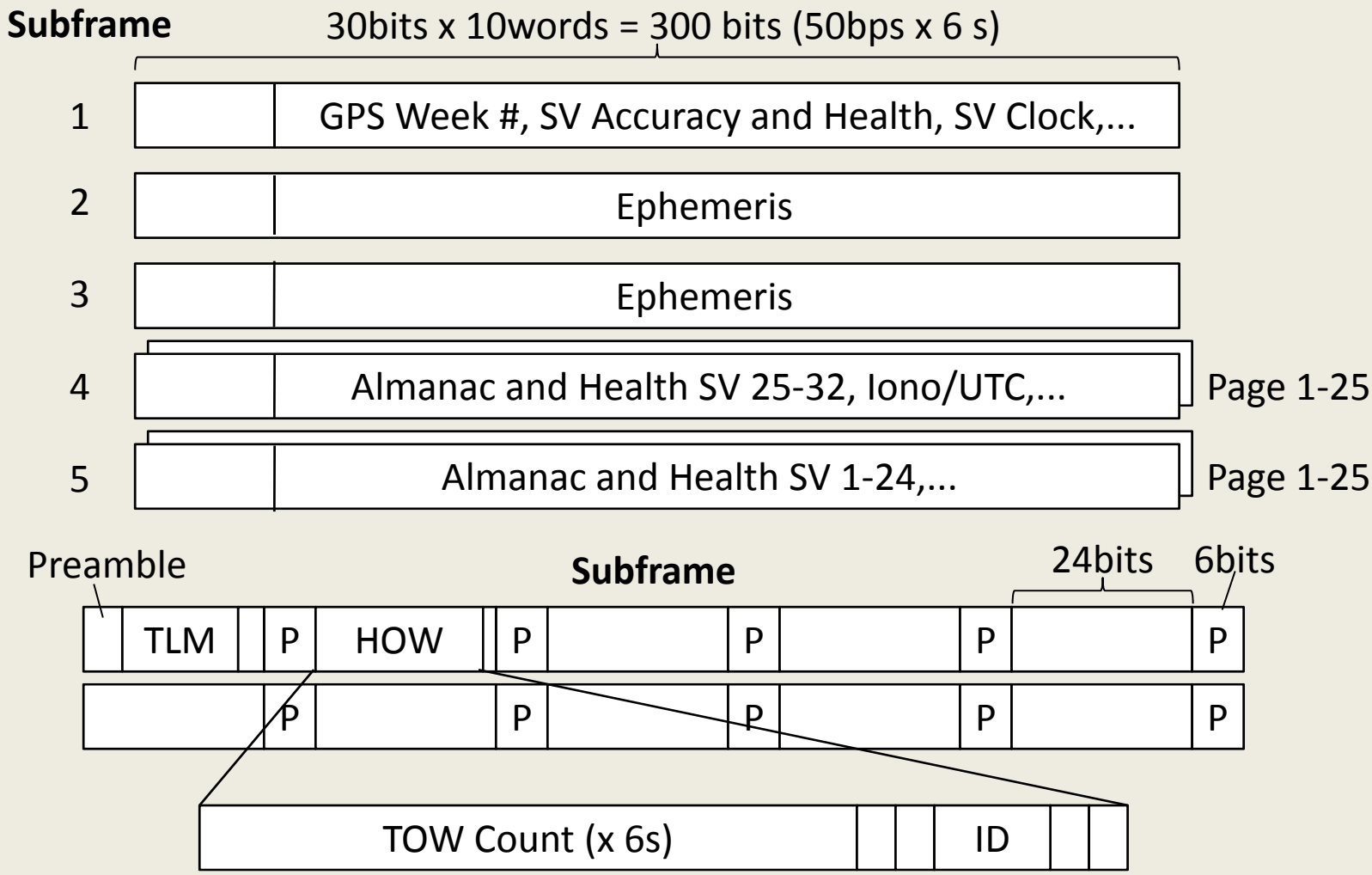
$$R(\tau) = \frac{1}{T}\int_0^T C^i(t)C^i(t-\tau)dt$$

Cross-correlation function



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

GPS Navigation Data

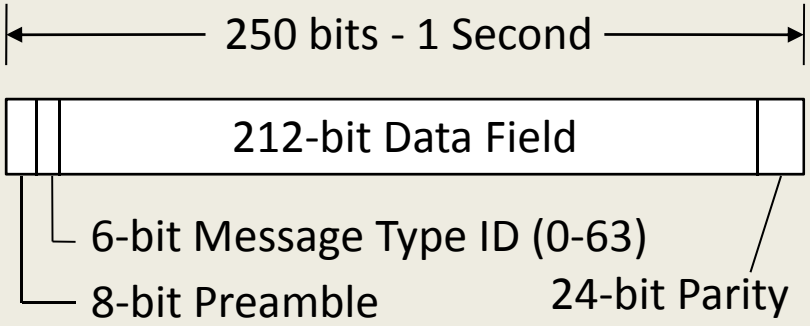


SBAS Message

RTCA/DO-229C

Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment
(Nov 28,2001)

SBAS Message Frame



RTCA: Radio Technical Commission for Aeronautics

MT	Message
0	For WAAS Testing
1	PRN Mask assignment
2-5	Fast Corrections
6	Integrity Information
7	Fast Correction Degration Factor
9	GEO Navigation Messages
10	Degradation Parameters
12	WAAS Network Time/UTC Offset
17	GEO Satellite Almanac
18	Ionospheric Grid Mask
24	Mixed Fast/Long Term Satellite Correct.
25	Long Term Satellite Error Corrections
26	Ionospheric Delay Corrections
27	WAAS Service Messages

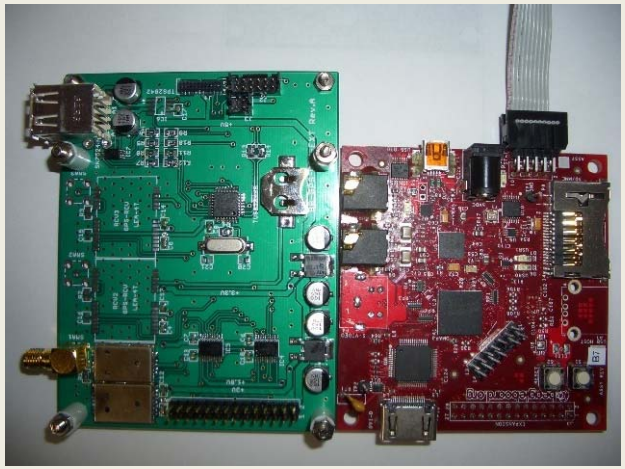
GNSS Receivers

Receiver Products: $20 - $30,000

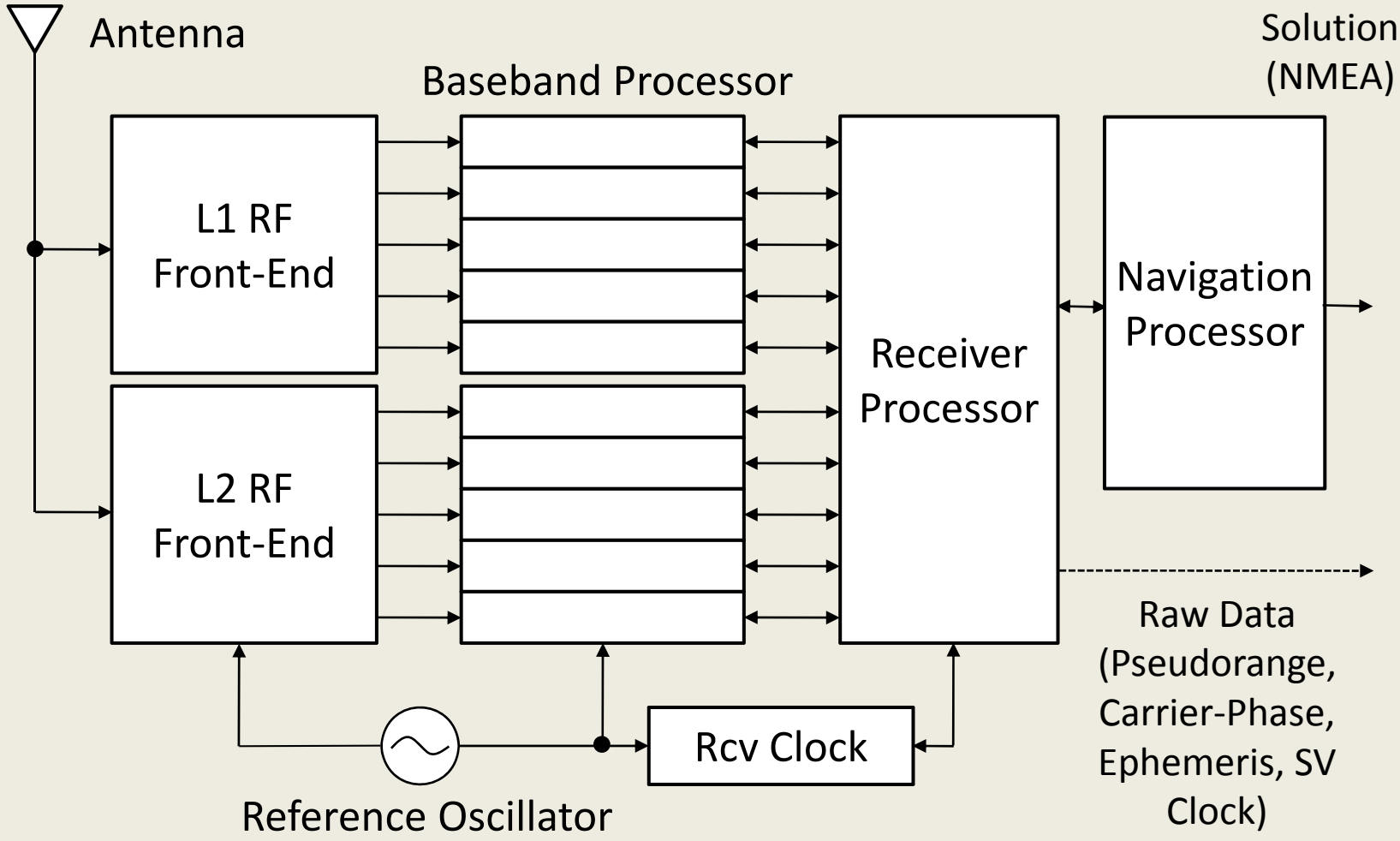



SiRF, u-blox, Garmin, Hemisphere, Trimble, Leica, Topcon, NovAtel, JAVAD, Magellan, ...

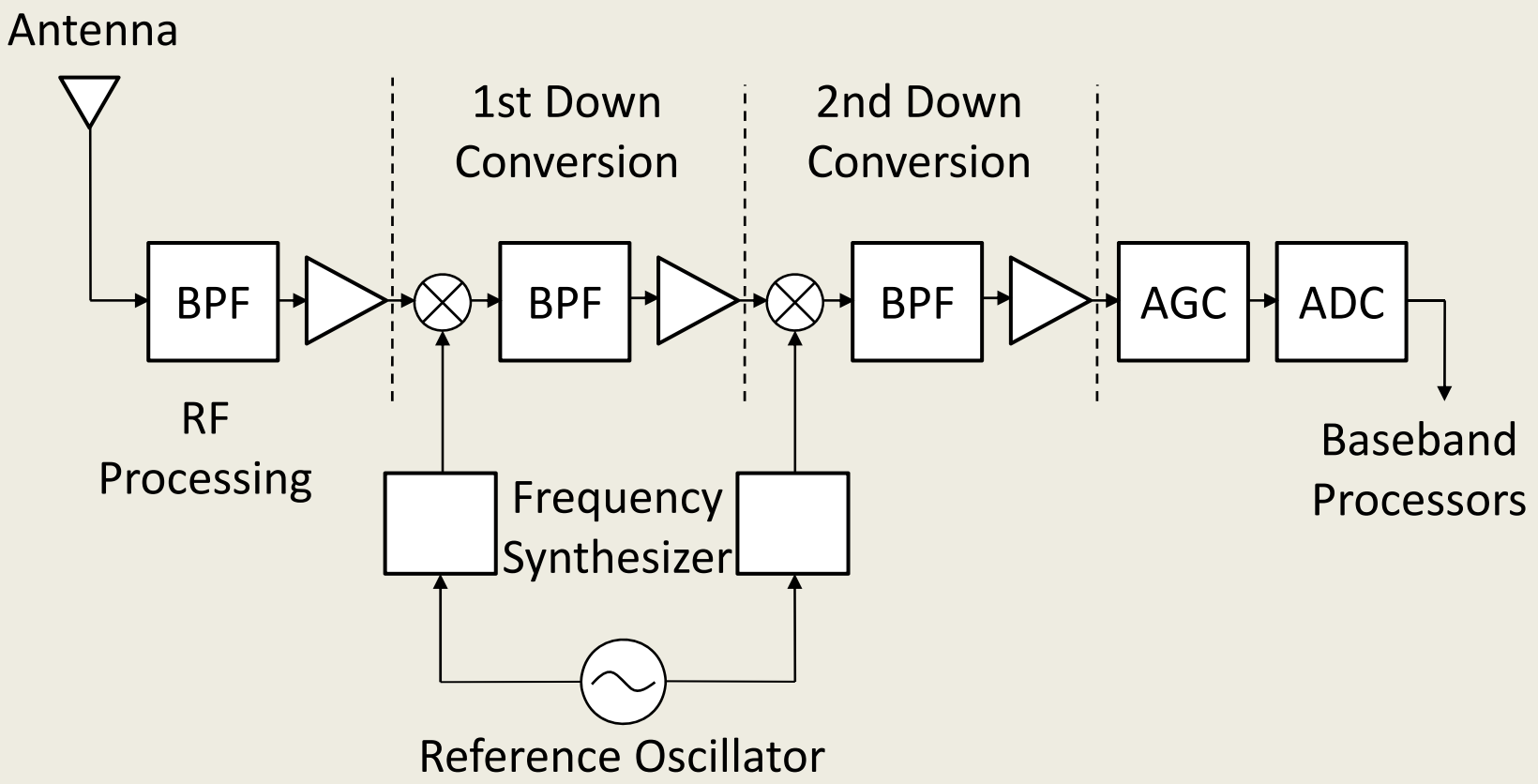
Handmade GPS receiver: $400



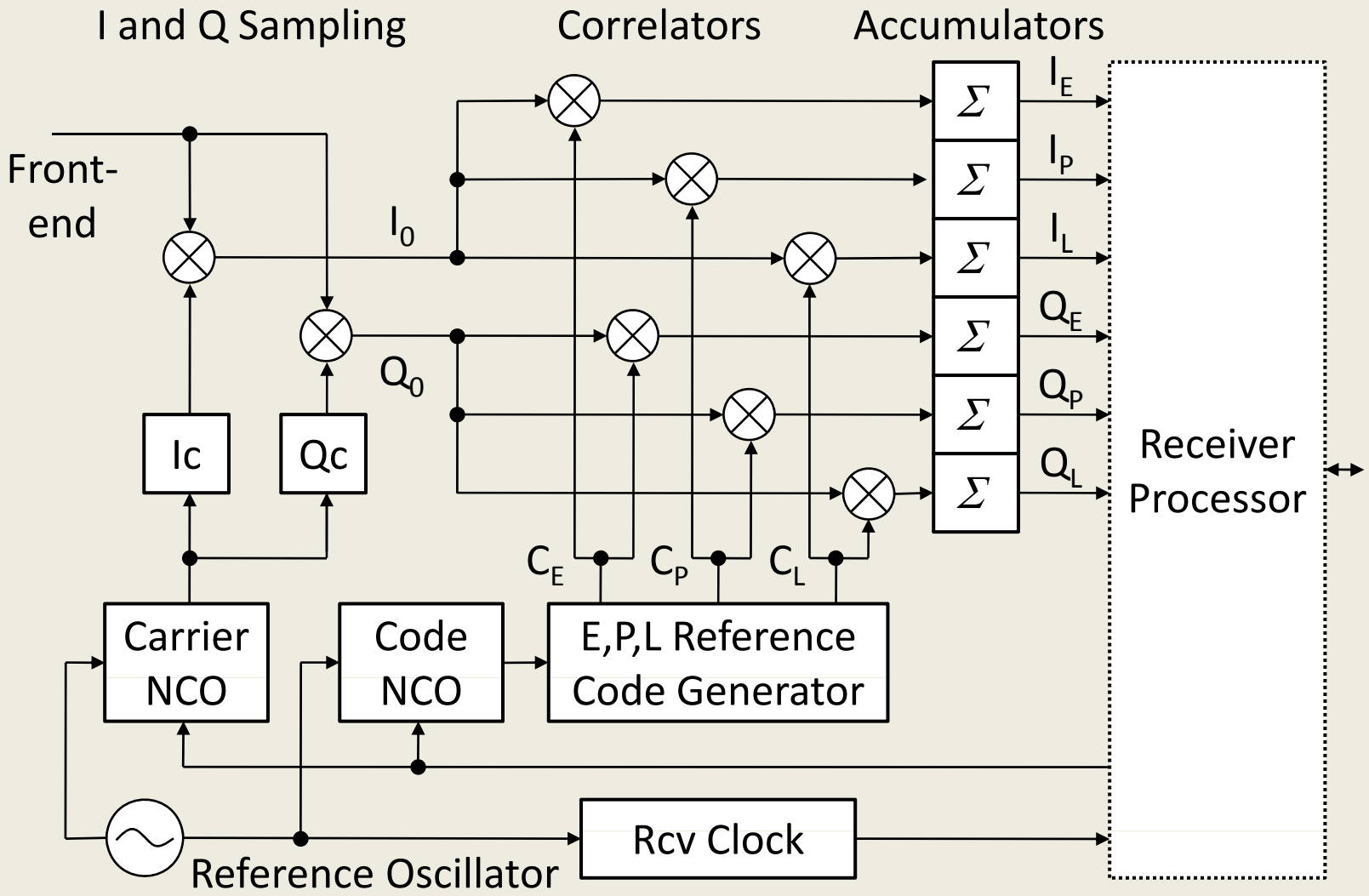

Receiver Architecture



RF Front-End


Antenna
1st Down Conversion
2nd Down Conversion
BPF
BPF
BPF
AGC
ADC
RF Processing
Frequency Synthesizer
Baseband Processors
Reference Oscillator

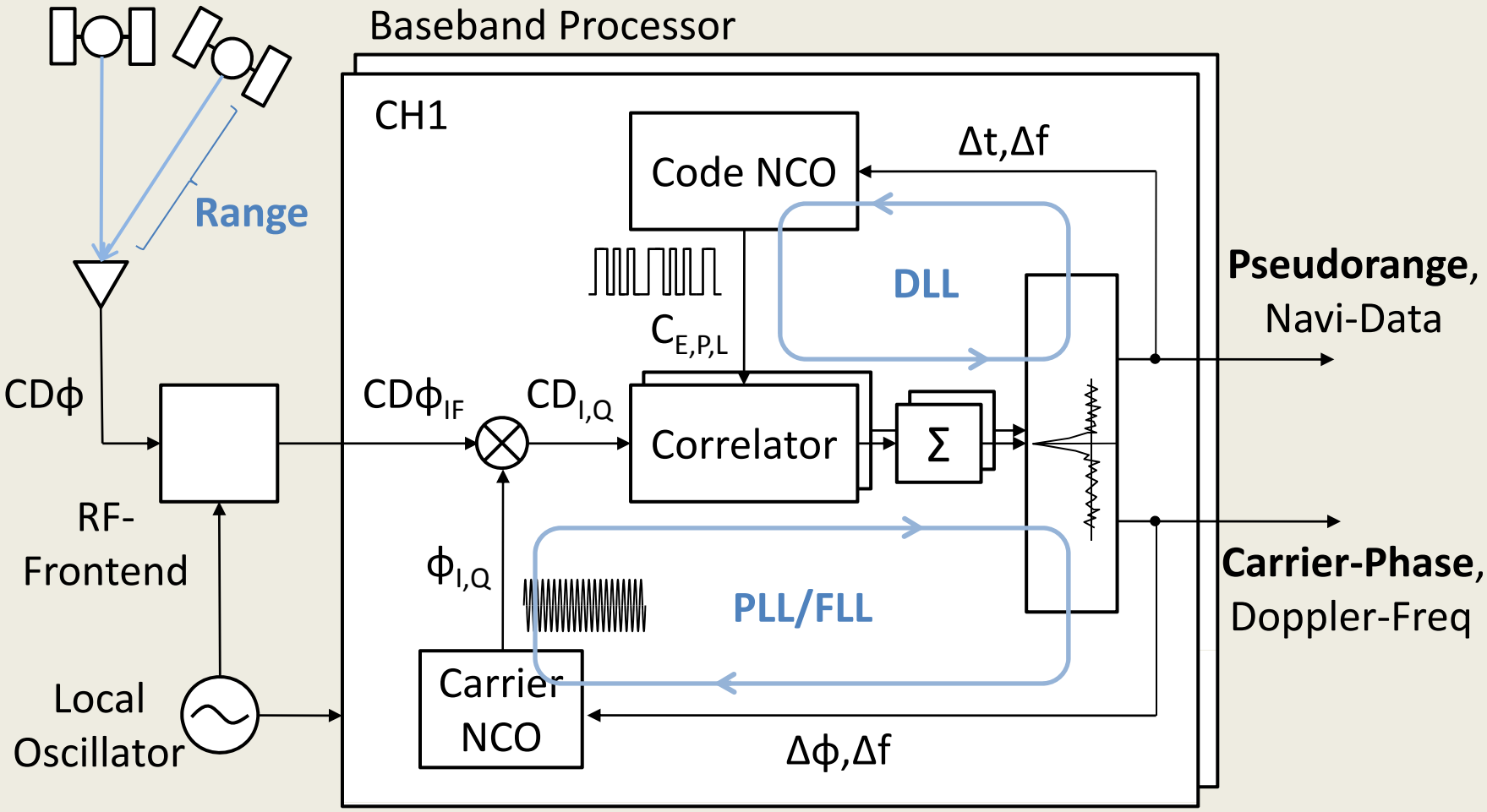
Baseband Processor



Receiver/Navigation Processor

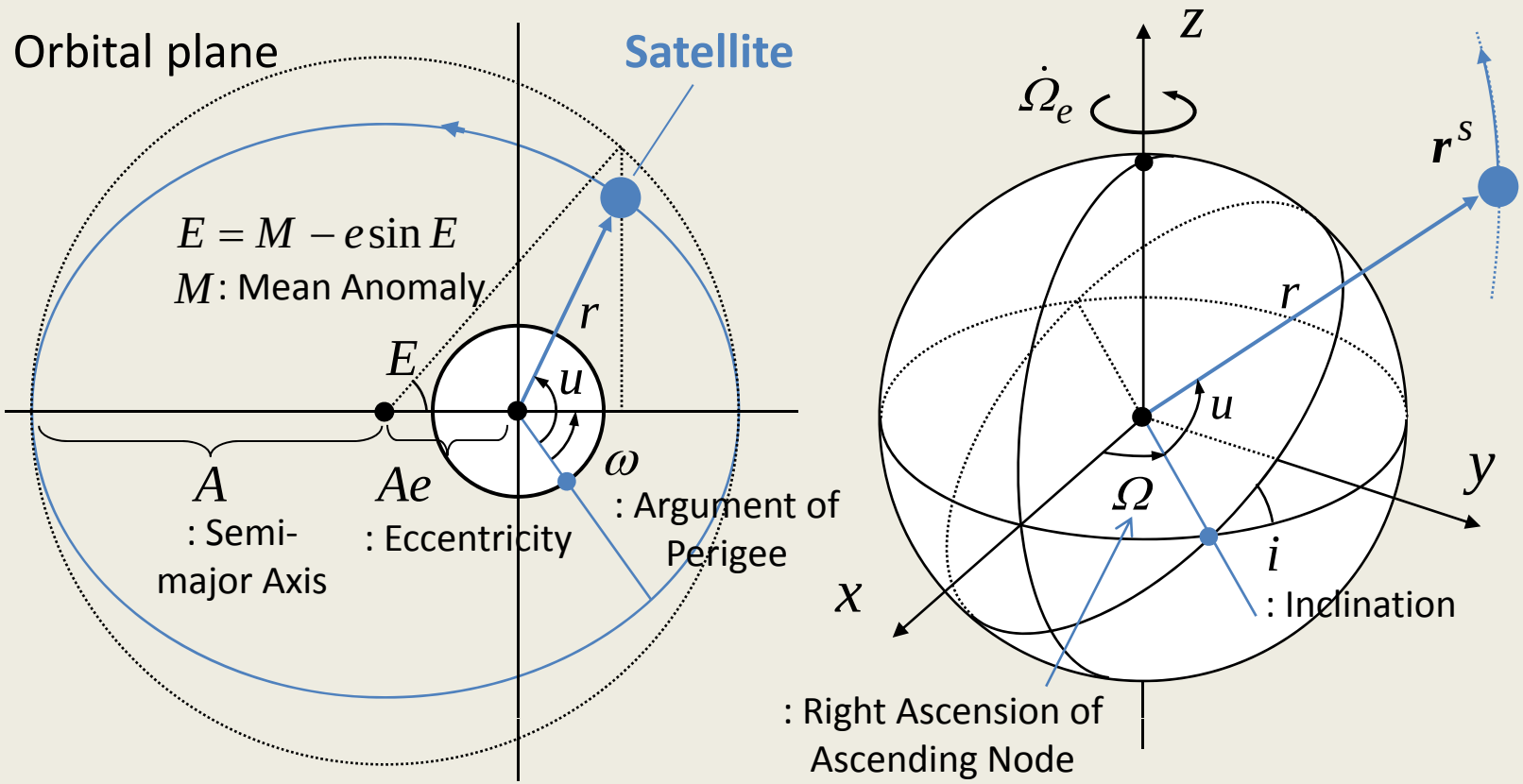
- **Receiver Processor**
  - Acquisition : Search Doppler Shift and Code Phase
  - Code Tracking : DLL (Delay Lock Loop)
  - Carrier Tracking: FLL/PLL (Freq/Phase Lock Loop)
  - Navigation Message Decode (Ephemeris, SV Clock, SBAS,...)
  - Generate Pseudorange, Carrier-Phase, Doppler-Freq
- **Navigation Processor**
  - Navigation Processing (Single Point, DGPS, SBAS, RTK, ...)
  - XYZ to LLH, Geoid model, Code Smoothing
  - Output NMEA

Carrier/Code Tracking



GPS Ephemeris

$$M_0, \Delta n, e, \sqrt{A}, \Omega_0, i_0, \omega, \dot{\Omega}, IDOT, C_{uc}, C_{us}, C_{rc}, C_{rs}, C_{ic}, C_{is}, T_{oe}$$



Satellite Position (XYZ-ECEF)

$$t_k = t - t_{oe}$$

$$n = \sqrt{\mu / A^3} + \Delta n$$

$$M = M_0 + n t_k$$

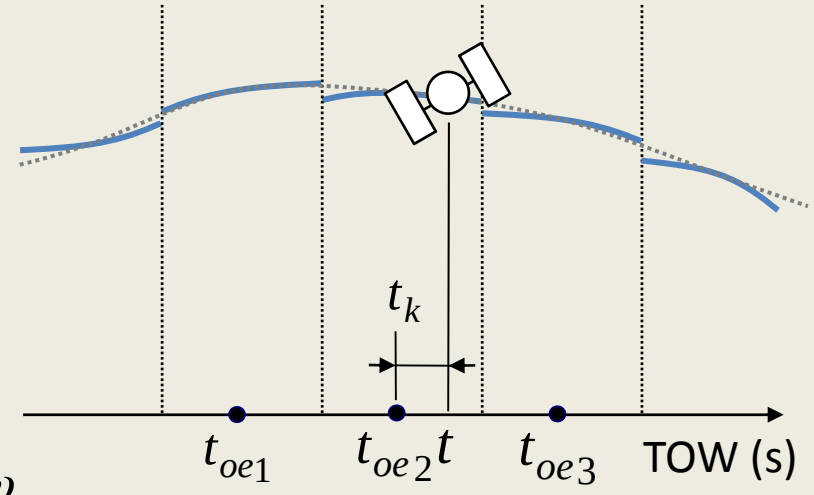
$$E = M + e \sin E \quad \text{: Kepler Equation}$$

$$\phi = ATAN2(\sqrt{1-e^2}\sin E, \cos E - e) + \omega$$

$$\begin{pmatrix} u \\ r \\ i \end{pmatrix} = \begin{pmatrix} \phi \\ A(1 - e\cos E) \\ i_0 + IDOT\ t_k \end{pmatrix} + \begin{pmatrix} C_{us} & C_{uc} \\ C_{rs} & C_{rc} \\ C_{is} & C_{ic} \end{pmatrix} \begin{pmatrix} \sin 2\phi \\ \cos 2\phi \end{pmatrix}$$

$$\Omega = \Omega_0 + (\dot{\Omega} - \omega_e) t_k - \omega_e t_{oe}$$

$$\boldsymbol{r}^s(t) = \boldsymbol{R}_z(-\Omega)\boldsymbol{R}_x(-i)(r\cos u, r\sin u, 0)^T$$



$$\boldsymbol{R}_x(\theta) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix}$$

$$\boldsymbol{R}_y(\theta) = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix}$$

$$\boldsymbol{R}_z(\theta) = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

GPS SV Clock Parameters

$$a_{f0}, a_{f1}, a_{f2}, T_{GD}, t_{oc}$$

Satellite Clock Bias

$$dT(t) = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_{rel} + \Delta t_{GD}$$

Relativity Correction:

$$\Delta t_{rel} = \frac{-2\sqrt{\mu A}e \sin E}{c^2}$$

Group Delay Correction:

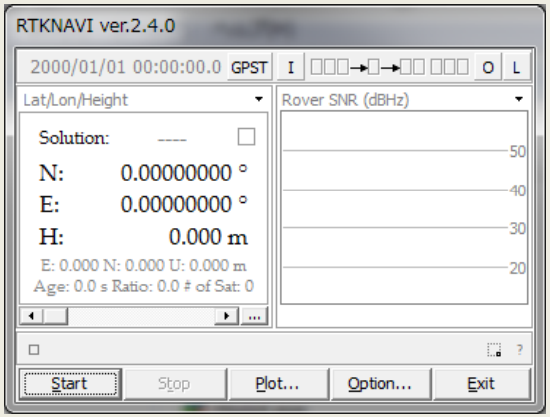
$$\Delta t_{GD} = \begin{cases} -T_{GD} & (L1) \\ -\gamma T_{GD} & (L2) \quad (\gamma = f_1^2 / f_2^2) \\ 0 & (LC) \end{cases}$$

2. Signal and Receiver: Exercise

Monitor Receiver Output Data

- **Objective**
  monitor receiver output data
- **Program**
  ...¥rtklib_2.4.0¥bin¥rtknavi.exe
  ...¥rtklib_2.4.1b¥bin¥rtknavi.exe
- **Data**
  ...¥seminar¥sample2¥
  ubx_20090515c.ubx (u-blox)
  oemv_2009515c.gps (NovAtel)

RTKLIB - RTKNAVI

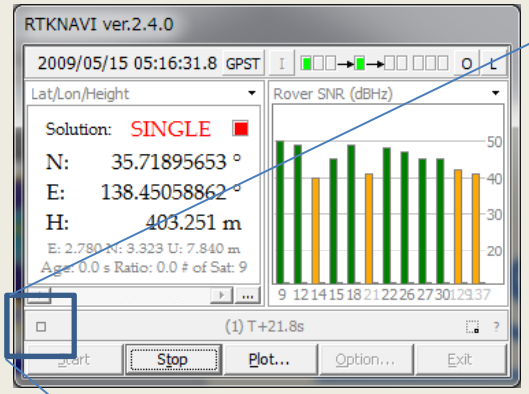


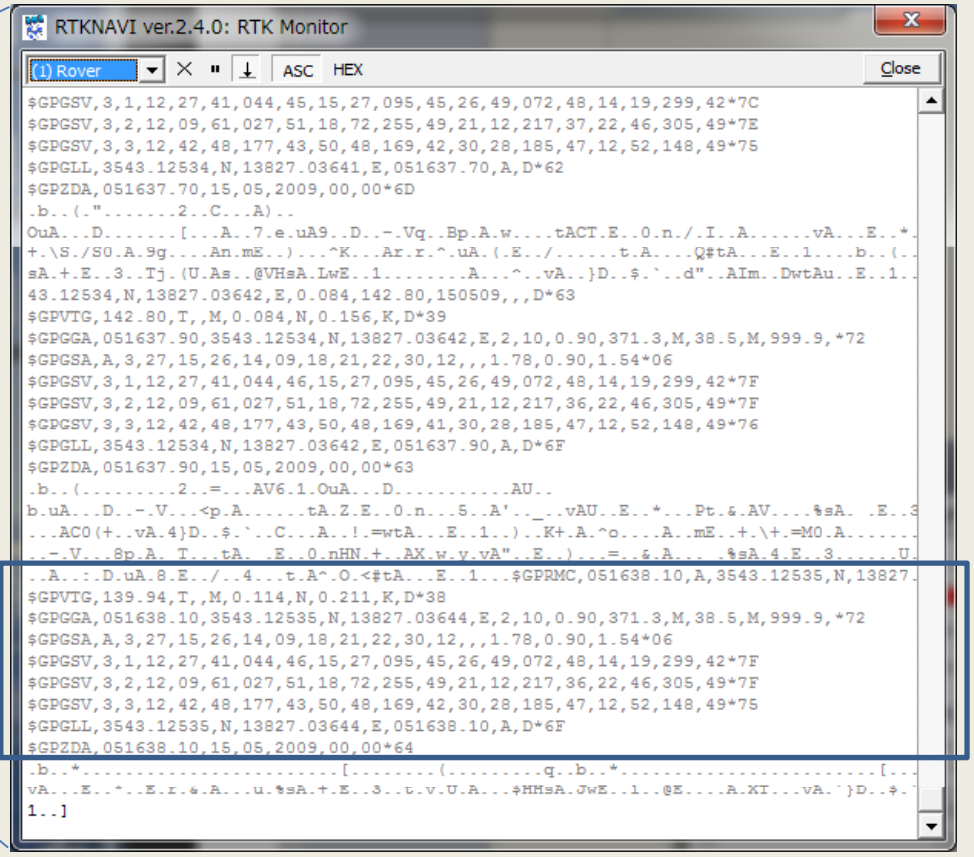
u-blox AEK-4T (LEA-4T)

NovAtel OEMV-3G

Output of u-blox

RTK Monitor





NMEA0183:

$GPRMC : Recommended minimum data for GPS

$GPGGA : Fix Information

$GPGSA : Overall Satellite Data

$GPGSV : Derailed Satellite Data

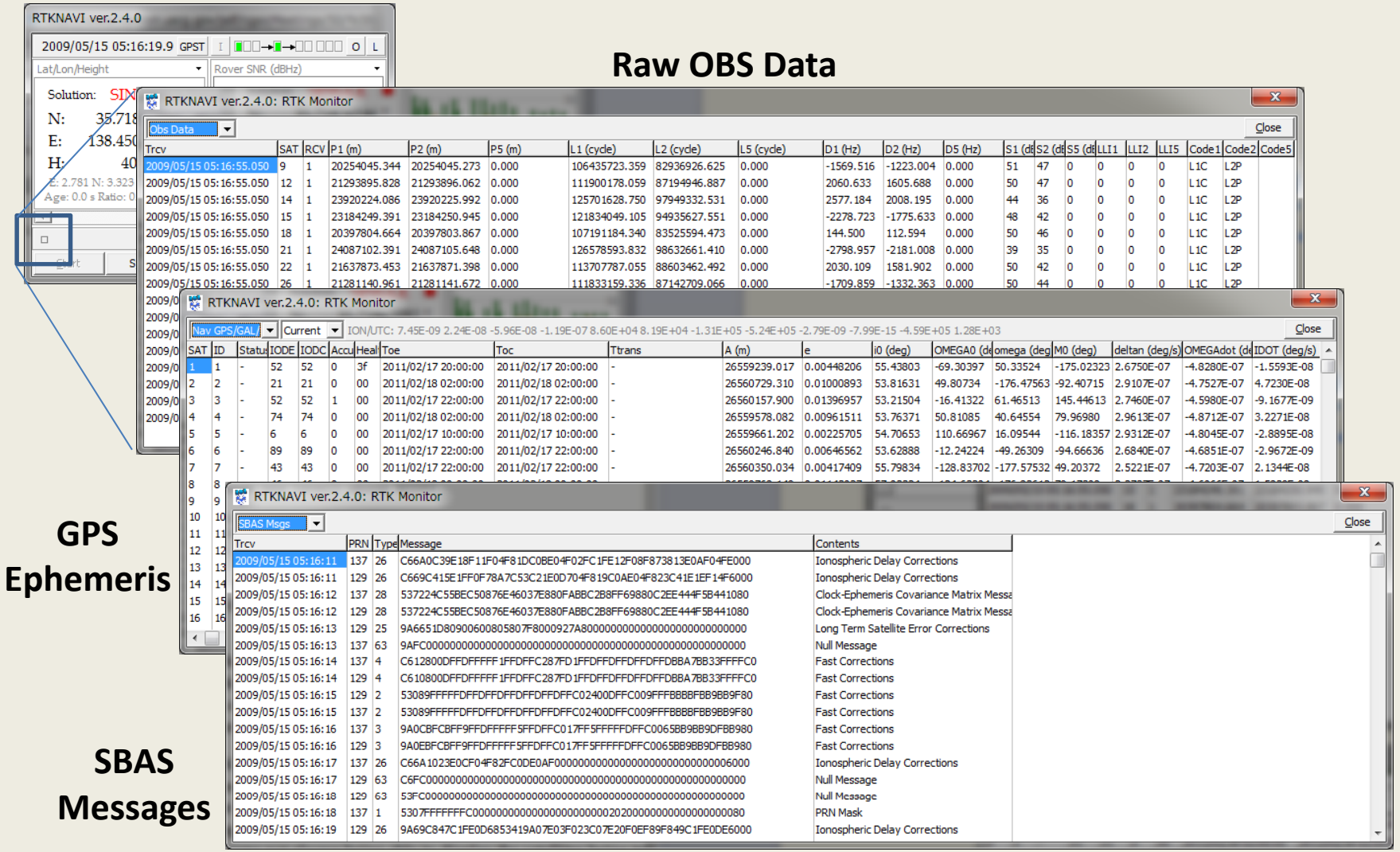
$GPGLL : Lat/Lon Data, ...

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Time (UTC) Latitude Longitude # of Sats Altitude Geoid Height

Quality HDOP

Output of NovAtel



Raw OBS Data

GPS Ephemeris

SBAS Messages

3. Standard Positioning

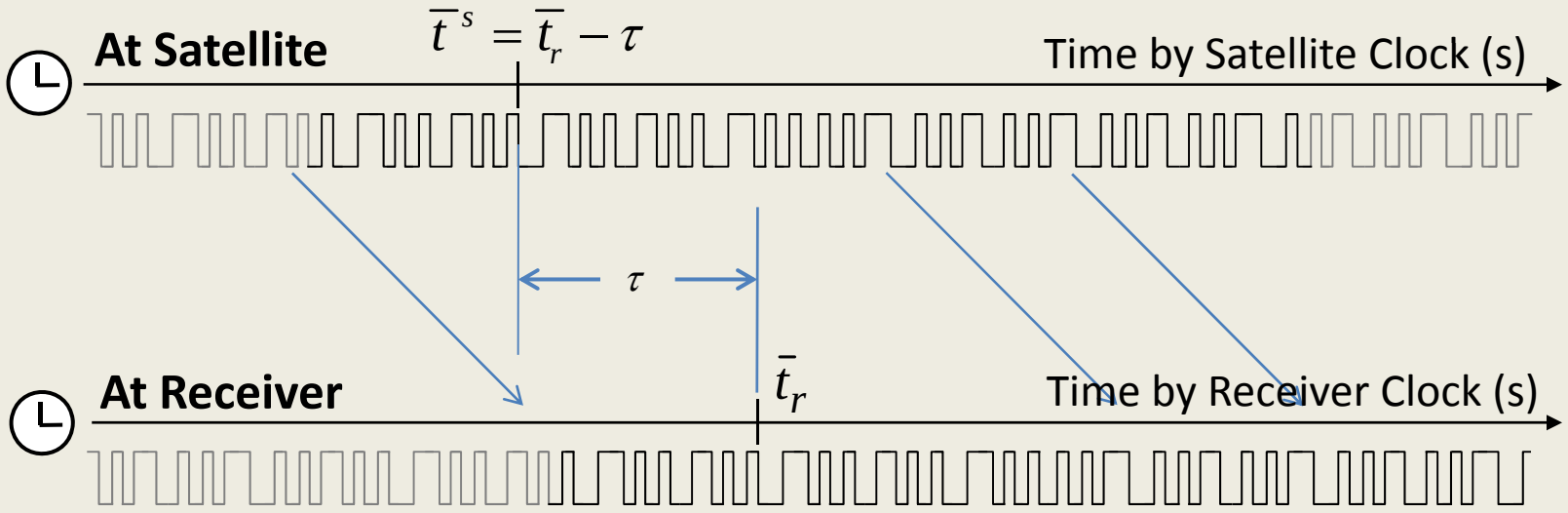
Pseudorange

Definition:

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

(m)

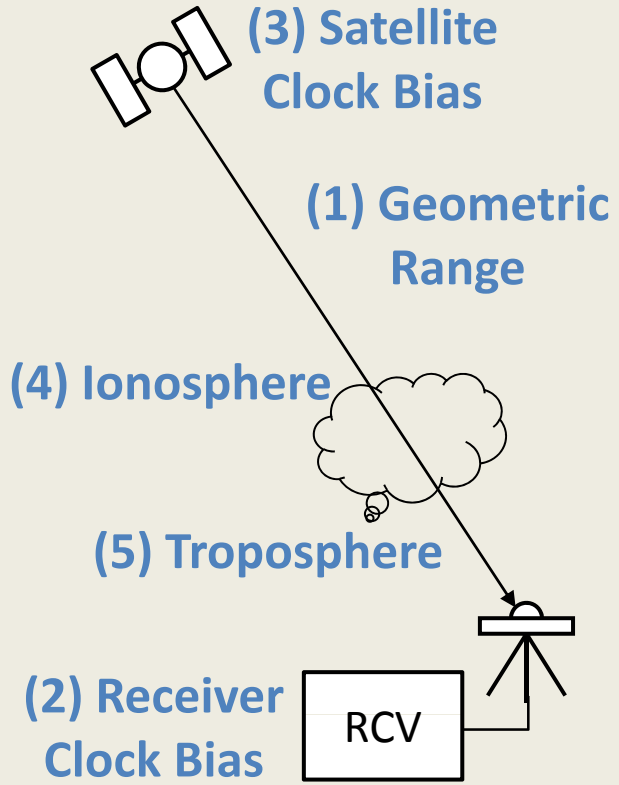
The pseudo-range (PR) is the distance from the receiver antenna to the satellite antenna including receiver and satellite clock offsets (and other biases, such as atmospheric delays) *(RINEX 2.10)*



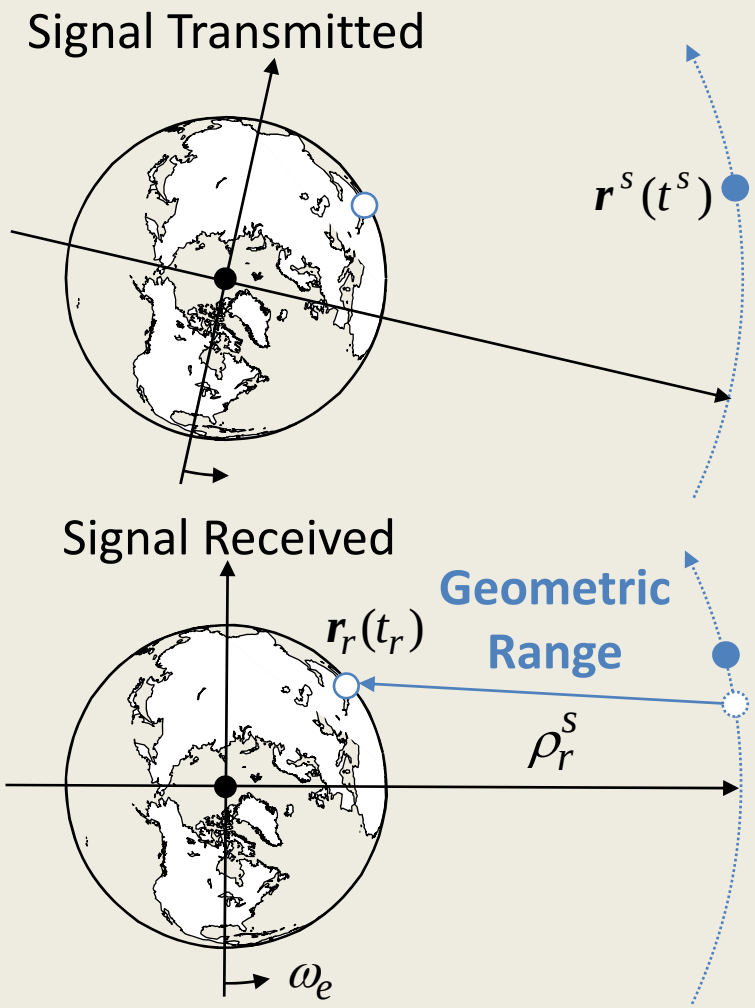
Pseudorange Model

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

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



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)

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

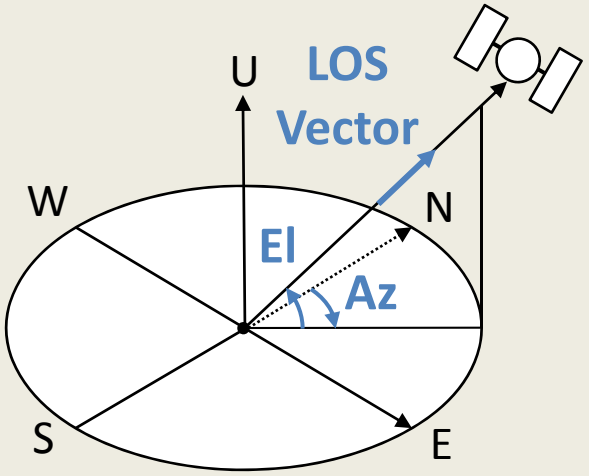
Sagnac Effect Correction

LOS (Line-of-Sight) Vector

LOS Vector:

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

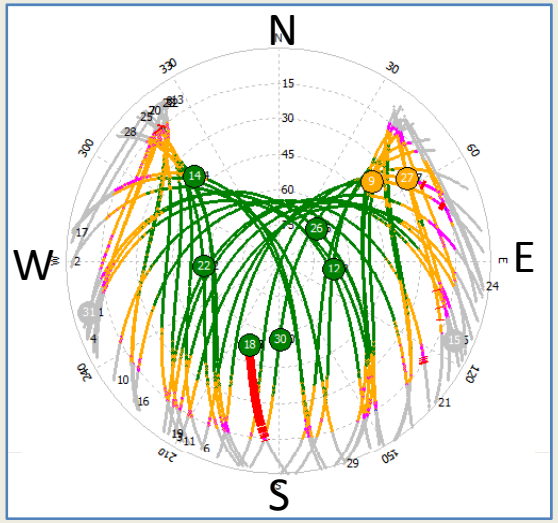
$$\boldsymbol{E}_{ecef \to enu} = \begin{pmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\phi\cos\lambda & -\sin\phi\sin\lambda & \cos\phi \\ \cos\phi\cos\lambda & \cos\phi\sin\lambda & \sin\phi \end{pmatrix}$$



Satellite Azimuth/Elevation Angle:

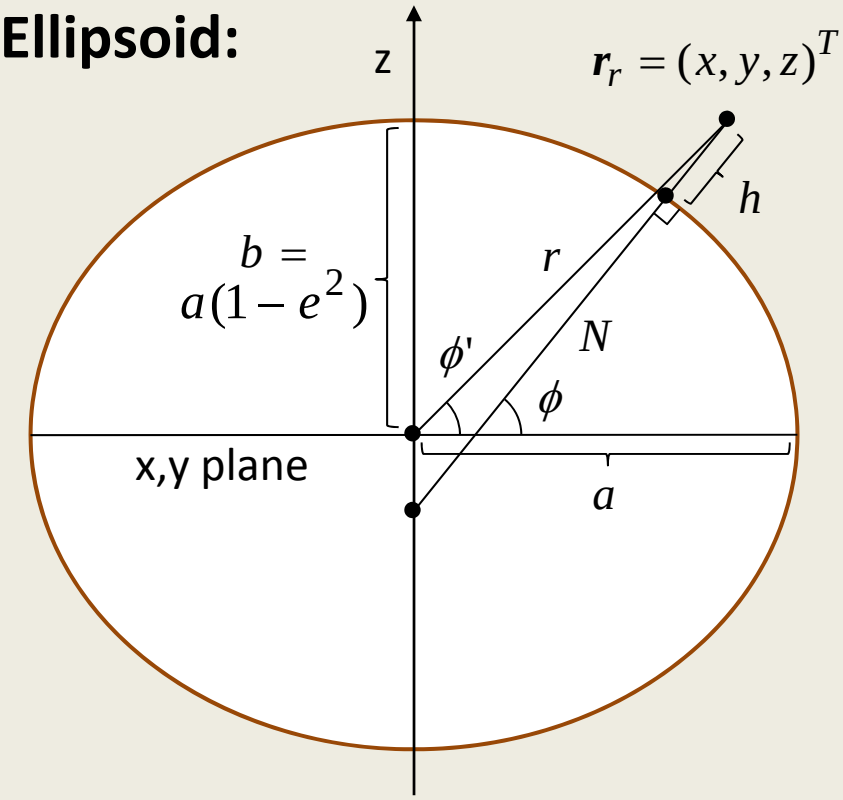
$$Az = \mathrm{ATAN2}(e_e, e_n)$$

$$El = \arcsin e_u$$



Ellipsoid and Datum

Reference Ellipsoid:



	GRS 80	WGS 84
a (m)	6378137	6378137
f	1/298.257222 101	1/298.257223 563
GM (m^3/s^2)	3986005.000 x 10^8	3986004.418 x 10^8

ϕ' : Geocentric Latitude λ : Longitude

ϕ : Geodetic Latitude h : Ellipsoidal Height

Lat/Lon/Height to X/Y/Z-ECEF:

$$e^2 = f(2 - f)$$

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 \phi}}$$

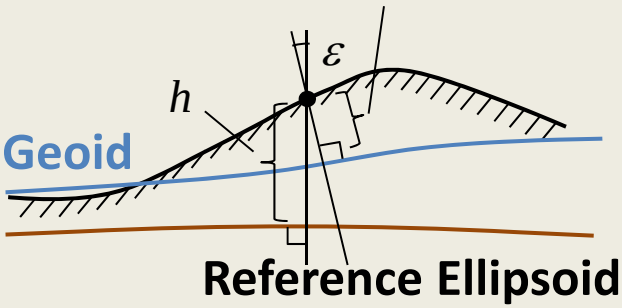
$$\boldsymbol{r}_r = \begin{pmatrix} (N + h)\cos\phi\cos\lambda \\ (N + h)\cos\phi\sin\lambda \\ (N(1 + e^2) + h)\sin\phi \end{pmatrix}$$

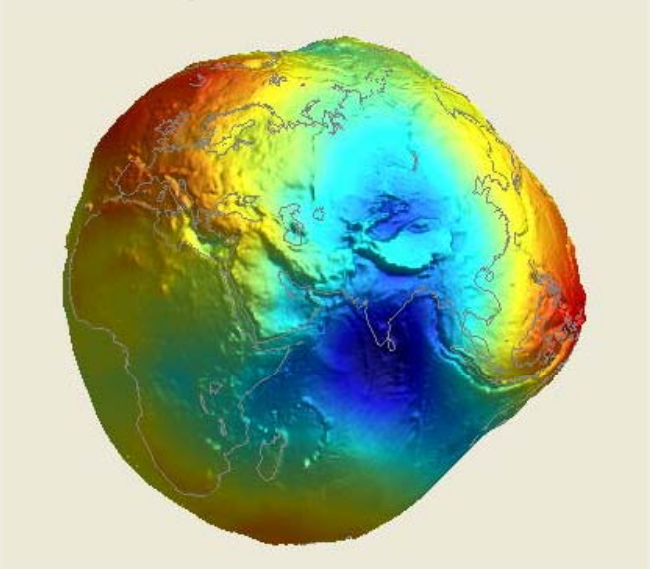
Geoid

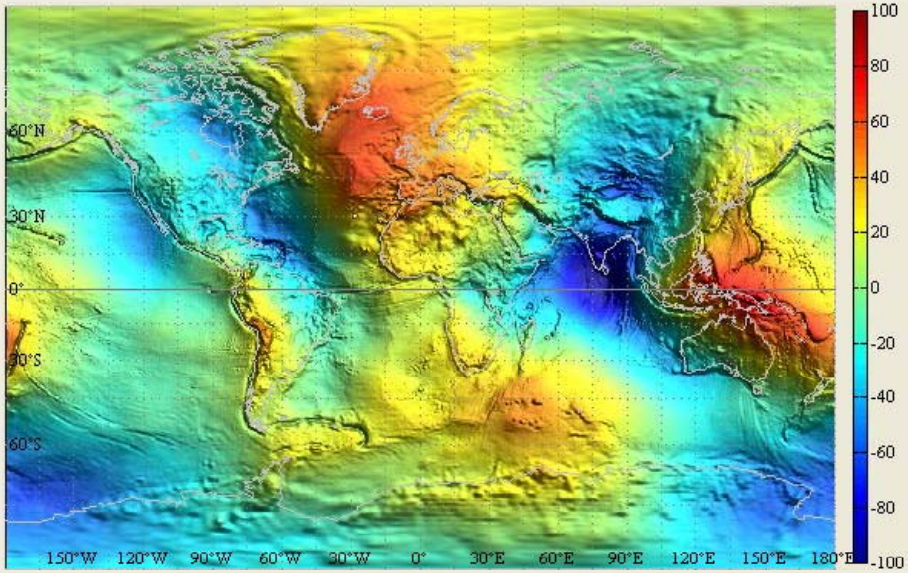
Geopotential:

$$V(r,\phi',\lambda) = \frac{GM}{r}\left\{1 + \sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^n (\bar{C}_{nm}Y_{nmc} + \bar{S}_{nm}Y_{nms})\right\}$$

H : **Geodetic Height**







EGM96 Geoid Model (m)

Ionospheric Model

$$\alpha_0, \alpha_1, \alpha_2, \alpha_3, \beta_0, \beta_1, \beta_2, \beta_3$$

Klobuchar Model:

$$\psi = 0.0137/(El + 0.11) - 0.022$$

$$\phi_i = \phi + \psi \cos Az$$

$$\lambda_i = \lambda + \psi \sin Az / \cos\phi_i$$

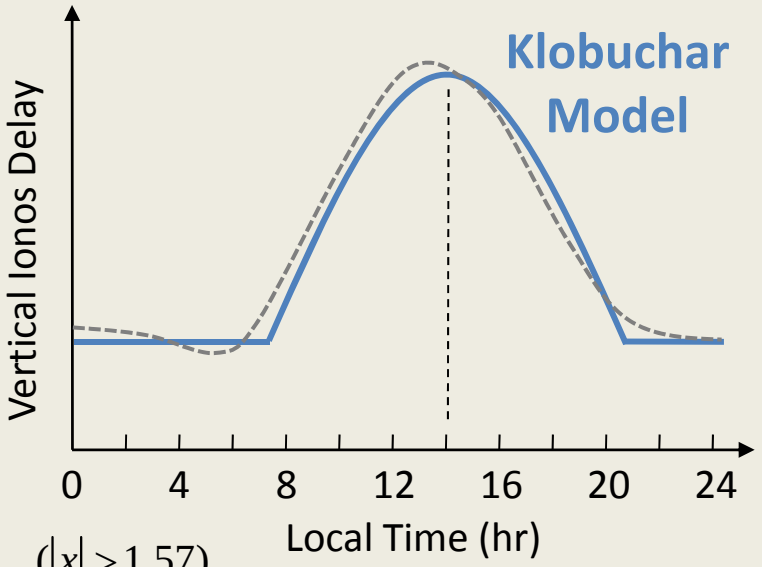
$$\phi_m = \phi_i + 0.064\cos(\lambda_i - 1.617)$$

$$t = 4.32 \times 10^4 \lambda_i + t$$

$$F = 1.0 + 16.0 \times (0.53 - El)^3$$

$$x = 2\pi(t - 50400) / \sum_{n=0}^{3} \beta_n {\phi_m}^n$$

$$I = \begin{cases} F \times 5 \times 10^{-9} & (|x| > 1.57) \\ F \times \left(5 \times 10^{-9} + \sum_{n=1}^{4} \alpha_n {\phi_m}^n \times \left(1 - \frac{x^2}{2} + \frac{x^4}{24} \right) \right) & (|x| \le 1.57) \end{cases}$$



Troposphere Model

Standard Atmosphere:

$$p = 1013.25 \times (1 - 2.2557 \times 10^{-5} H)^{5.2568}$$

$$T = 15.0 - 6.5 \times 10^{-3} H + 273.15$$

$$e = 6.108 \times \exp\left\{\frac{17.15\mathrm{T} - 4684.0}{\mathrm{T} - 38.45}\right\} \times \frac{h_{rel}}{100}$$

p : Pressure (hPa)

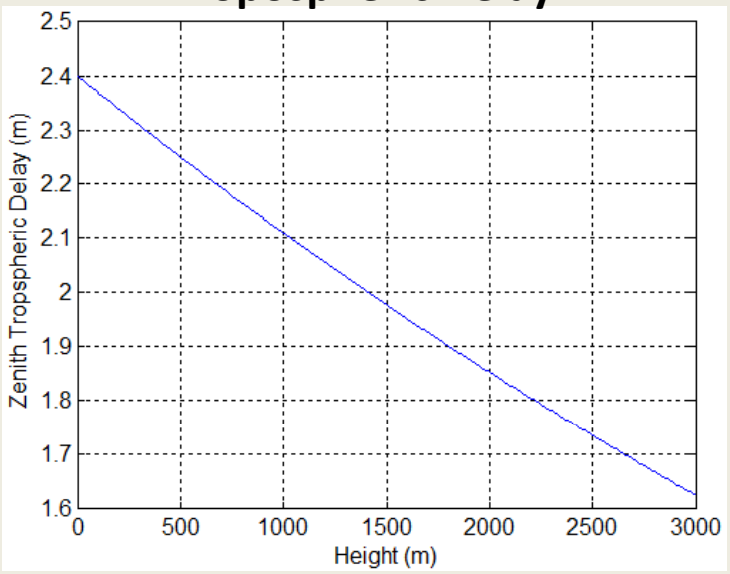
H : Geopotential Height (m)

T : Temperature (K)

e : Partial Pressure of WV (hPa)

h_{rel} : Relative Humidity (%)

Tropospheric Delay



h_{rel}=50%, z=90°

Saastamoinen Model:

$$T_r^s = \frac{0.002277}{\cos z}\left\{p + \left(\frac{1255}{T} + 0.05\right)e - \tan^2 z\right\}$$

(z : Zenith Angle)

LSE (Least Square Estimation)

Measurement Equation:

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{v}$$

$\boldsymbol{y}$: Measurement vector $\quad \boldsymbol{H}$: Design matrix

$\boldsymbol{x}$: Parameter vector $\quad \boldsymbol{v}$: Residual vector

$$J_{LS} = v_1^2 + v_2^2 + \ldots + v_m^2 = \boldsymbol{v}^T\boldsymbol{v} = (\boldsymbol{y} - \boldsymbol{H}\boldsymbol{x})^T(\boldsymbol{y} - \boldsymbol{H}\boldsymbol{x})$$

$$= \boldsymbol{y}^T\boldsymbol{y} - \boldsymbol{y}^T\boldsymbol{H}\boldsymbol{x} - \boldsymbol{x}^T\boldsymbol{H}^T\boldsymbol{y} + \boldsymbol{x}^T\boldsymbol{H}^T\boldsymbol{H}\boldsymbol{x} \rightarrow \min$$

$$\frac{\partial J_{LS}}{\partial \boldsymbol{x}} = \boldsymbol{0}^T - \boldsymbol{y}^T\boldsymbol{H} - (\boldsymbol{H}^T\boldsymbol{y})^T + (\boldsymbol{H}^T\boldsymbol{H}\boldsymbol{x})^T + \boldsymbol{x}^T\boldsymbol{H}^T\boldsymbol{H}$$

$$= -2\boldsymbol{y}^T\boldsymbol{H} + 2\boldsymbol{x}^T\boldsymbol{H}^T\boldsymbol{H} = \boldsymbol{0}$$

Normal Equation (NEQ):

$$\boldsymbol{H}^T\boldsymbol{H}\hat{\boldsymbol{x}} = \boldsymbol{H}^T\boldsymbol{y} \rightarrow \hat{\boldsymbol{x}} = (\boldsymbol{H}^T\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{y}$$

Weighted LSE:

$$\hat{\boldsymbol{x}} = (\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{y} \quad (J_{WLS} = \boldsymbol{v}^T\boldsymbol{W}\boldsymbol{v} \rightarrow \min)$$

Non-linear LSE

Measurement Equation:

$$y = h(x) + v$$

$$h(x) = h(x_0) + H(x - x_0) + \ldots \quad \text{: Taylor Polynomial}$$

$$y \approx h(x_0) + H(x - x_0) + v$$

$$y - h(x_0) = H(x - x_0) + v$$

$$H^T H(\hat{x} - x_0) = H^T (y - h(x_0))$$

$$\hat{x} = x_0 + (H^T H)^{-1} H^T (y - h(x_0))$$

$$\left(H = \left. \frac{\partial h(x)}{\partial x} \right|_{x = x_0} \right)$$

Partial Derivatives

Iterative Solution (Gauss-Newton):

$$\hat{x}_{i+1} = \hat{x}_i + (H^T H)^{-1} H^T (y - h(\hat{x}_i))$$

$$\hat{x} = \lim_{i \to \infty} \hat{x}_i$$

Navigation Processing

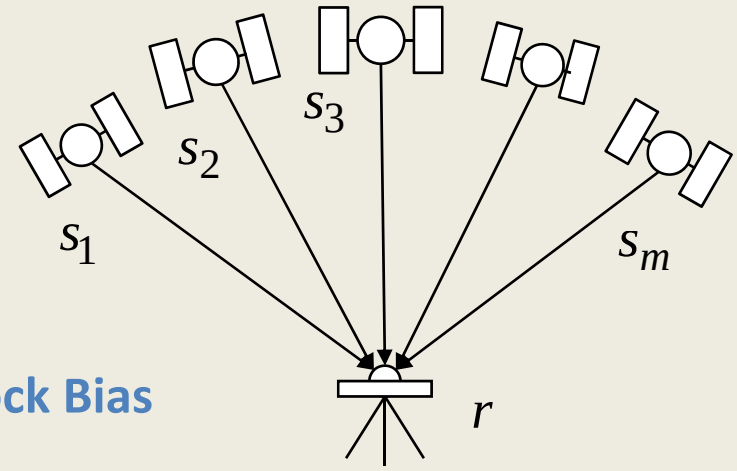
$$\boldsymbol{x} = (\boldsymbol{r}_r{}^T, cdt)^T, \quad \boldsymbol{y} = (P_r^{s_1}, P_r^{s_2}, P_r^{s_3}, ..., P_r^{s_m})^T$$

$$\boldsymbol{h}(\hat{\boldsymbol{x}}) = \begin{pmatrix} \rho_r^{s_1} + c\hat{dt} - cdT^{s_1} + I_r^{s_1} + T_r^{s_1} \\ \rho_r^{s_2} + c\hat{dt} - cdT^{s_2} + I_r^{s_2} + T_r^{s_2} \\ \rho_r^{s_3} + c\hat{dt} - cdT^{s_3} + I_r^{s_3} + T_r^{s_3} \\ \vdots \\ \rho_r^{s_m} + c\hat{dt} - cdT^{s_m} + I_r^{s_m} + T_r^{s_m} \end{pmatrix} \quad \boldsymbol{H} = \begin{pmatrix} -\boldsymbol{e}_r^{s_1}{}^T & 1 \\ -\boldsymbol{e}_r^{s_2}{}^T & 1 \\ -\boldsymbol{e}_r^{s_3}{}^T & 1 \\ \vdots & \vdots \\ -\boldsymbol{e}_r^{s_m}{}^T & 1 \end{pmatrix}$$

$$\hat{\boldsymbol{x}}_0 = (0,0,0,0)^T$$

$$\hat{\boldsymbol{x}}_{i+1} = \hat{\boldsymbol{x}}_i + (\boldsymbol{H}^T\boldsymbol{H})^{-1}\boldsymbol{H}^T(\boldsymbol{y} - \boldsymbol{h}(\hat{\boldsymbol{x}}_i))$$

$$\hat{\boldsymbol{x}} = \lim_{i\to\infty} \hat{\boldsymbol{x}}_i = (\hat{\boldsymbol{r}}_r{}^T, c\hat{dt})^T$$



Single-Point Solution + Receiver Clock Bias

Solution Convergence

Estimated Parameters in LSE Iteration Loop

i	x (m)	y (m)	z (m)	cdt (m)
(0) X=	0.0000000	0.0000000	0.0000000	0.0000000
(1) X=	-4739338.8790644	3968053.3426383	4470195.0681293	1290751.6350707
(2) X=	-3990084.5939062	3334559.7805777	3763444.6383541	50195.3310677
(3) X=	-3957255.7455862	3310242.1098583	3737755.6233736	510.7878812
(4) X=	-3957205.2229884	3310203.7001970	3737718.0508664	432.5789153
(5) X=	-3957205.1820501	3310203.6651692	3737718.0078941	432.4910365
(6) X=	-3957205.1820116	3310203.6651363	3737718.0078537	432.4909539
(7) X=	-3957205.1820116	3310203.6651363	3737718.0078536	432.4909538
(8) X=	-3957205.1820116	3310203.6651363	3737718.0078536	432.4909538
(9) X=	-3957205.1820116	3310203.6651363	3737718.0078536	432.4909538
(10) X=	-3957205.1820116	3310203.6651363	3737718.0078536	432.4909538

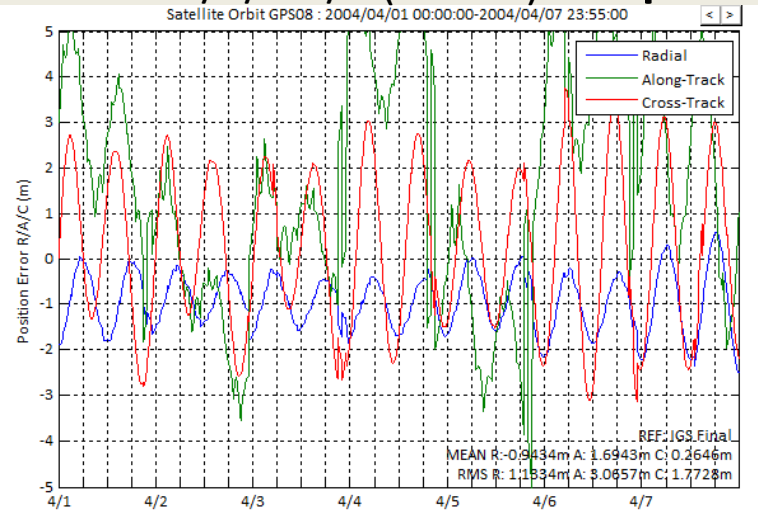
2001/1/1 0:00:00, TKSB, processed by RTKLIB 2.2.1, n=8

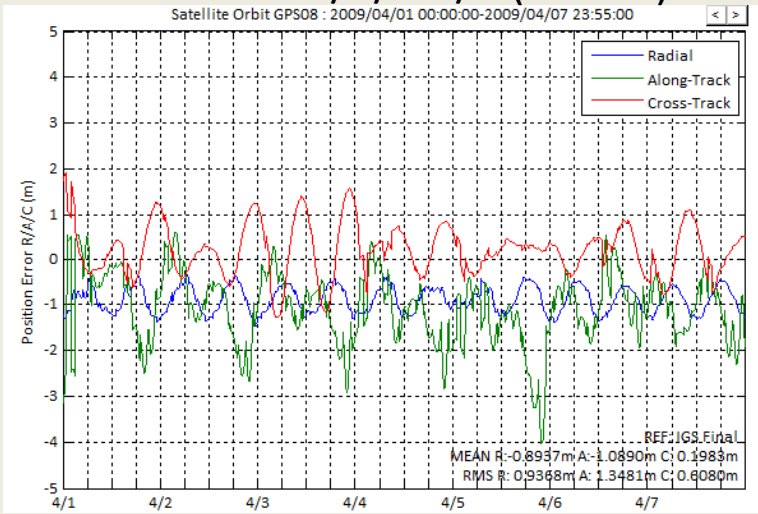
Error Sources and DOP

- **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)

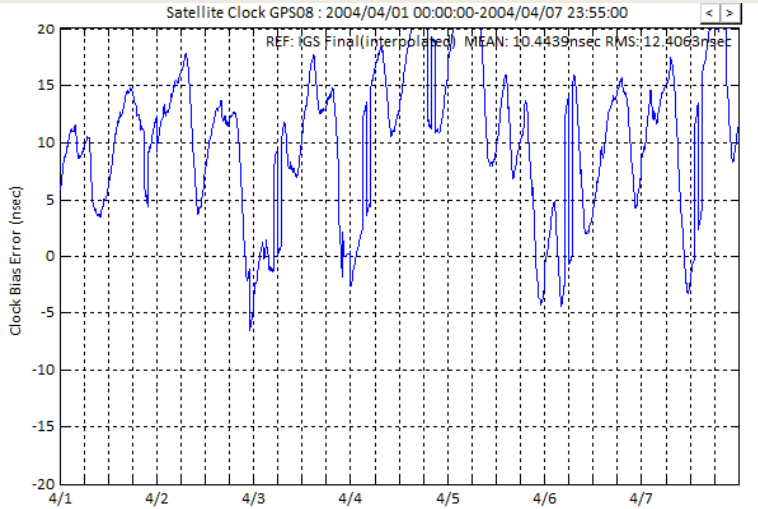
Ephemeris/SV Clock Error

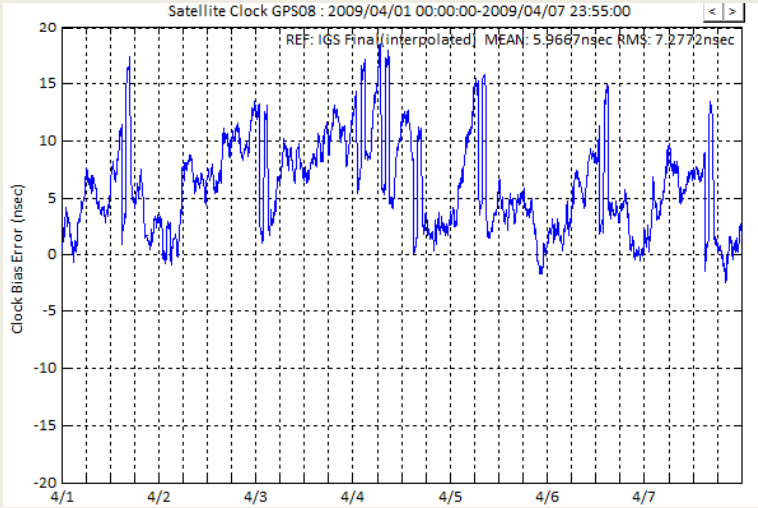
2004/4/1-4/7 (PRN08) **Ephemeris Error** 2009/4/1-4/7 (PRN08)



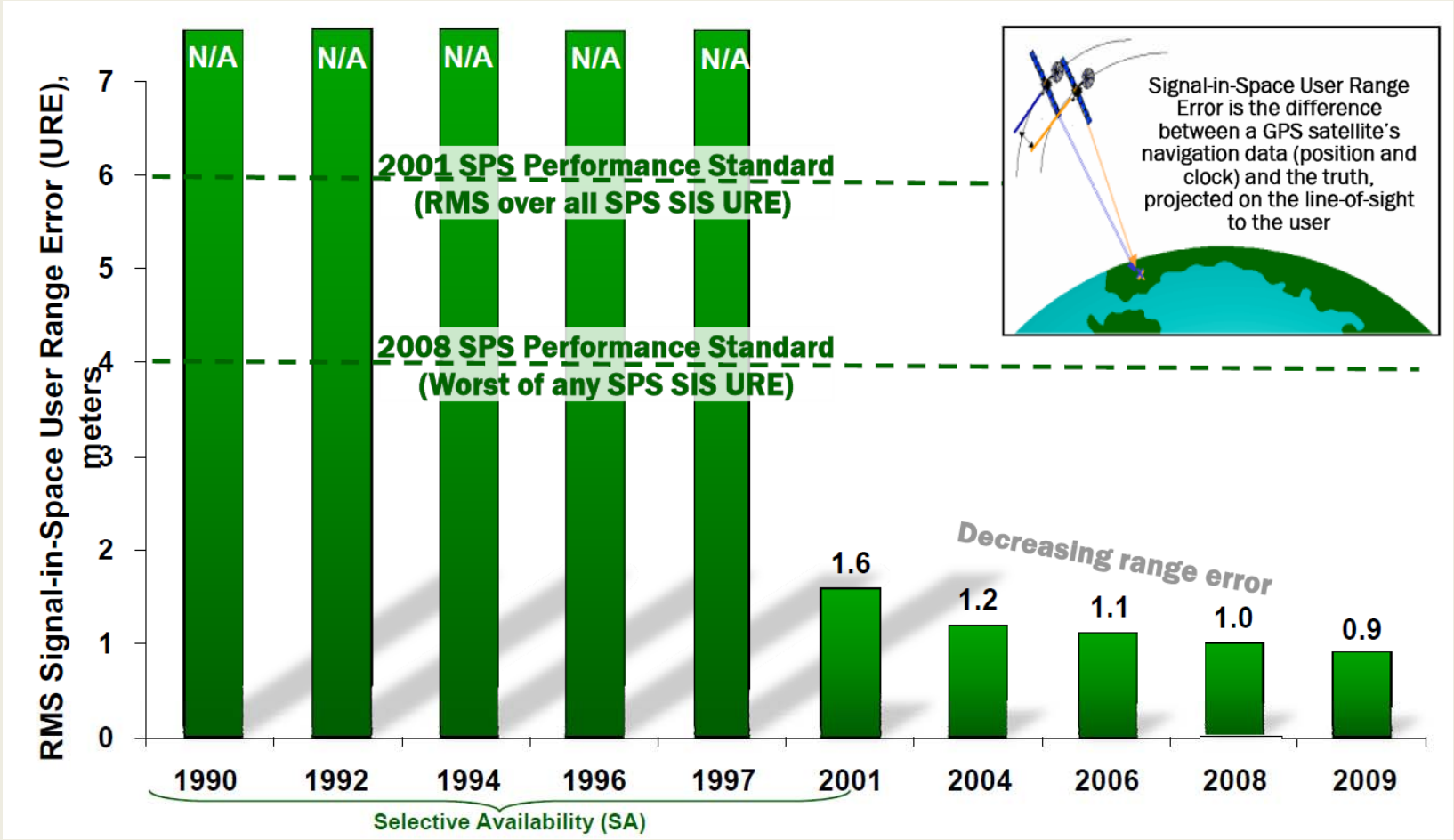


SV Clock Parameter Error



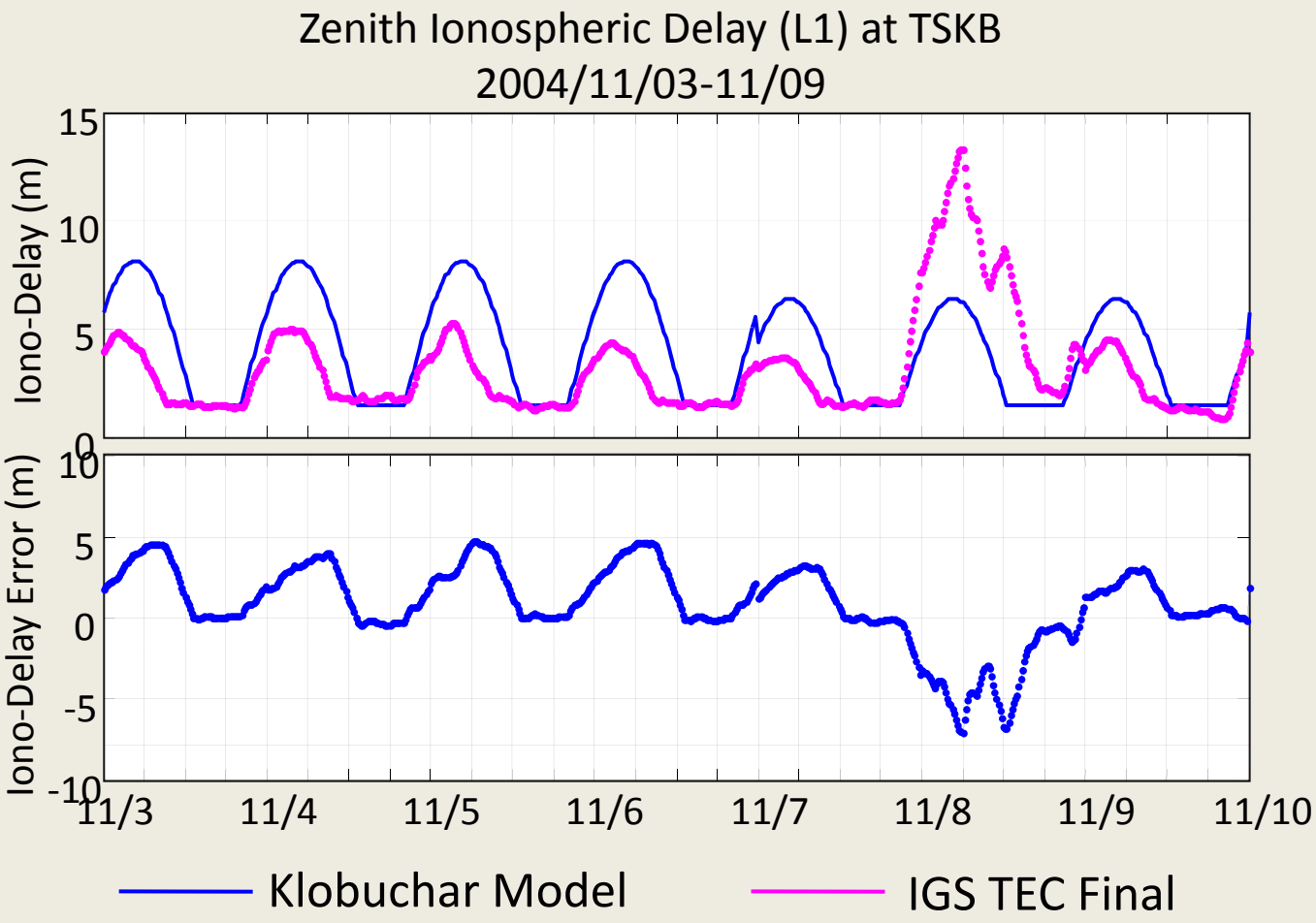


GPS SIS URE



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

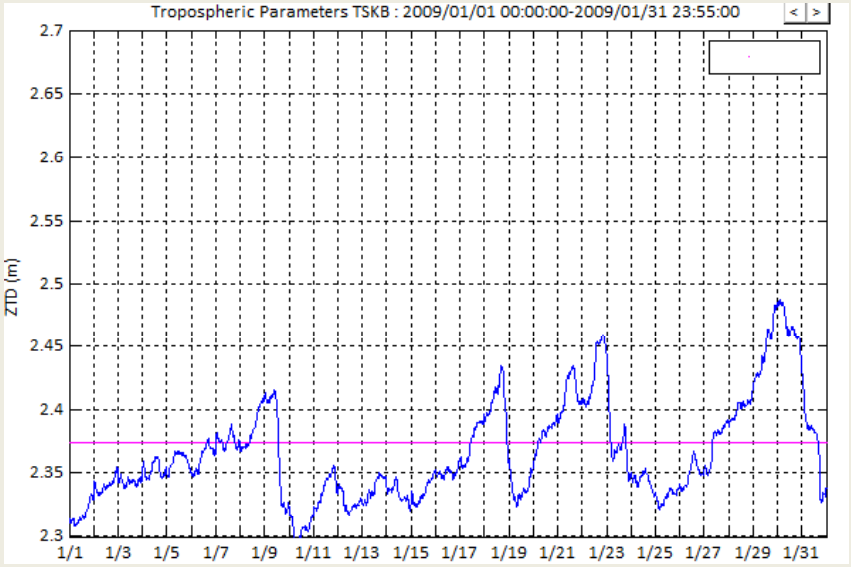
Ionospheric Model Error



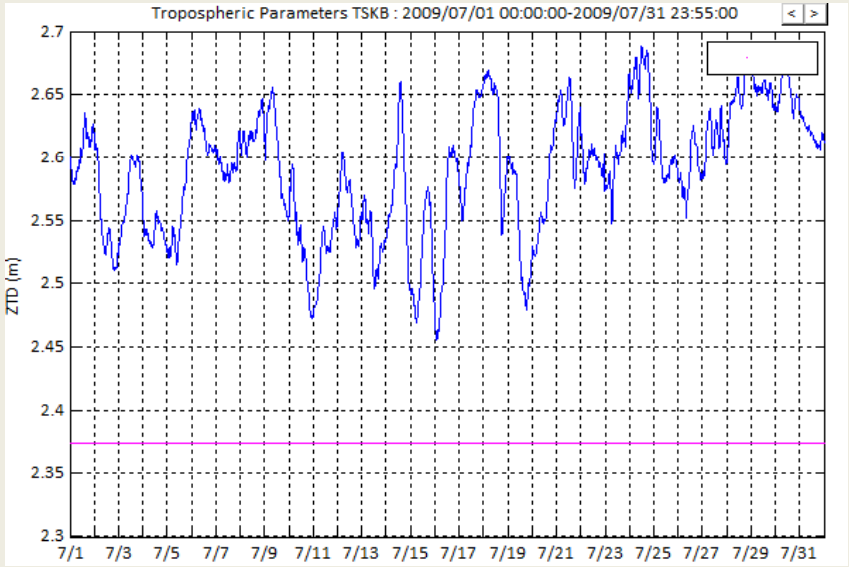
Tropospheric Model Error

ZTD (Zenith Total Delay) at TSKB

2009/1/1-2009/1/31



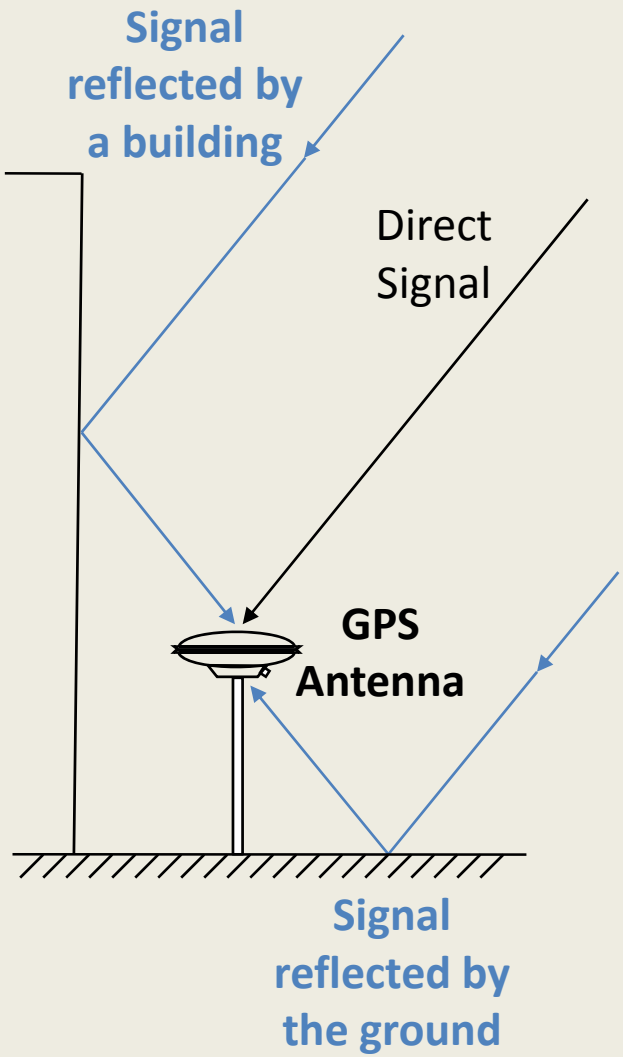
2009/7/1-2009/7/31



Saastamoinen Model

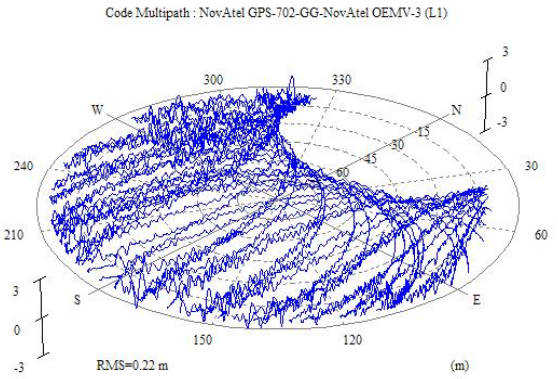
Estimated by PPP

Multipath

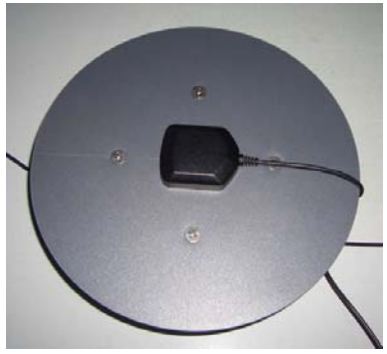


Geodetic-Grade Antenna

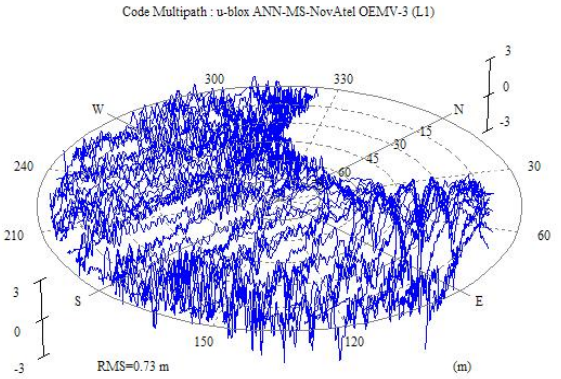
NovAtel GPS-702-GG



Consumer-Grade Antenna



u-blox ANN-MS



DOP (Dilution of Precision)

GDOP, PDOP, HDOP, VDOP

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

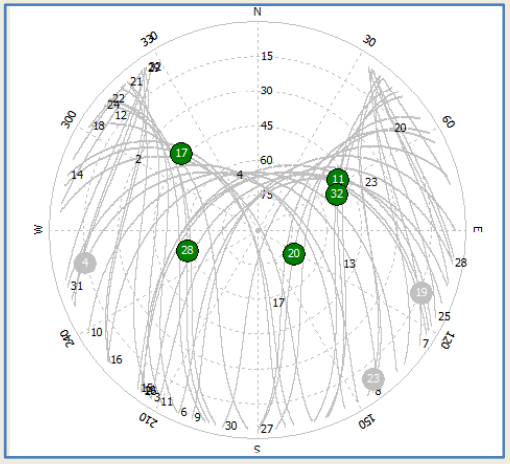
$$PDOP = \sqrt{q_{ee} + q_{nn} + q_{uu}}$$

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

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

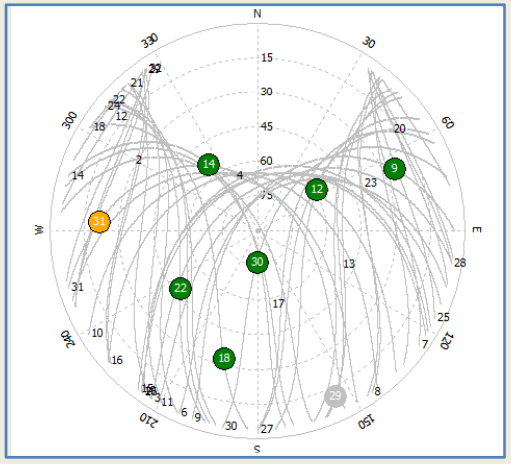
$$\boldsymbol{Q} = (\boldsymbol{H}^T \boldsymbol{H})^{-1} = \begin{pmatrix} q_{ee} & q_{en} & q_{eu} & q_{et} \\ q_{ne} & q_{nn} & q_{nu} & q_{nt} \\ q_{ue} & q_{un} & q_{uu} & q_{ut} \\ q_{te} & q_{tn} & q_{tu} & q_{tt} \end{pmatrix} \quad \boldsymbol{H} = \begin{pmatrix} -\boldsymbol{e}_{r,enu}^{s_1\,T}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

# of satellites = 5



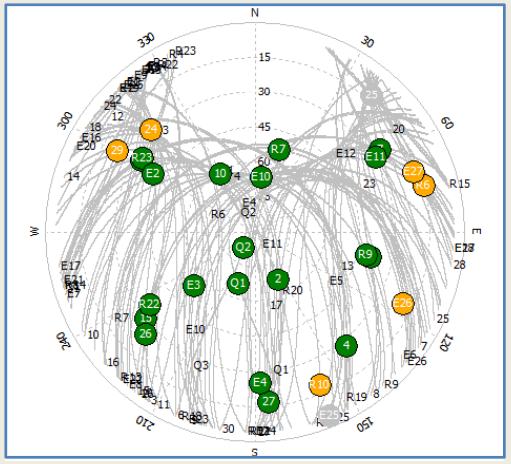
GDOP=33.4 PDOP=25.9
HDOP=8.1 VDOP=24.7

# 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

DGPS (Differential GPS)

- **Differential GPS**
  - Fixed Reference Stations at Known Position
  - Generate Correction Messages
  - Broadcast Correction Messages to User
  - Eliminate Most of Errors of Positioning
- **Service of DGPS**
  - Space Based DGPS: OmniSTAR, SkyFix, StarFix
  - Maritime DGPS: Marine Beacons
  - National DGPS: VHF/FM-band, Cellular Network, Internet

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

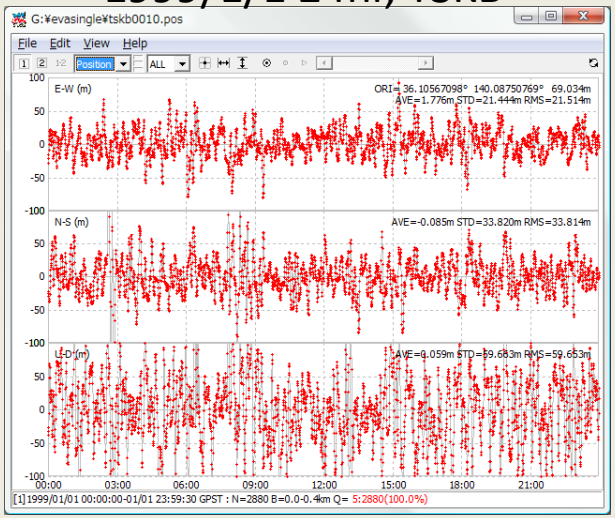
Error Budget

Error Source	Single-Point		DGPS (BL=100km)		SBAS	
Ephemeris Error	1.0 m		0.1 m		0.1 m	
SV Clock Param Error			0.0 m			
Ionospheric Error	1.5 m		0.2 m		0.2 m	
Tropospheric Error	0.3 m		0.1 m		0.3 m	
Multipath	1.0 m		1.2 m		1.0 m	
S/A	0.0 m		0.0 m		0.0 m	
Rcv Tracking Noise	0.3 m		0.3 m		0.3 m	
UERE	2.1 m		1.3 m		1.1 m	
HDOP/VDOP	1.5	2.5	1.5	2.5	1.5	2.5
Horizontal/Vertical RMS Error	**3.2 m**	**5.3 m**	**2.0 m**	**3.3 m**	**1.7 m**	**2.8 m**

Single-Point Positioning

1999/1/1 24hr, TSKB

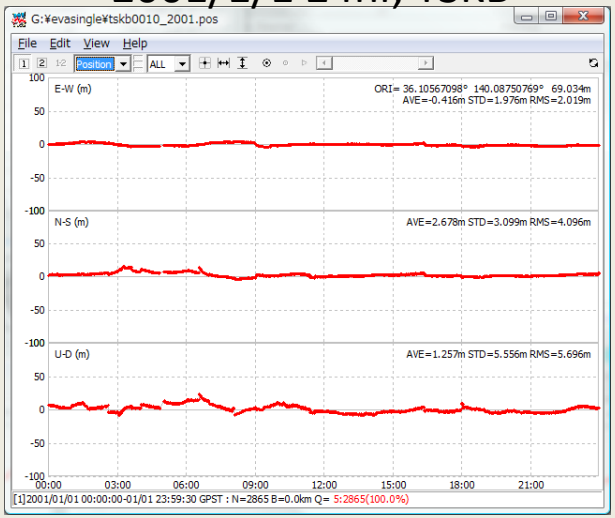
RMS Error:
E: 21.51m
N: 33.81m
U: 59.65m



100m

2001/1/1 24hr, TSKB

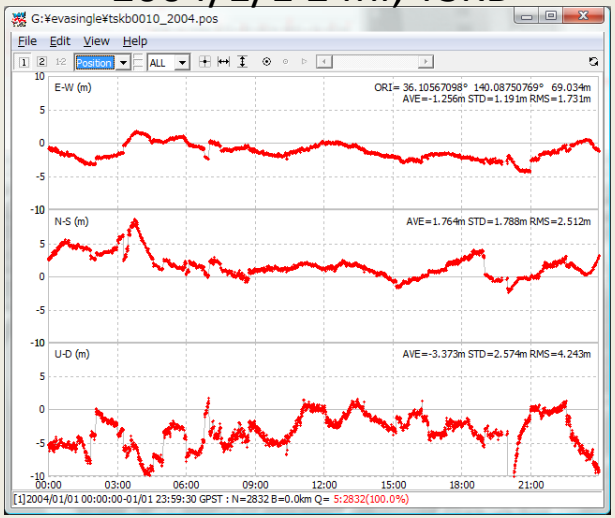
RMS Error:
E: 2.02m
N: 4.10m
U: 5.70m



100m

2004/1/1 24hr, TSKB

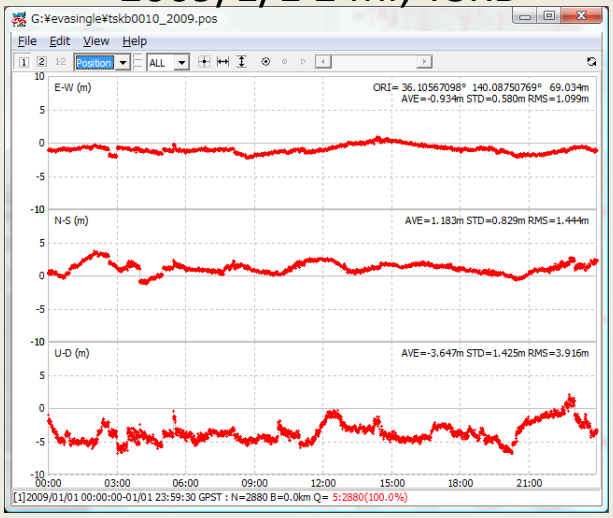
RMS Error:
E: 1.73m
N: 2.51m
U: 4.24m



10m

2009/1/1 24hr, TSKB

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



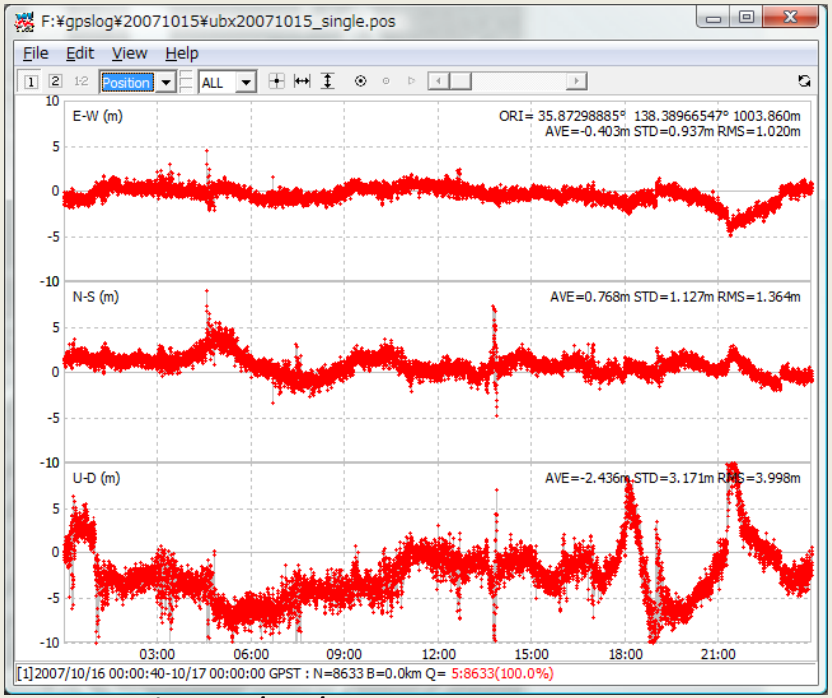
10m

SBAS DGPS Positioning

Single-Point

RMS Error:

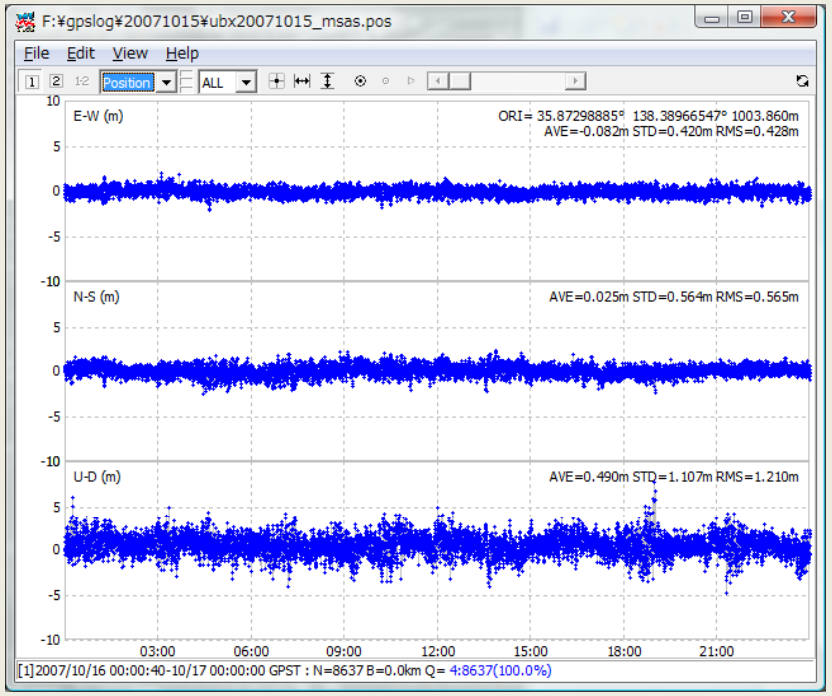
E: 1.02m N: 1.36m U: 4.00m



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)

Standard Data Format

- **RINEX (Receiver Independent Echange)**
  - 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, ...)

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)

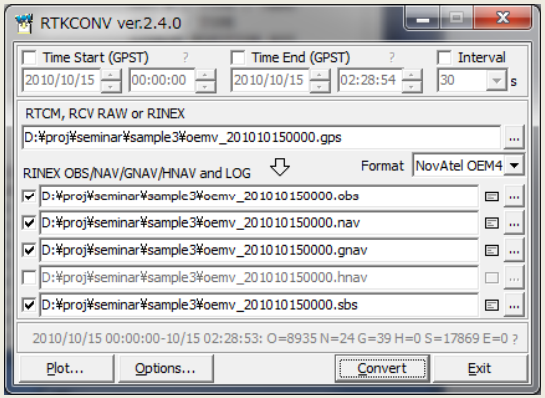
```
 2.10           N: GPS NAV DATA                         RINEX VERSION / TYPE
RTKCONV 2.4.0                           20110423 090647 UTC PGM / RUN BY / DATE
    1.1176E-08  0.0000E+00 -5.9605E-08  0.0000E+00           ION ALPHA
    9.0112E+04  0.0000E+00 -1.9661E+05  0.0000E+00           ION BETA
    -.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

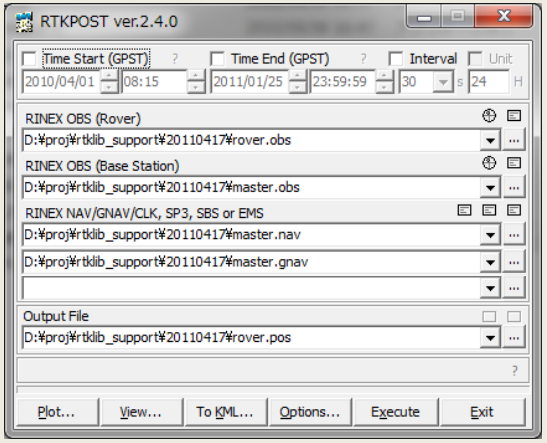
3. Standard Positioning: Exercise

Analysis by Standard Positioning

- **Objective**
  Analysis by standard positioning
- **Program**
  ...¥rtklib_2.4.0¥bin¥rtkconv.exe
  ...¥rtklib_2.4.0¥bin¥rtkpost.exe
  ...¥rtklib_2.4.1b¥bin¥rtkconv.exe
  ...¥rtklib_2.4.1b¥bin¥rtkpost.exe
- **Data**
  ...¥seminar¥sample3¥
  oemv_201010150000.gps



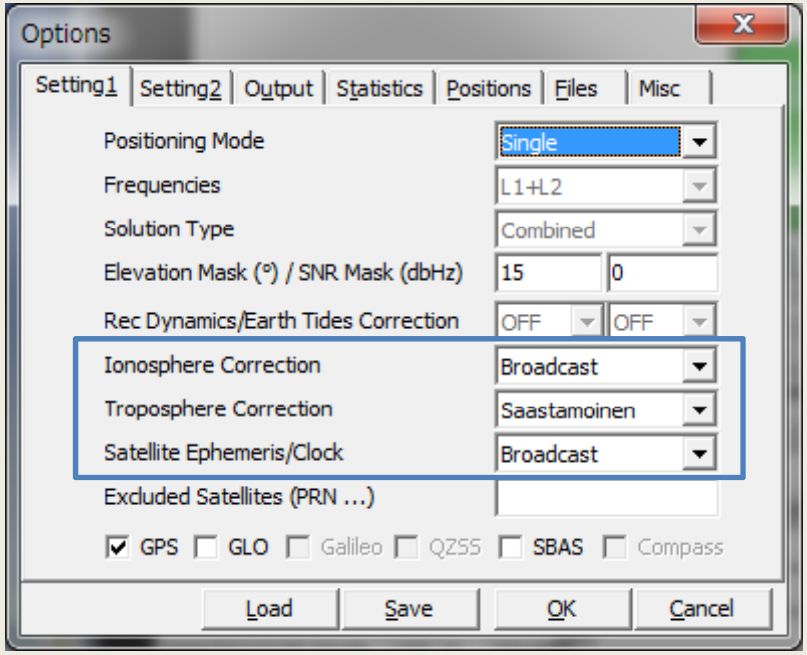
RTKLIB - RTKCONV



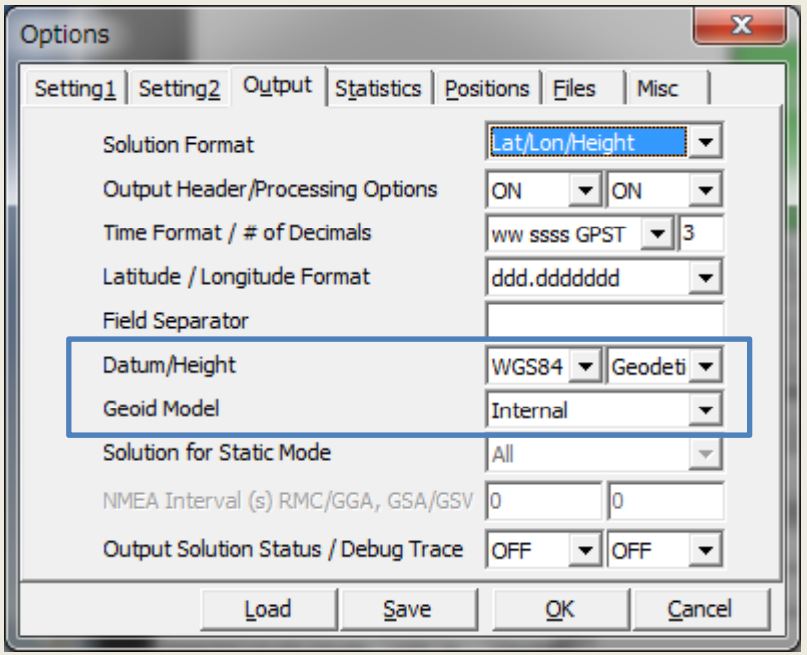
RTKLIB - RTKPOST

RTKPOST - Options

Setting1



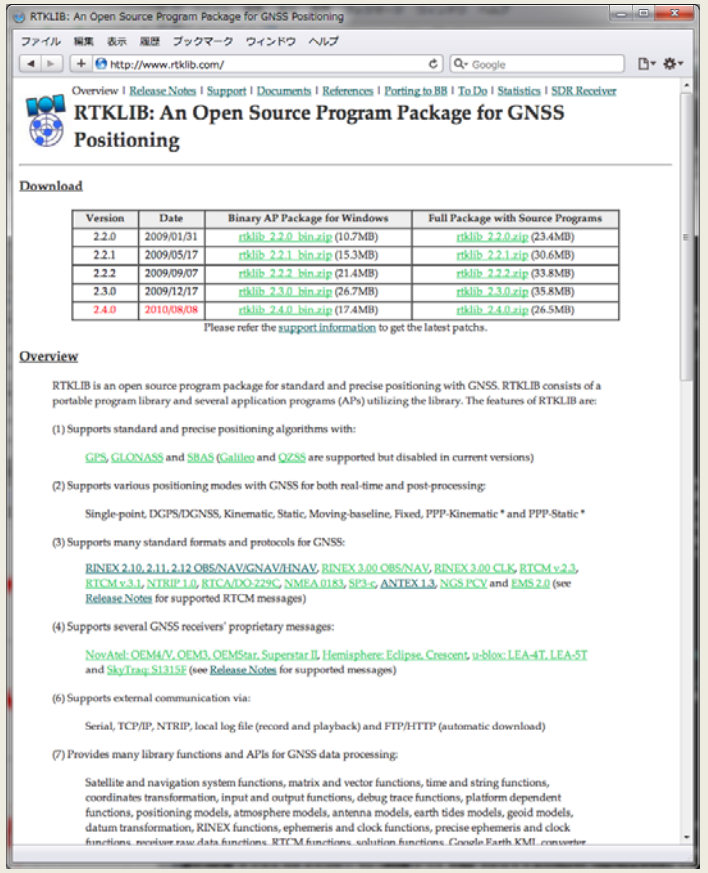
Output



4. RTKLIB

RTKLIB

- **An Open Source Program Package for GNSS Positioning**
  - Distributed under GPLv3
  - Has been developed by the author since 2006
  - Latest version: 2.4.0 (formal), 2.4.1b (beta)
- **Portable Library + useful positioning APs**
  - GUI APs on Windows
  - CUI APs on Linux etc...



http://www.rtklib.com

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)
- 2011/5(?) v.2.4.1 Support QZSS, JAVAD receiver
- 2011/12(?) v.2.5.0 Support Galileo, SDR-receiver Front-End

Download

version	2.2.0	2.2.1	2.2.2	2.3.0	2.4.0
2009/1-4	733	-	-	-	-
2009/5	51	120	-	-	-
2009/6	31	141	-	-	-
2009/7	28	110	-	-	-
2009/8	43	168	-	-	-
2009/9	30	45	211	-	-
2009/10	25	18	190	-	-
2009/11	65	31	987	-	-
2009/12	46	22	218	1380	-
2010/01	47	15	25	471	-
2010/02	38	16	23	324	-
2010/03	40	10	13	1556	-
2010/04	30	9	17	775	-
2010/05	33	12	15	1007	-
2010/06	34	5	13	860	-
2010/07	28	2	3	916	-
2010/08	63	20	26	118	1245
2010/09	51	9	10	222	1356
2010/10	58	11	13	490	382
2010/11	62	20	39	48	484
2010/12	44	12	12	32	974
2011/01	43	18	12	42	400
2011/02	65	20	13	29	441
2011/03	53	9	10	21	861
Total	**1741**	**843**	**1837**	**8291**	**6143**

RTKLIB Features

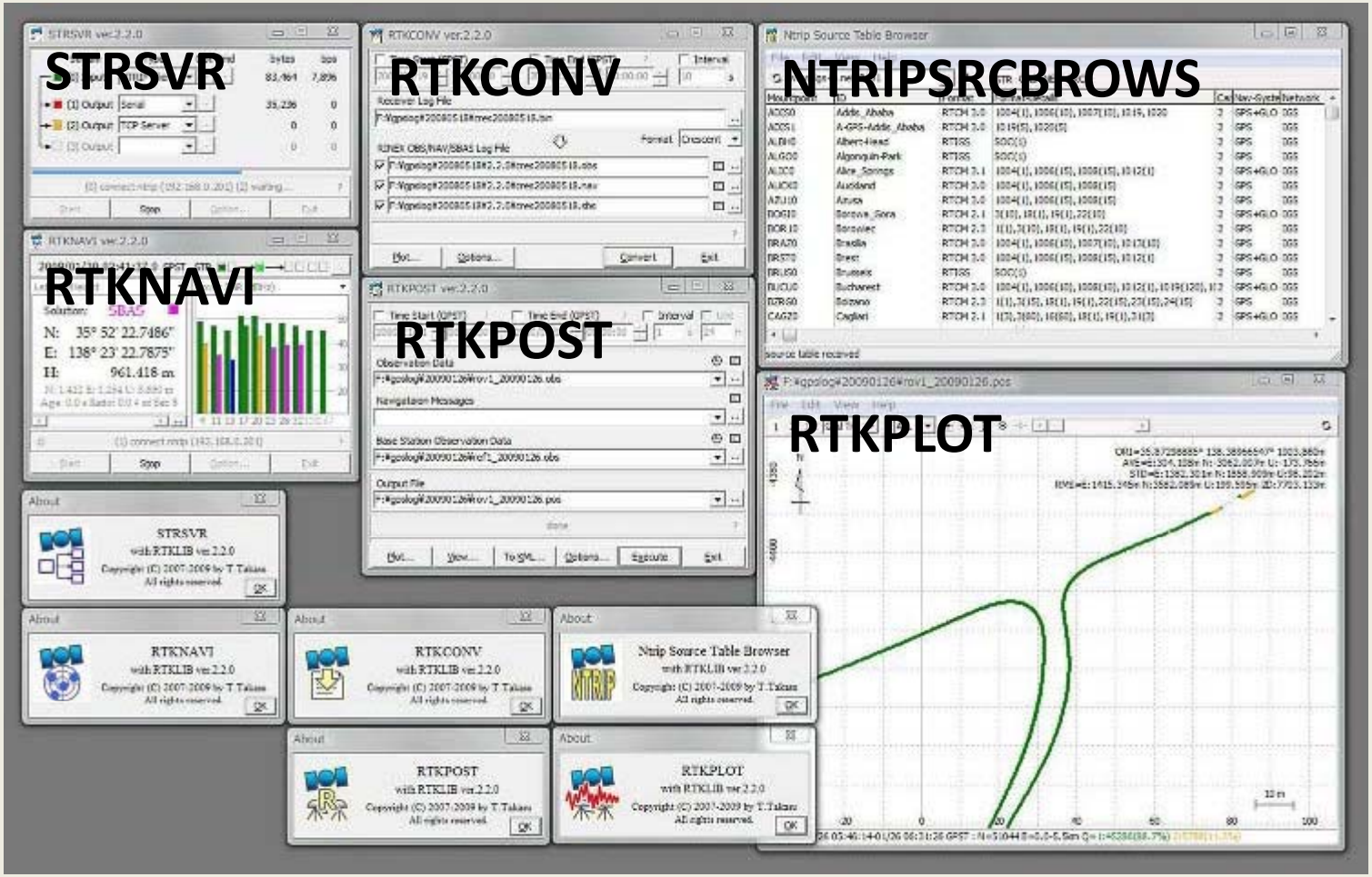
- **Standard and precise positioning algorithms with**:
  - GPS, GLONASS, SBAS, QZSS, (Galileo)
- **Positioning mode for real-time and post-processing**:
  - Single, SBAS, DGPS, RTK, Static, Moving-base and PPP
- **Supports many formats/protocols and receivers**:
  - RINEX 2.2, RINEX 3.0, RTCM v.2, RTCM v.3, NTRIP 1.0, NMEA0183, SP3, RINEX CLK, ANTEX, NGS PCV, …
  - NovAtel, Hemisphere, u-blox, SkyTraq, JAVAD, …
- **External communication via**:
  - Serial, TCP/IP, NTRIP and file streams

Package Structure

rtklib_<ver>.zip

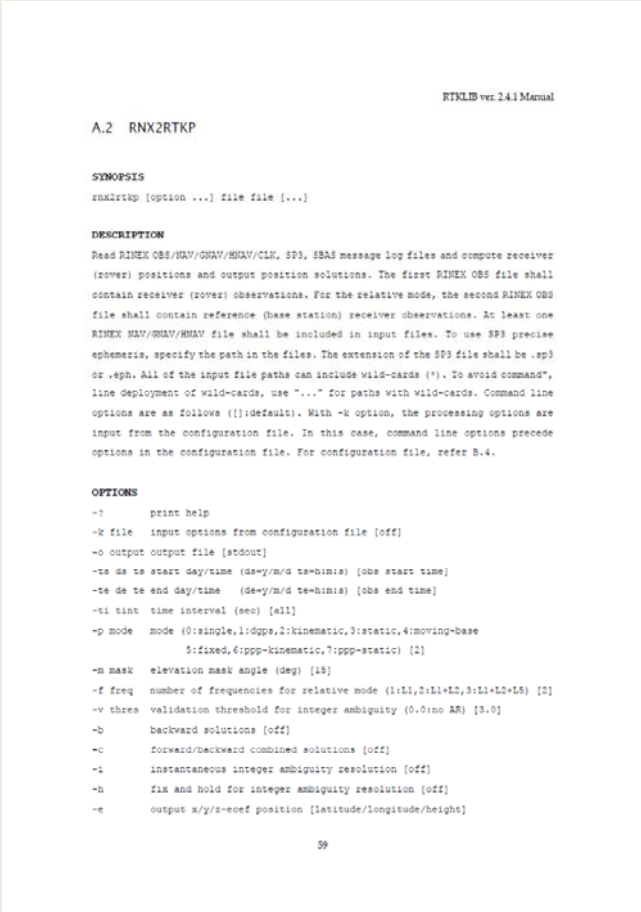
```
/src                    : Source programs of RTKLIB libraries
     /rcv               : Source programs depending on GPS/GNSS receiv.
/bin                    : Executable binary APs and DLLs for Windows
/data                   : Sample data for APs
/app                    : Build environment for 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
```

GUI APs on Windows



CUI APs on Linux or Others

- **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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CUI Command Reference

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() ...
```

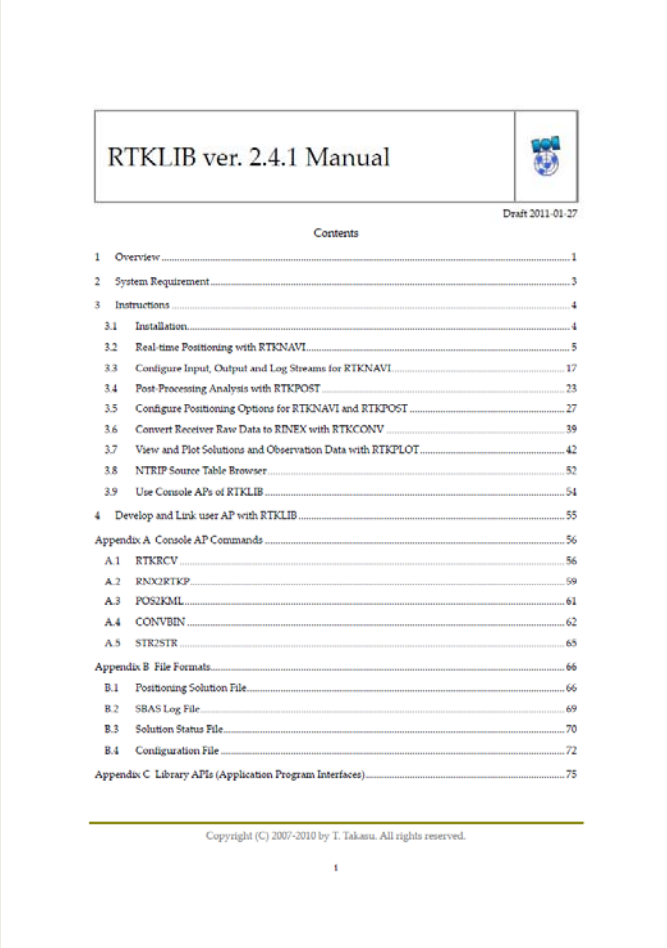
Supported Receivers by RTKLIB

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

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**
  - CUI AP : GCC, MS VS, Borland C, ...
  - GUI AP : Borland Turbo C++ 2006 on Windows

References

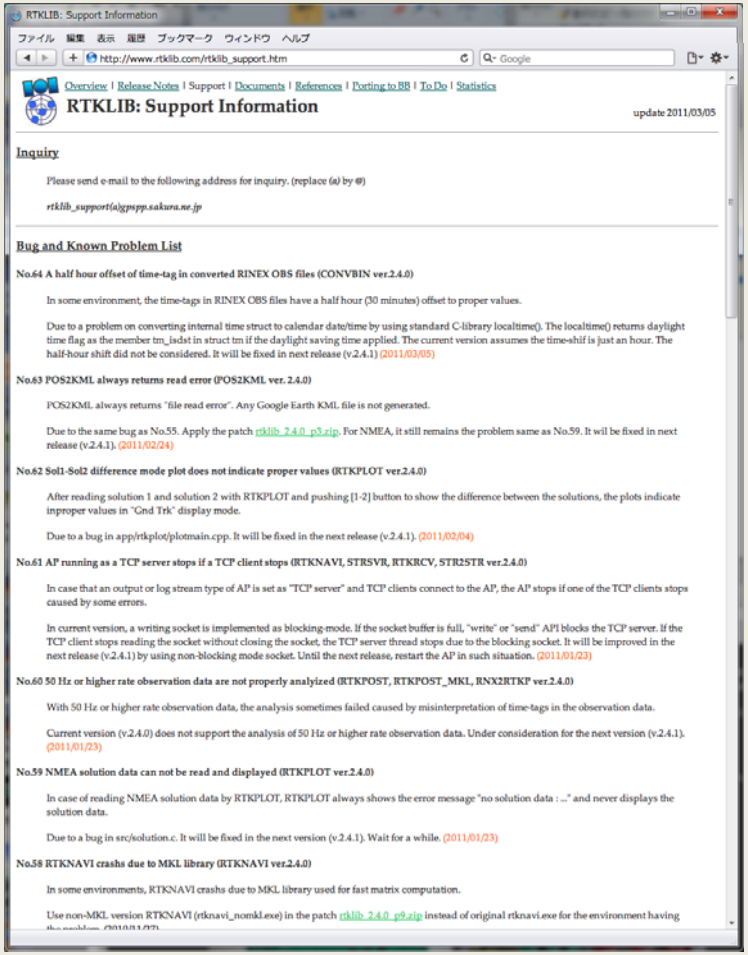


RTKLIB ver. 2.4.1 Manual

Draft 2011-01-27

Contents

rtklib_<ver>/doc/manual_<ver>.pdf



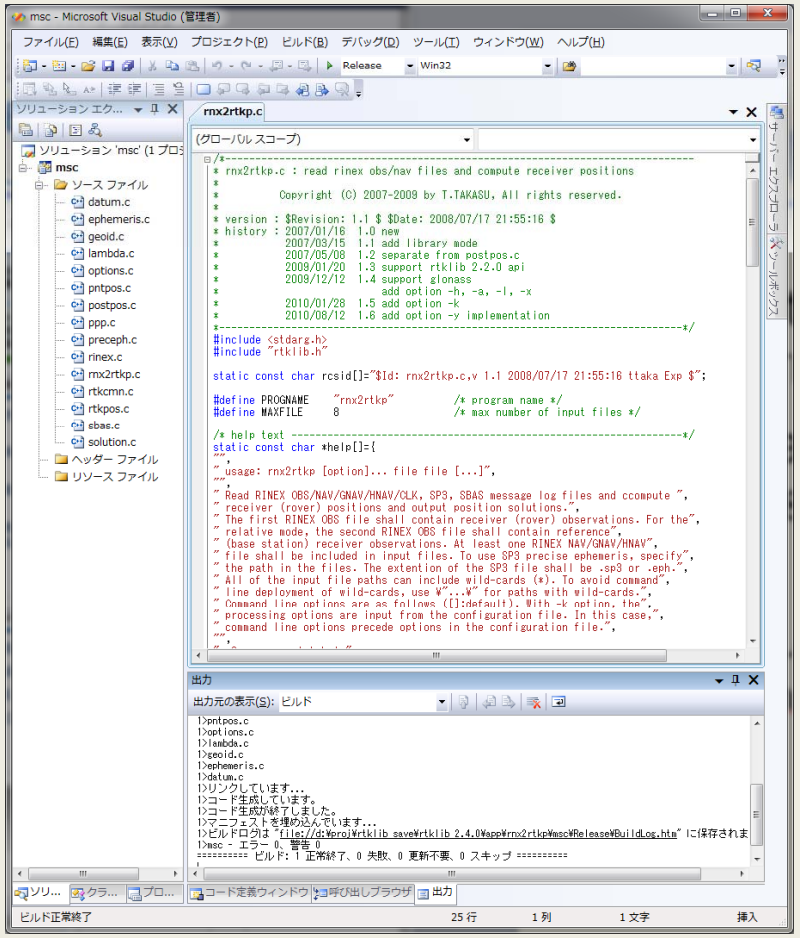
RTKLIB: Support Information

http://www.rtklib.com

4. RTKLIB: Exercise

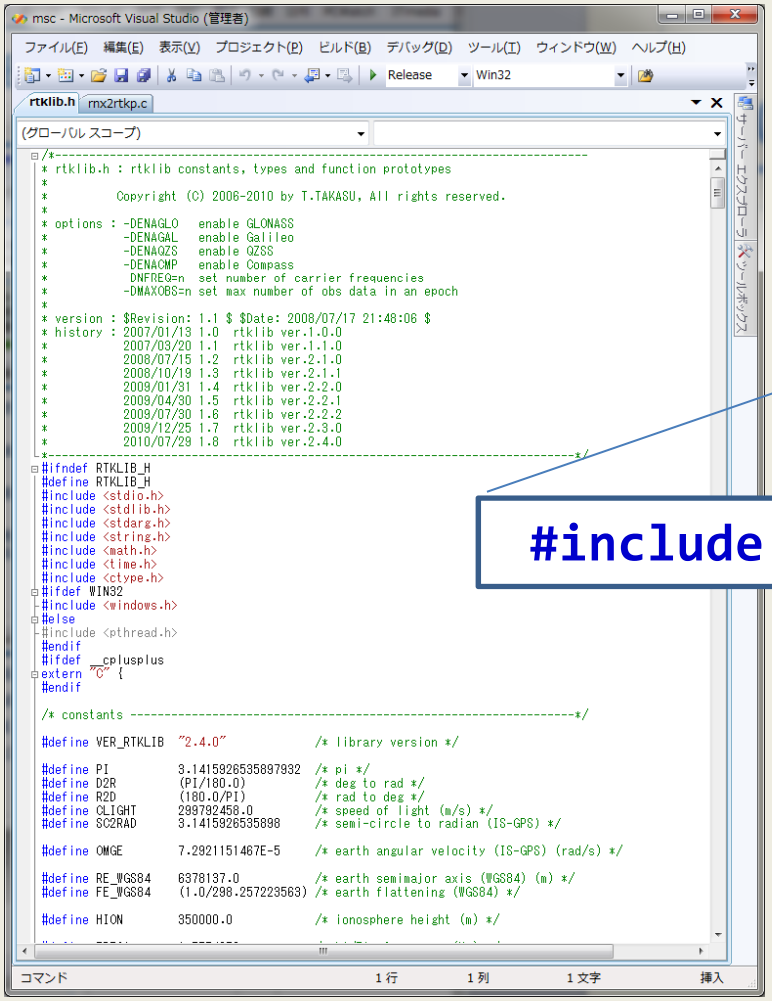
Build RTKLIB AP

- **Objective**
  Build RTKLIB AP (RNX2RTKP)
- **Programs**
  MS Visual Studio (VC++)
- **Project File**
  …¥rtklib_2.4.0¥app
  ¥rnx2rtkp¥msc¥msc.vcproj

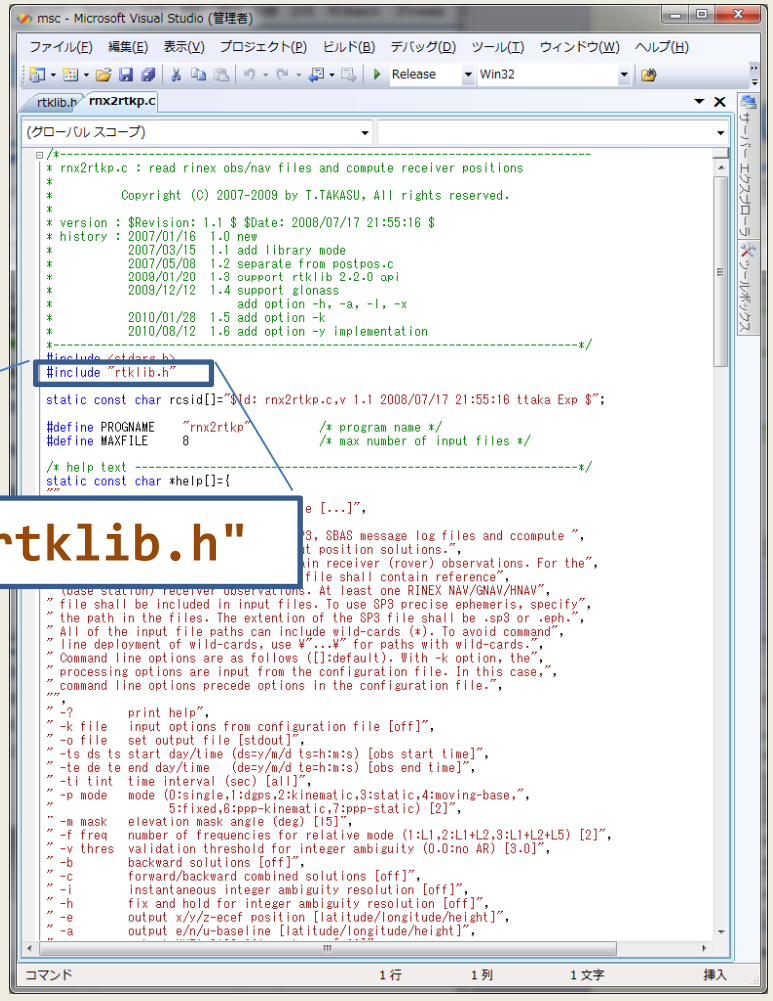


MS Visual Studio 2008

rtklib.h and AP Source



rtklib_<ver>/src/rtklib.h



rtklib_<ver>/app/<app>/<app>.c

#include "rtklib.h"

Library Source Files

…¥rtklib_<ver>¥src¥

convkml.c : Google Earth KML Converter
convrnx.c : RINEX Converter
datum.c : Datum Transformation
ephemeris.c : Ephemeris Functions
geoid.c : Geoid Functions
ionex.c : IONEX Functions
lambda.c : Integer Ambiguity Resolution
options.c : Options Functions
pntpos.c : Point Positioning
postpos.c : Post-Processing Positioning
ppp.c : Precise Point Positioning
preceph.c : Precise Ephemeris Functions
rcvraw.c : Receiver Raw Data Functions
rinex.c : RINEX Functions
rtcm.c : RTCM Functions
rtkcmn.c : RTKLIB Common Functions
rtkpos.c : Real-time Positioning
rtksvr.c : RTK Server
sbas.c : SBAS Functions
solution.c : Solution Functions
stream.c : Stream I/O Functions
streamsvr.c : Stream I/O Server

rcv/ : Receiver Dependant Func.
rcv/crescent.c : Hemisphere
rcv/gw10.c : Furuno GW 10
rcv/javad.c : JAVAD GRIL/GREIS
rcv/novatel.c : NovAtel OEM3/OEMV
rcv/skytraq.c : SkyTraq S1315F
rcv/ss2.c : NovAtel SuperStar II
rcv/ublox.c : u-blox LEA-4T, 5T

Test Execution

```
>d:
>cd <dir>¥rtklib_2.4.0¥app¥rnx2rtkp¥msc¥Release
>rnx2rtkp ..¥..¥..¥..¥test¥data¥07590920.05* -p 0 -o test.txt
```