

2019年度測位航法学会 全国大会 セミナー②

RTKおよびPPP技術の基礎と実習

 Tokyo Univ. of Marine Science and Technology (TUMSAT)

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2019-05-15 @東京海洋大学 越中島

Timetable

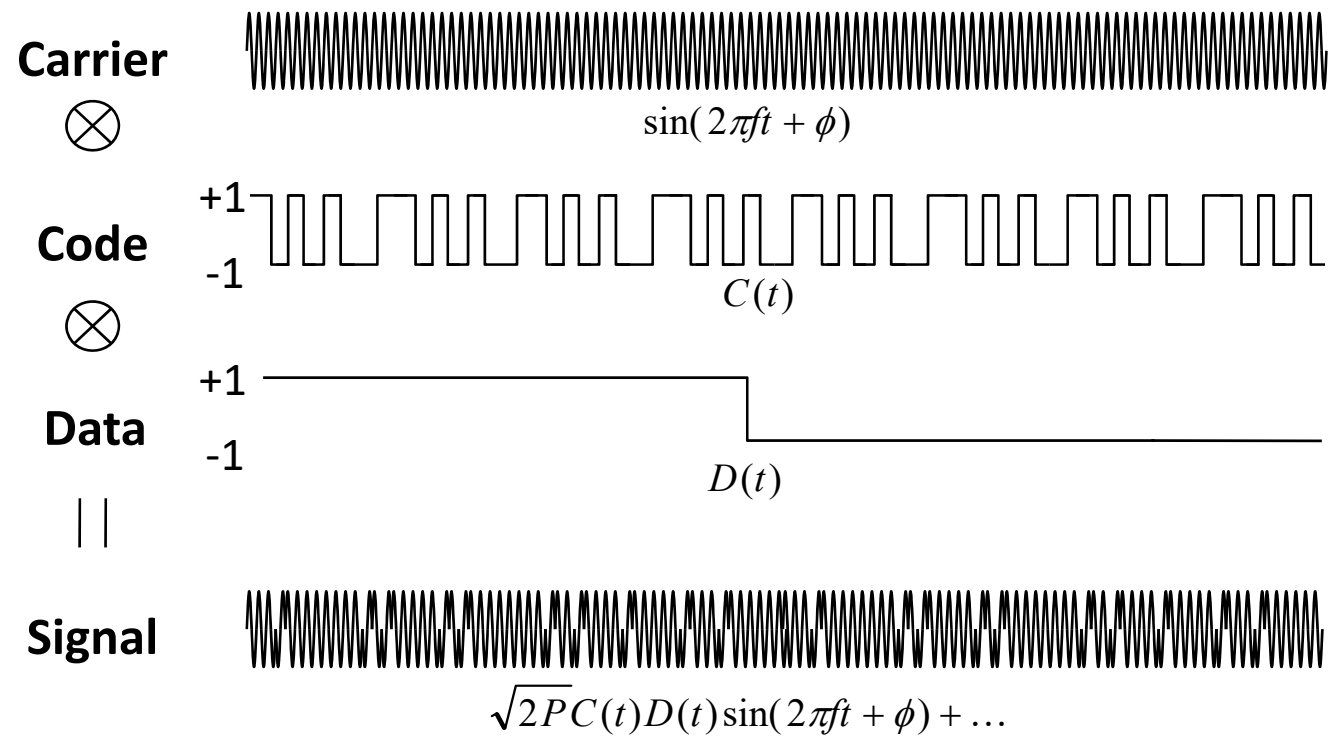
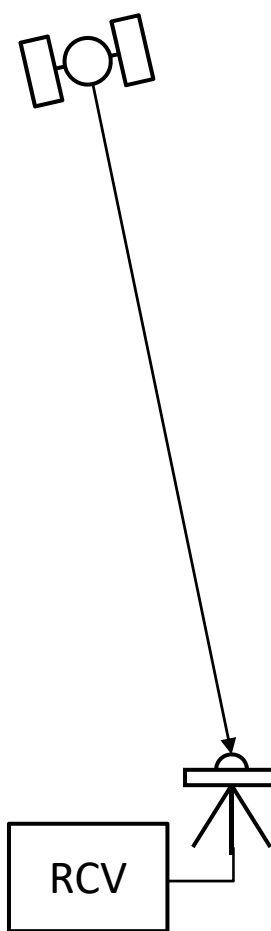
May 15, 2019

| | | |
|----------|---|--------------------|
| 1 | Theory of PP (precise positioning) | 9:30-10:10 |
| 2 | RTK Basics | 10:10-10:50 |
| 3 | RTK Practice | 11:00-12:30 |
| | Lunch Break | 12:30-13:30 |
| 4 | PPP Basics | 13:30-14:10 |
| 5 | PPP Practice | 14:20-16:00 |
| 6 | Advanced Topics of PP | 16:10-16:30 |

1 Theory of PP (precise positioning)

GNSS Signal Structure

satellite

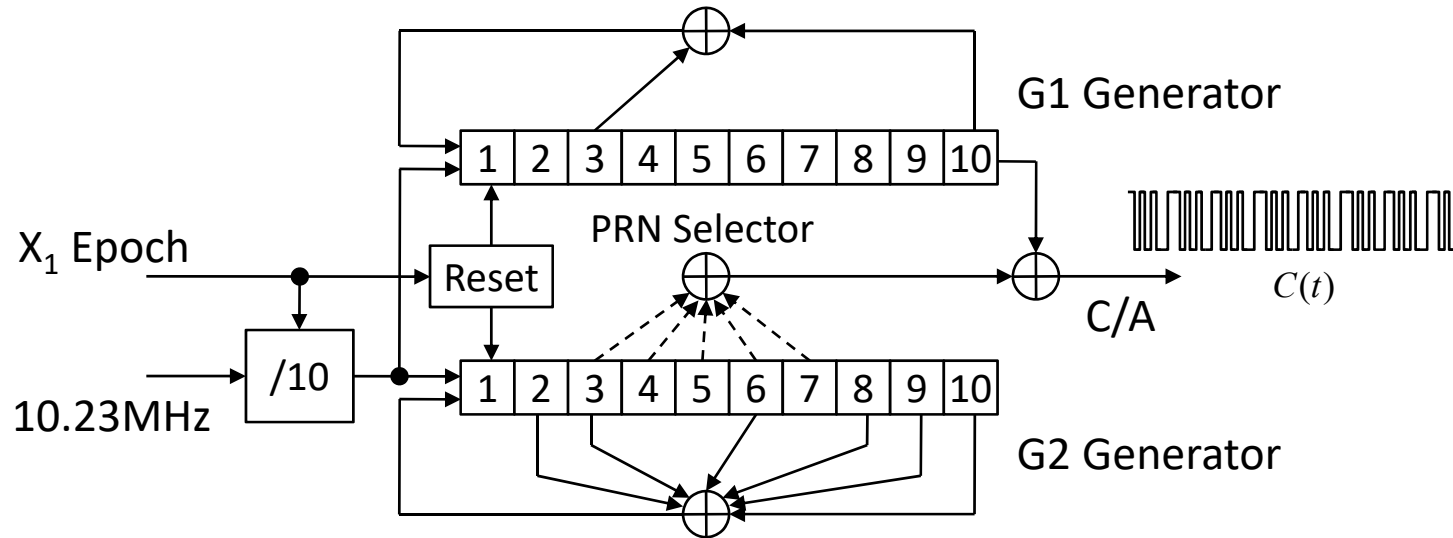


GNSS Signal Specifications

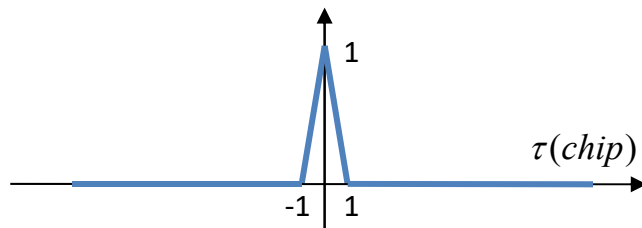
| Carrier Freq (MHz) | | Code | Modulation | Data Rate | GNSS |
|--------------------|--------------|---------|-----------------|------------|----------------------|
| L1/E1 | 1575.42 | C/A | BPSK (1) | 50 bps | GPS, QZSS |
| | | | | 250 bps | QZSS (L1-SAIF), SBAS |
| | | P(Y) | BPSK (10) | 50 bps | 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 L1C/A)

PRN Code Generator

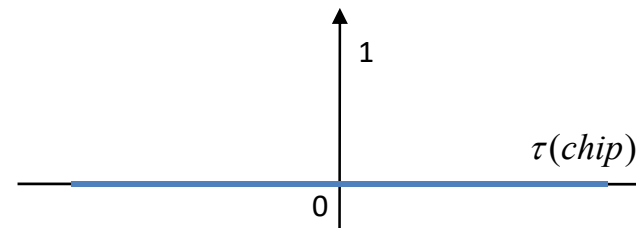


Auto-correlation function



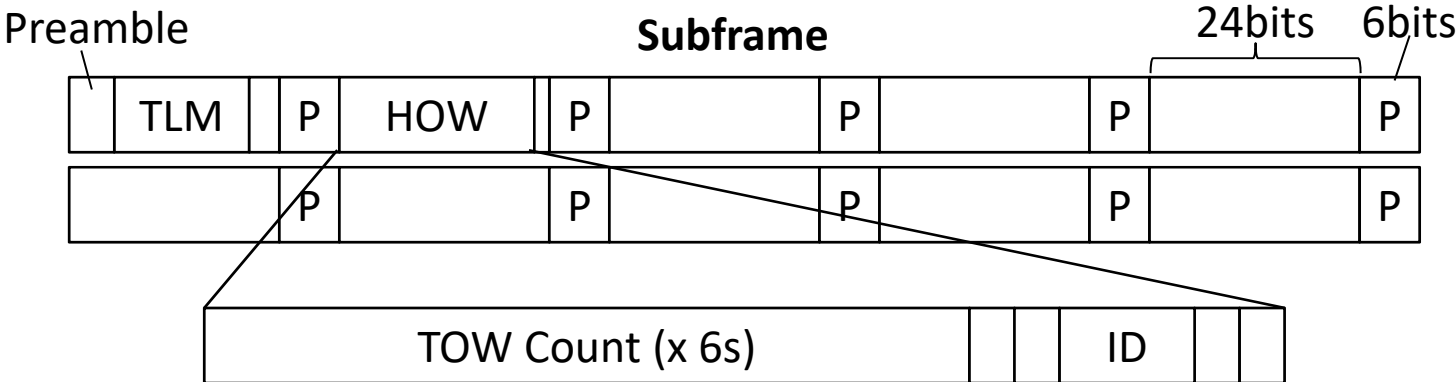
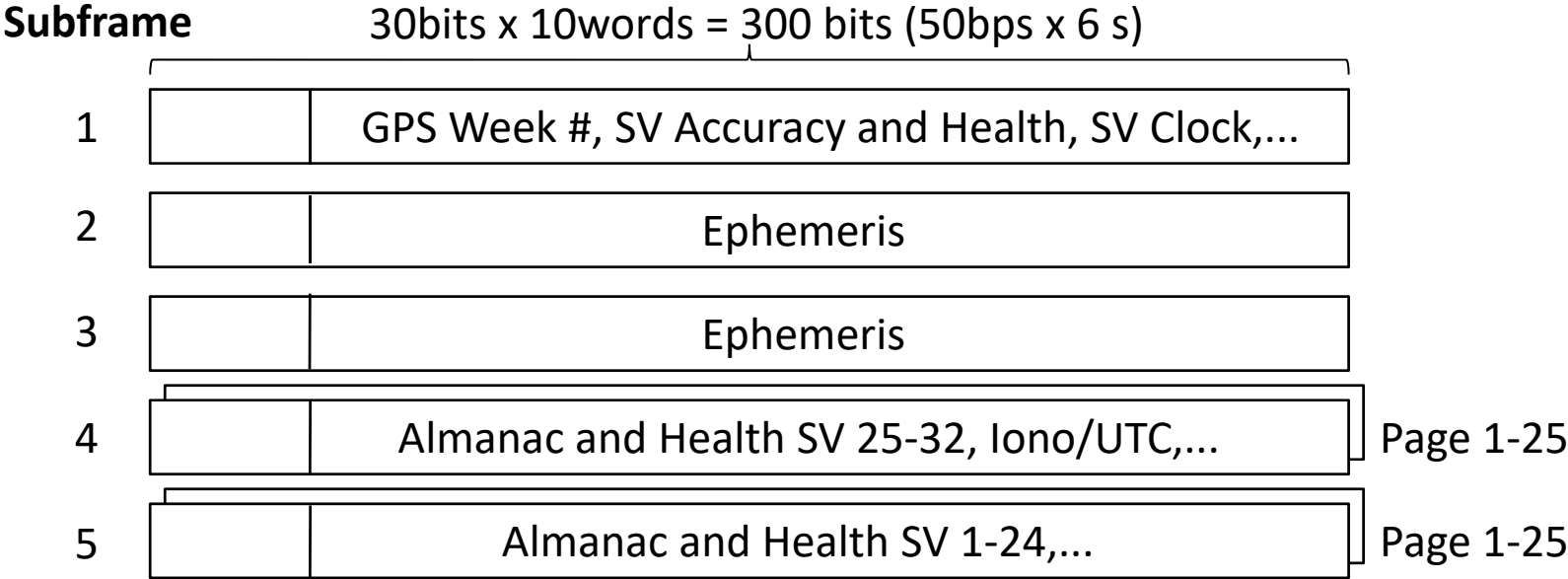
$$R(\tau) = \frac{1}{T} \int_0^T C^i(t) C^i(t - \tau) dt$$

Cross-correlation function

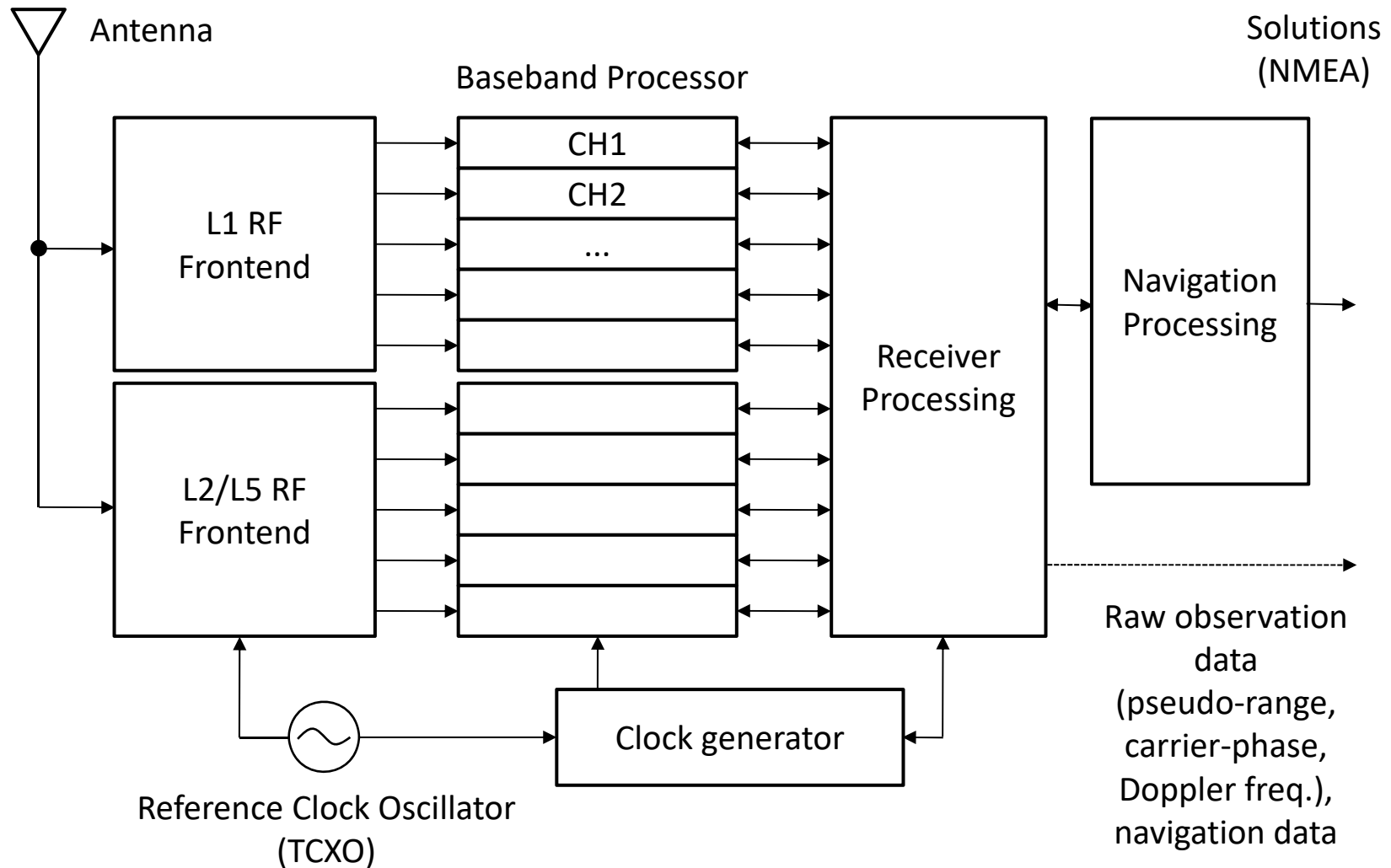


$$R(\tau) = \frac{1}{T} \int_0^T C^i(t) C^j(t - \tau) dt \quad (i \neq j)$$

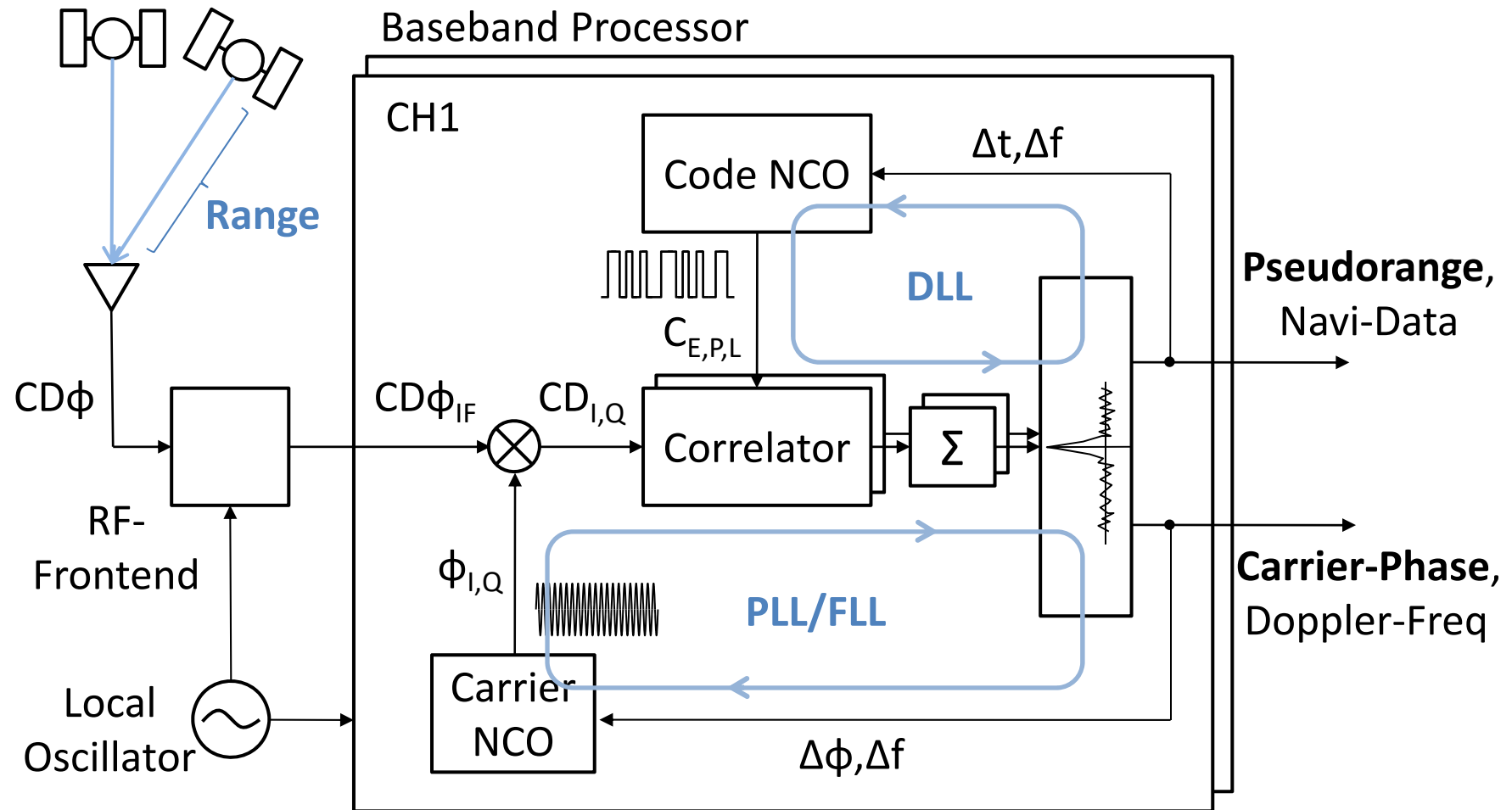
Navigation Data (GPS LNAV)



Receiver Functional Diagram



Carrier/Code Tracking in Receiver



Receiver and Navigation Processing

- **Receiver processing**
 - Acquisition : Doppler-freq/code-phase search
 - Code tracking : DLL (Delay Lock Loop)
 - Carrier tracking : PLL/FLL (Phase/Freq Lock Loop)
 - Decode navigation data
 - Generation of pseudorange and carrier-phase
- **Navigation processing**
 - Positioning algorithms (single, DGPS, RTK, ...)
 - Coordinates transformation
 - I/O message handling (NMEA, RTCM, ...)

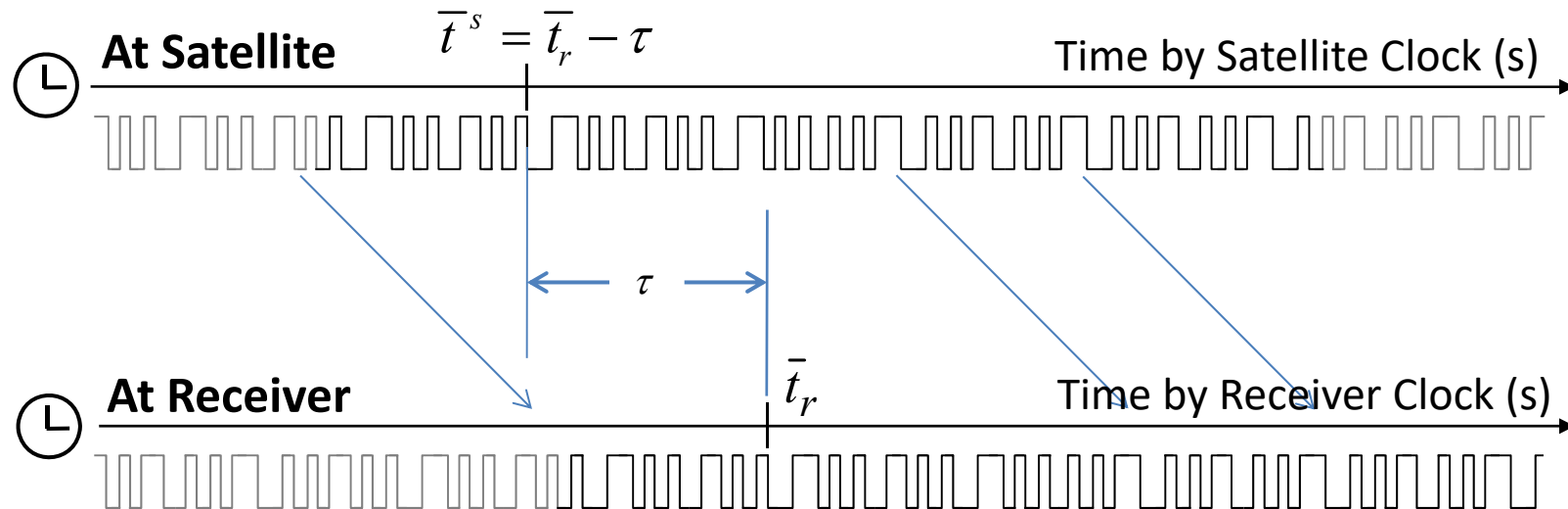
Pseudorange

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*)



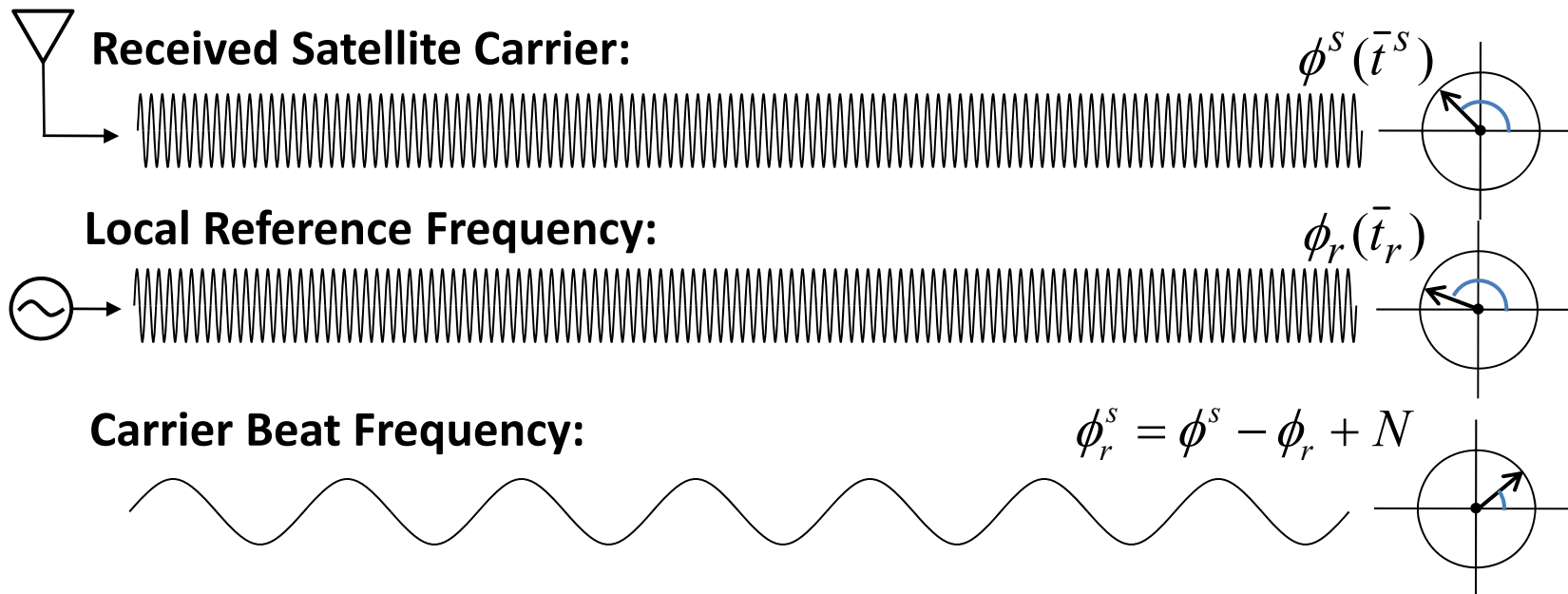
Carrier-Phase

Definition:

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

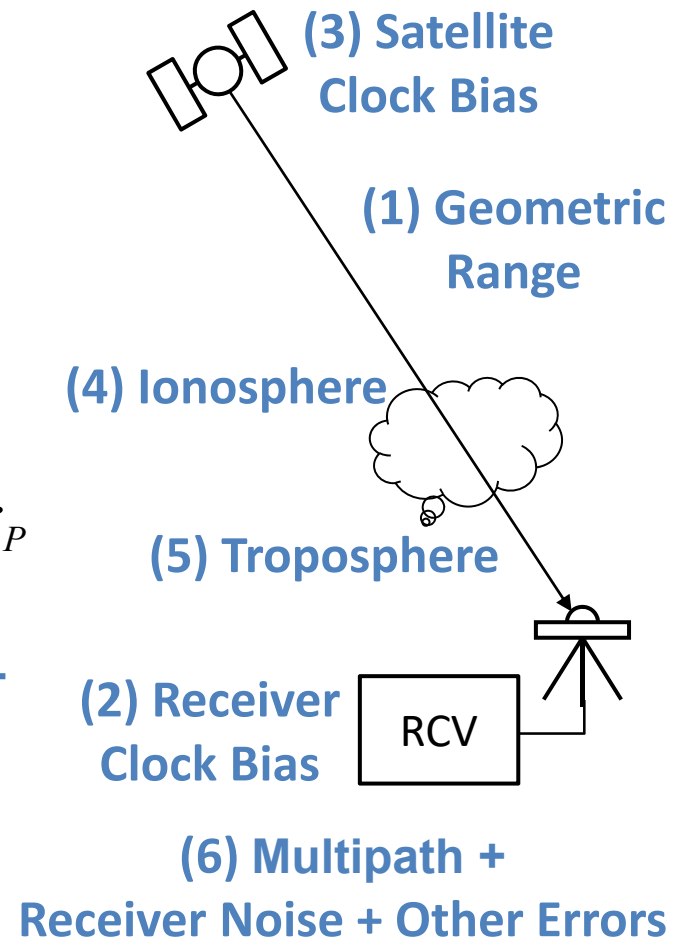
(cycle)

... 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*)



Pseudorange Model

$$\begin{aligned}
 P_r^s &\equiv c\tau \\
 &= c(\bar{t}_r - \bar{t}^s) \\
 &= c((t_r + dt) - (t^s + dT^s)) + \varepsilon_P \\
 &= c(t_r - t^s) + c(dt_r - dT^s) + \varepsilon_P \\
 &= (\rho_r^s + I_r^s + T_r^s) + c(dt_r - dT^s) + \varepsilon_P \\
 &= \underbrace{\rho_r^s}_{(1)} + \underbrace{c(dt_r)}_{(2)} - \underbrace{dT^s}_{(3)} + \underbrace{I_r^s}_{(4)} + \underbrace{T_r^s}_{(5)} + \underbrace{\varepsilon_P}_{(6)}
 \end{aligned}$$



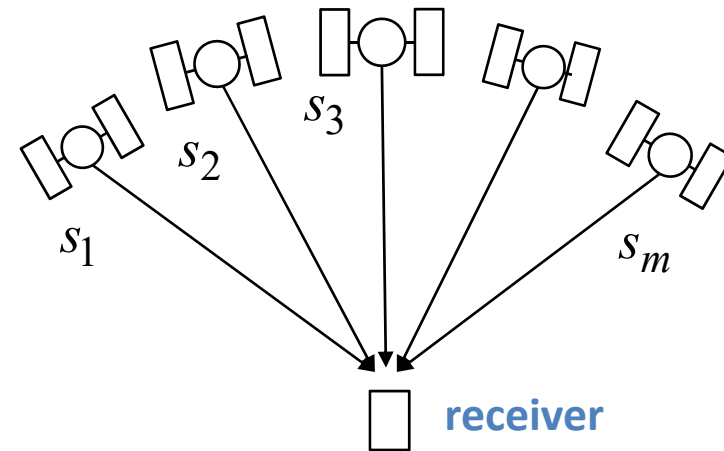
SD (standard positionig)

$$\mathbf{x} = (\mathbf{r}_r^T, cdt)^T, \quad \mathbf{y} = (P_r^{s_1}, P_r^{s_2}, P_r^{s_3}, \dots, P_r^{s_m})^T \quad \text{pseudo-ranges}$$

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

range
receiver
satellite

clock
clock
clock



$$\hat{\mathbf{x}} = \underline{(\hat{\mathbf{r}}_r^T, c\hat{d}t)^T} \quad \text{solution}$$

$$= \hat{\mathbf{x}}_0 + (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T (\mathbf{y} - \mathbf{h}(\hat{\mathbf{x}}_0))$$

Code vs Carrier-Based Positioning

| | SD (standard positioning, code-based) | PP (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, ... |

Carrier-Phase Model (1)

Carrier-Phase:

$$\begin{aligned}
 \phi_r^s &= \phi_r(t_r) - \phi^s(t^s) + N_r^s + \varepsilon_\phi && (\phi_{r,0} = \phi_r(t_0), \phi_0^s = \phi^s(t_0)) \\
 &= (f(t_r + dt_r - t_0) + \phi_{r,0}) - (f(t^s + dT^s - t_0) + \phi_0^s) + N_r^s + \varepsilon_\phi \\
 &= \frac{c}{\lambda}(t_r - t^s) + \frac{c}{\lambda}(dt_r - dT^s) + (\phi_{r,0} - \phi_0^s + N_r^s) + \varepsilon_\phi && \text{(cycle)} \\
 \Phi_r^s &\equiv \lambda\phi_r^s = c(t_r - t^s) + c(dt_r - dT^s) + \lambda(\phi_{r,0} - \phi_0^s + N_r^s) + \lambda\varepsilon_\phi \\
 &= \underbrace{\rho_r^s + c(dt_r - dT^s)}_{\text{Carrier-Phase Bias}} - \underbrace{I_r^s + T_r^s}_{\text{Other}} + \underbrace{\lambda B_r^s + d_r^s}_{\text{Correction Terms}} + \varepsilon_\phi && \text{(m)}
 \end{aligned}$$

Carrier-Phase Bias Other Correction Terms

Pseudorange:

$$P_r^s = \underbrace{\rho_r^s + c(dt_r - dT^s)}_{\text{Carrier-Phase Bias}} + I_r^s + T_r^s + \varepsilon_P$$

Carrier-Phase Model (2)

Carrier-Phase Bias:

$$\underline{B_r^S} = \phi_{r,0} - \phi_0^S + N_r^S \quad (\text{cycle})$$

N_r^S : Integer Ambiguity

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

ϕ_0^S : Satellite Initial Phase

Other Correction Terms:

$$\underline{d_r^S} = -\mathbf{d}_{r,pco}^T \mathbf{e}_{r,enu}^S + \left(\mathbf{E}_{sat \rightarrow ecef} \mathbf{d}_{pco}^S \right)^T \mathbf{e}_r^S + d_{r,pcv} + d_{pcv}^S - \mathbf{d}_{disp}^T \mathbf{e}_{r,enu}^S + d_{pw} + d_{rel} \quad (\text{m})$$

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

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

\mathbf{d}_{pco}^S : Satellite Antenna Phase Center Offset

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

\mathbf{d}_{disp} : Site Displacement

d_{pw} : Phase Wind-up Effect

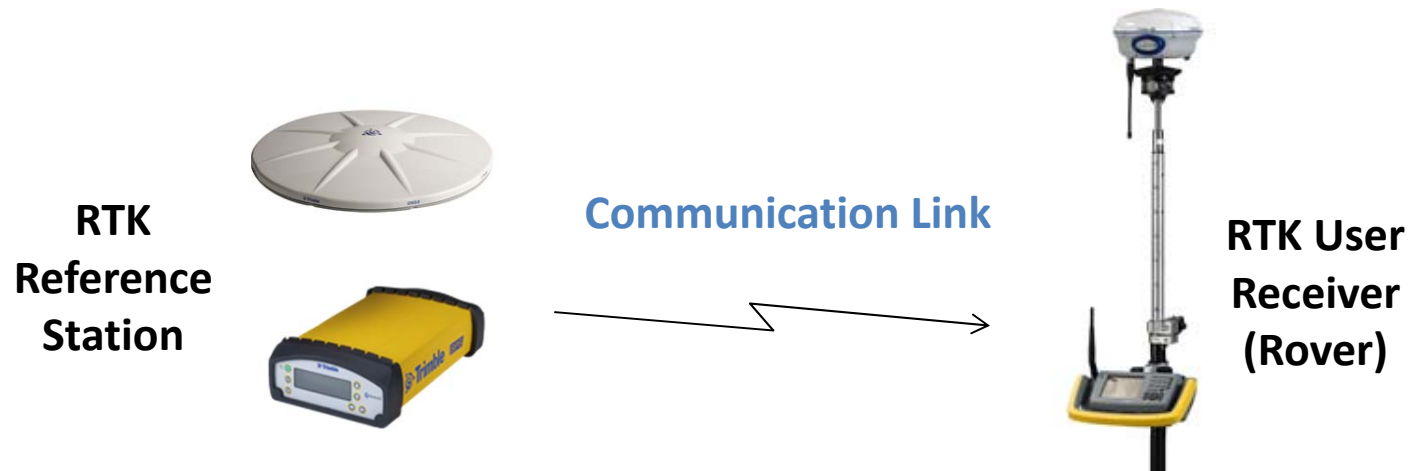
d_{rel} : Relativistic Effect

2 RTK Basics

RTK (Real-Time Kinematic)

- **Technique with Baseline Processing**

- Real-time Position of Rover Antenna
- Transmit Reference Station Data to Rover via Comm. Link
- OTF (On-the-Fly) Integer Ambiguity Resolution
- Typical Accuracy: 1 cm + 1ppm x BL RMS (Horizontal)



RTK Applications



Geodetic Survey



Construction Machine Control



Precision Agriculture



Self-driving Car



Mapping



UAV (Drone)

RTK Algorithm (1)

Carrier-Phase:

$$\begin{aligned}
 \phi_r^s &= \phi_r(t_r) - \phi^s(t^s) + N_r^s + \varepsilon_\phi \quad (\phi_{r,0} = \phi_r(t_0), \phi_0^s = \phi^s(t_0)) \\
 &= (f(t_r + dt_r - t_0) + \phi_{r,0}) - (f(t^s + dT^s - t_0) + \phi_0^s) + N_r^s + \varepsilon_\phi \\
 &= \frac{c}{\lambda}(t_r - t^s) + \frac{c}{\lambda}(dt_r - dT^s) + (\phi_{r,0} - \phi_0^s + N_r^s) + \varepsilon_\phi \quad (\text{cycle}) \\
 \Phi_r^s &\equiv \lambda\phi_r^s = c(t_r - t^s) + c(dt_r - dT^s) + \lambda(\phi_{r,0} - \phi_0^s + N_r^s) + \lambda\varepsilon_\phi \\
 &= \rho_r^s + c(dt_r - dT^s) - I_r^s + T_r^s + \underbrace{\lambda B_r^s}_{\text{Carrier-Phase Bias}} + \underbrace{d_r^s}_{\text{Other Correction Terms}} + \varepsilon_\phi \quad (\text{m})
 \end{aligned}$$

Carrier-Phase Bias:

$$\begin{aligned}
 B_r^s &= \phi_{r,0} - \phi_0^s + N_r^s \quad (\text{cycle}) \\
 N_r^s &: \text{Integer Ambiguity} \\
 \phi_{r,0} &: \text{Receiver Initial Phase} \\
 \phi_0^s &: \text{Satellite Initial Phase}
 \end{aligned}$$

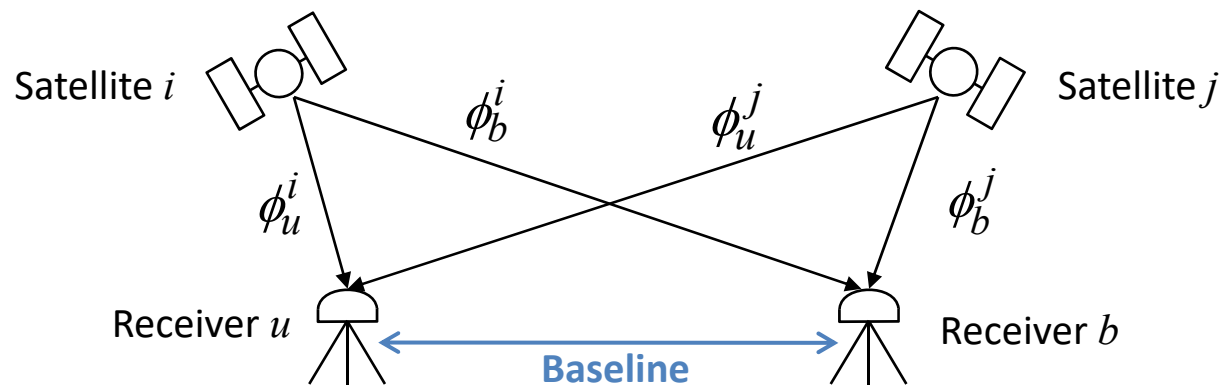
RTK Algorithm (2)

DD (Double-difference) :

$$\begin{aligned} \Phi_{ub}^{ij} &\equiv \lambda((\phi_u^i - \phi_b^i) - (\phi_u^j - \phi_b^j)) \\ &= \rho_{ub}^{ij} + c(dt_{ub}^{ij} - dT_{ub}^{ij}) - I_{ub}^{ij} + T_{ub}^{ij} + \lambda B_{ub}^{ij} + d_{ub}^{ij} + \varepsilon_{\Phi} \\ &= \rho_{ub}^{ij} - I_{ub}^{ij} + T_{ub}^{ij} + \lambda N_{ub}^{ij} + d_{ub}^{ij} + \varepsilon_{\Phi} \\ dt_{ub}^{ij} &= dt_u^{ij} - dt_b^{ij} = 0, dT_{ub}^{ij} = dT_{ub}^i - dT_{ub}^j \approx 0 \\ B_{ub}^{ij} &= (\phi_{u,0} - \phi_0^i + N_u^i) - (\phi_{b,0} - \phi_0^i + N_b^i) - (\phi_{u,0} - \phi_0^j + N_u^j) + (\phi_{b,0} - \phi_0^j + N_b^j) = N_{ub}^{ij} \end{aligned}$$

(short Baseline and same antenna type)

$$\Phi_{ub}^{ij} \approx \rho_{ub}^{ij} + \lambda N_{ub}^{ij} + \varepsilon_{\Phi} \quad I_{ub}^{ij} = I_{ub}^i - I_{ub}^j \approx 0, T_{ub}^{ij} = T_{ub}^i - T_{ub}^j \approx 0, d_{ub}^{ij} = d_{ub}^i - d_{ub}^j \approx 0$$



RTK Algorithm (3)

Nonlinear-LSE:

Parameter Vector:

$$\mathbf{x} = (\mathbf{r}_u^T, N_{ub}^{s_2s_1}, N_{ub}^{s_3s_1}, \dots, N_{ub}^{s_ms_1})^T$$

Measurement Vector:

$$\mathbf{y} = (\mathbf{y}_{t_1}^T, \mathbf{y}_{t_2}^T, \dots, \mathbf{y}_{t_n}^T)^T$$

Meas Model, Design Matrix:

$$\mathbf{h}(\mathbf{x}) = (\mathbf{h}_{t_1}(\mathbf{x})^T, \mathbf{h}_{t_2}(\mathbf{x})^T, \dots, \mathbf{h}_{t_n}(\mathbf{x})^T)^T$$

$$\mathbf{H} = (\mathbf{H}_{t_1}^T, \mathbf{H}_{t_2}^T, \dots, \mathbf{H}_{t_n}^T)^T$$

Meas Error Covariance:

$$\mathbf{R} = \text{blkdiag}(\mathbf{R}_{t_1}, \mathbf{R}_{t_2}, \dots, \mathbf{R}_{t_n})$$

Solution (Static/Float):

$$\hat{\mathbf{x}} = \mathbf{x}_0 + (\mathbf{H}^T \mathbf{R}^{-1} \mathbf{H})^{-1} \mathbf{H}^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{h}(\mathbf{x}_0))$$

$$\mathbf{y}_{t_k} = (\Phi_{ub,t_k}^{s_2s_1}, \Phi_{ub,t_k}^{s_3s_1}, \dots, \Phi_{ub,t_k}^{s_ms_1})^T$$

$$\mathbf{h}_{t_k}(\mathbf{x}) = \begin{pmatrix} \rho_{u,t_k}^{s_2s_1} - \rho_{b,t_k}^{s_2s_1} + \lambda N_{ub}^{s_2s_1} \\ \rho_{u,t_k}^{s_3s_1} - \rho_{b,t_k}^{s_3s_1} + \lambda N_{ub}^{s_3s_1} \\ \vdots \\ \rho_{u,t_k}^{s_ms_1} - \rho_{b,t_k}^{s_ms_1} + \lambda N_{ub}^{s_ms_1} \end{pmatrix}$$

$$\mathbf{H}_{t_k} = \begin{pmatrix} -\mathbf{e}_{u,t_k}^{s_2s_1 T} & \lambda & 0 & \dots & 0 \\ -\mathbf{e}_{u,t_k}^{s_3s_1 T} & 0 & \lambda & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\mathbf{e}_{u,t_k}^{s_ms_1 T} & 0 & 0 & \dots & \lambda \end{pmatrix}$$

$$\mathbf{R}_{t_k} = \begin{pmatrix} 4\sigma_\Phi^2 & 2\sigma_\Phi^2 & \dots & 2\sigma_\Phi^2 \\ 2\sigma_\Phi^2 & 4\sigma_\Phi^2 & \dots & 2\sigma_\Phi^2 \\ \vdots & \vdots & \ddots & \vdots \\ 2\sigma_\Phi^2 & 2\sigma_\Phi^2 & \dots & 4\sigma_\Phi^2 \end{pmatrix}$$

\mathbf{r}_b : Fixed Base-Station Position

Integer Ambiguity Resolution

ILS problem:

$$\begin{aligned} \mathbf{x} &= (\mathbf{a}^T, \mathbf{b}^T)^T, \mathbf{H} = (\mathbf{A}, \mathbf{B}) \\ \mathbf{y} &= \mathbf{H}\mathbf{x} + \mathbf{v} = \mathbf{A}\mathbf{a} + \mathbf{B}\mathbf{b} + \mathbf{v} \\ \tilde{\mathbf{x}} &= \arg \min_{\mathbf{a} \in \mathbf{Z}^n, \mathbf{b} \in \mathbf{R}^m} (\mathbf{y} - \mathbf{H}\mathbf{x})^T \mathbf{Q}_y^{-1} (\mathbf{y} - \mathbf{H}\mathbf{x}) \end{aligned}$$

Strategy to solve it:

(1) Conventional LSE

$$\hat{\mathbf{x}} = \begin{pmatrix} \hat{\mathbf{a}} \\ \hat{\mathbf{b}} \end{pmatrix} = \mathbf{Q}_x \mathbf{H}^T \mathbf{Q}_y^{-1} \mathbf{y}, \mathbf{Q}_x = \begin{pmatrix} \mathbf{Q}_a & \mathbf{Q}_{ab} \\ \mathbf{Q}_{ba} & \mathbf{Q}_b \end{pmatrix} = (\mathbf{H}^T \mathbf{Q}_y \mathbf{H})^{-1}$$

(2) Search Integer Vector with Minimum Squared Residuals

$$\tilde{\mathbf{a}} = \arg \min_{\mathbf{a} \in \mathbf{Z}^n} (\hat{\mathbf{a}} - \mathbf{a})^T \mathbf{Q}_a^{-1} (\hat{\mathbf{a}} - \mathbf{a})$$

(3) Improve solution

$$\tilde{\mathbf{b}} = \hat{\mathbf{b}} - \mathbf{Q}_{ba} \mathbf{Q}_a^{-1} (\hat{\mathbf{a}} - \tilde{\mathbf{a}})$$

ILS: Integer Least Square

LAMBDA

Teunissen, P.J.G. (1995)

The least-squares ambiguity decorrelation adjustment: a method for fast GPS integer ambiguity estimation. *Journal of Geodesy*, Vol. 70, No. 1-2, pp. 65-82.

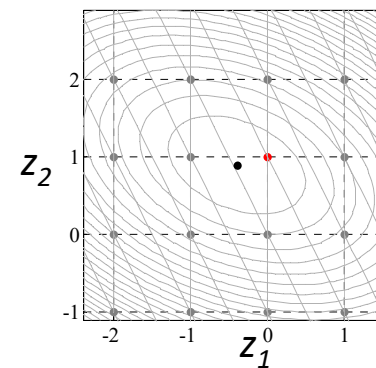
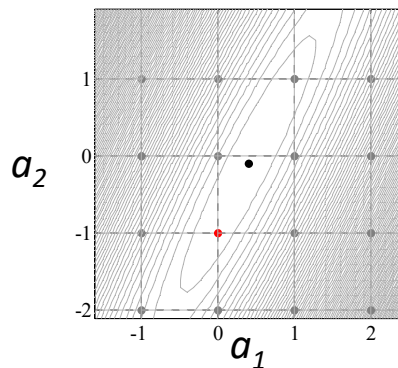
- **ILS Estimation with:**

- Shrink Integer Search Space with "Decorrelation"
- Efficient Tree Search Strategy
- Similar to *Closest Point Search with LLL Lattice Basis Reduction Algorithm*

$$\tilde{\mathbf{a}} = \underset{\mathbf{a} \in \mathbf{Z}^n}{\operatorname{argmin}} (\hat{\mathbf{a}} - \mathbf{a})^T \mathbf{Q}_a^{-1} (\hat{\mathbf{a}} - \mathbf{a})$$

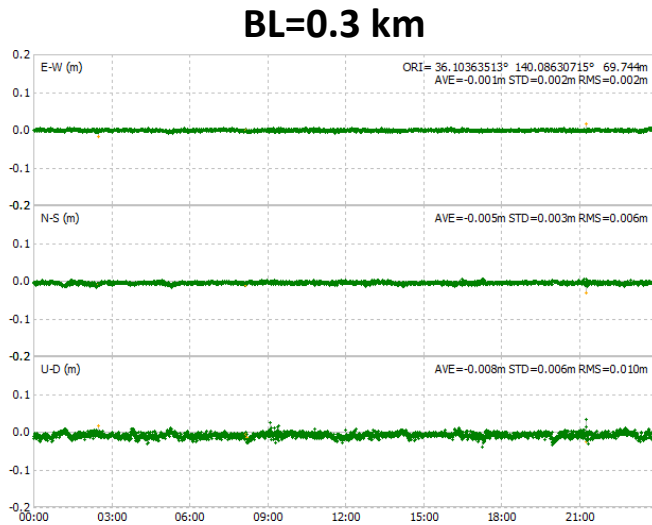


$$\begin{aligned} \hat{\mathbf{z}} &= \mathbf{Z}^T \hat{\mathbf{a}}, \mathbf{Q}_z = \mathbf{Z}^T \mathbf{Q}_a \mathbf{Z} \\ \tilde{\mathbf{z}} &= \underset{\mathbf{z} \in \mathbf{Z}^n}{\operatorname{argmin}} (\hat{\mathbf{z}} - \mathbf{z})^T \mathbf{Q}_z^{-1} (\hat{\mathbf{z}} - \mathbf{z}) \\ \tilde{\mathbf{a}}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

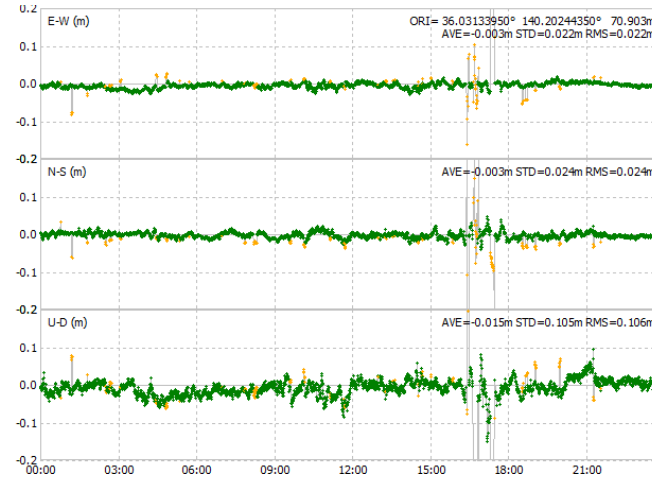


Effect of Baseline Length

RMS Error:
E: 0.2cm
N: 0.6cm
U: 1.0cm
Fix Ratio:
99.9%

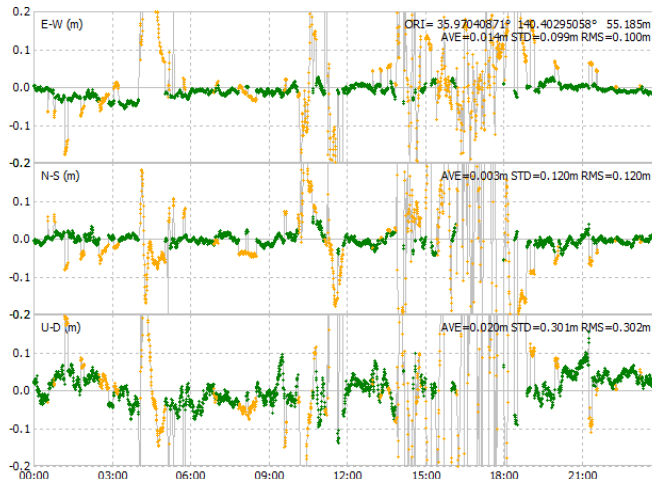


BL=13.3 km

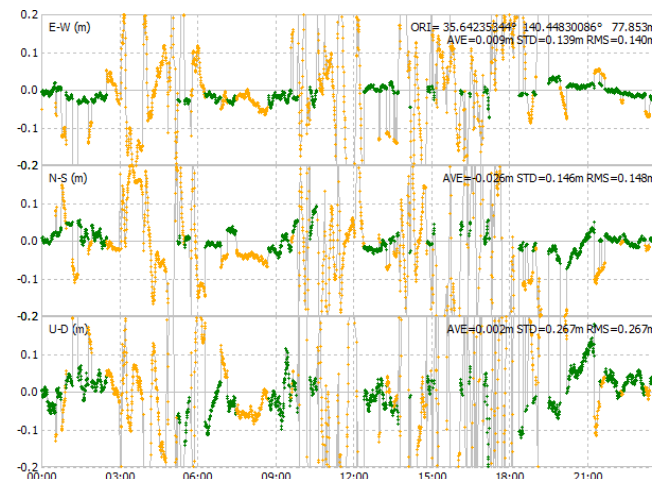


RMS Error:
E: 2.2cm
N: 2.4cm
U: 10.6cm
Fix Ratio:
94.2%

BL=32.2 km



BL=60.9 km



RMS Error:
E: 10.0cm
N: 12.0cm
U: 30.2cm
Fix Ratio:
64.3%

RMS Error:
E: 14.0cm
N: 14.8cm
U: 26.7cm
Fix Ratio:
44.4%

(24 hr Kinematic ● : Fixed Solution ● : Float Solution)

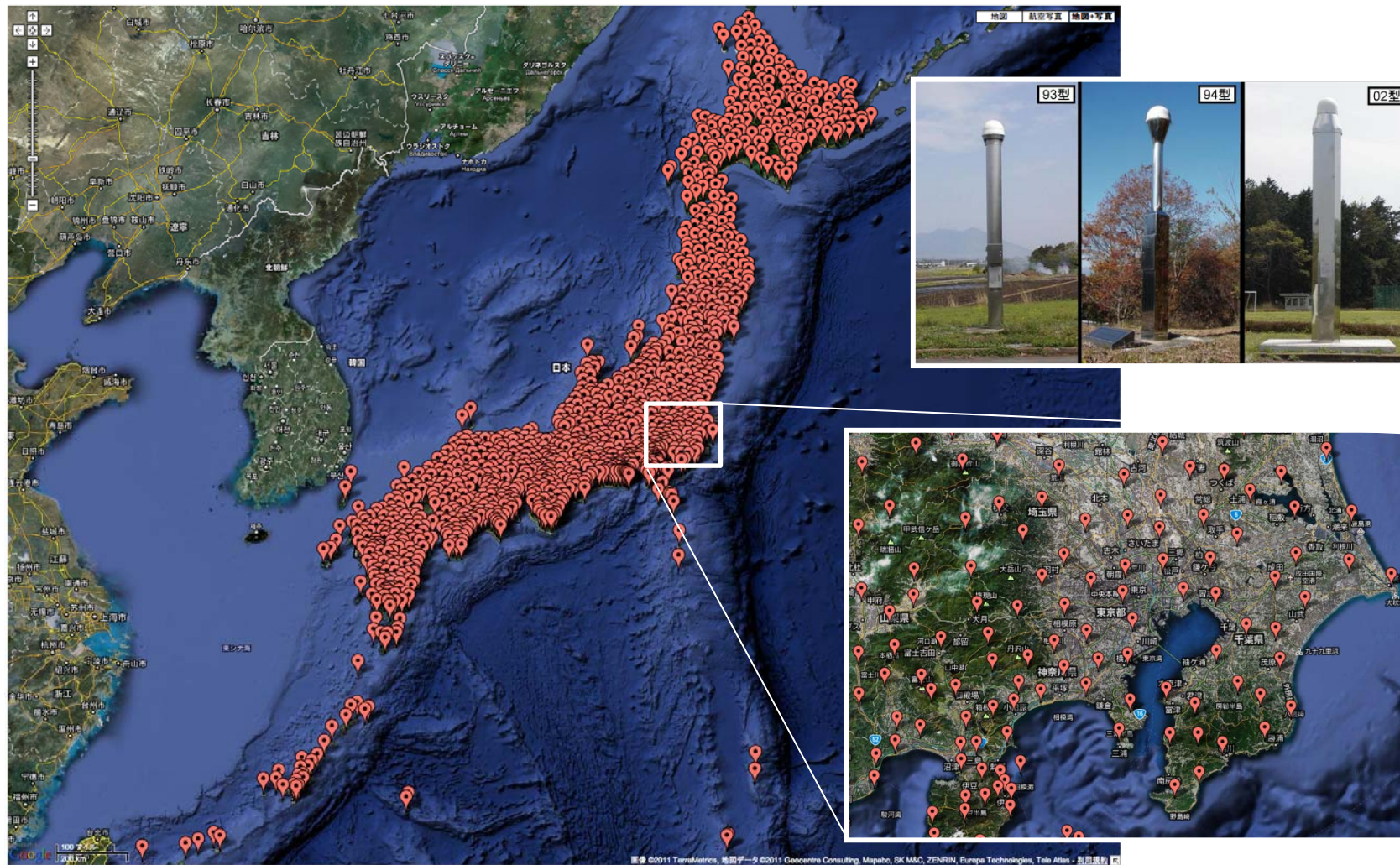
Network RTK (NRTK)

- **Extension of RTK**
 - RTK without User Reference Station
 - Sparse Networked Reference Stations
 - Correction Messages via Mobile-Phone Network
 - Format: **VRS**, **FKP**, MAC, RTCM 2.3, RTCM 3.2
 - Server S/W: Trimble GPSNet, GEO++ GNSMART, ...
 - NTRIP Networked Transport of RTCM via Internet Protocol
- **NRTK Service in Japan**
 - GEONET: ~1300 Reference Stations by GSI
 - NGDS (www.gpsdata.co.jp), JENOBA (www.jenoba.jp), Nihon Terasat (www.terasad.co.jp)

Japanese GEONET

GEONET STATIONS MAP by Google Map : [GEONET Stations](#)

[IGS Map | Home](#)

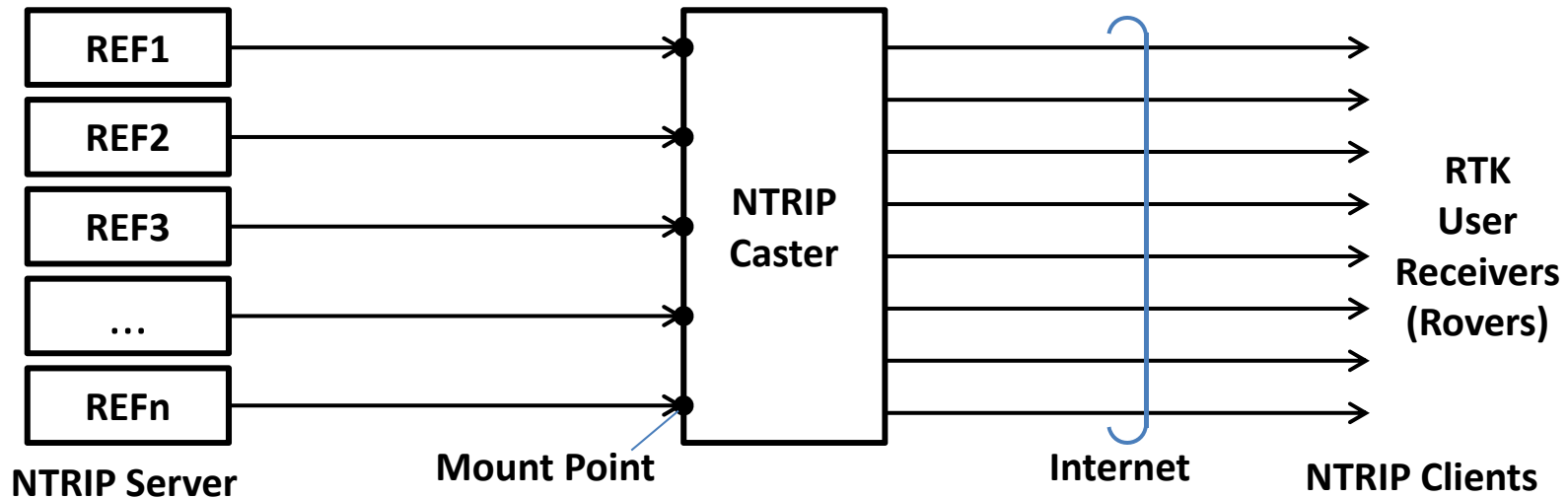


The station coordinates are based on the F2 solution on 2007/1/1 provided by GSI. Height : ellipsoidal height (WGS84)

(<http://terras.gsi.go.jp/ja/index.htm>)

NTRIP

- Networked Transport of RTCM via Internet Protocol



Ntrip Browser ver:2.4.3 b30

File Edit View Help

rt.igs.org:2101 STR CAS NET SRC MAP

| Mountpoint | ID | Format | Format-Details | Carri | Nav-System | Network | Cour | Latitude | Longitude | NM | So | Generator | Comj | Au | Fe | Bitrate |
|------------|----------------|----------|--|-------|-------------|------------|--------------|----------|-----------|----|----|----------------------|------|----|----|---------|
| FFMJ1 | Frankfurt | RTCM 3.1 | 1004(1),1006(10),1008(10),1012(1),1019(30),10 | 2 | GPS+GLO | IGS | DEU 50.09 | 8.66 | 0 | 0 | 0 | JAVAD TRE_G3TH DELT. | none | B | N | 2400 |
| GAMB1 | Rikitea CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO+GAL | REGINA,IGS | PYF -23.07 | -134.57 | 0 | 0 | 0 | Trimble NetR9 | none | B | N | 2400 |
| GAMG1 | Gamak CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO | REGINA,RG | KOR 35.59 | 127.92 | 0 | 1 | 0 | SEPT POLARX4TR | none | B | N | 2400 |
| GOP60 | Pecny-Ondrejov | RTCM 2.3 | 3(10),18(1),19(1),22(10) | 2 | GPS+GLO | IGS | CZE 49.91 | 14.79 | 0 | 0 | 0 | Topcon NetG3 | none | B | N | 4000 |
| GOP60 | Pecny-MGEX | RTCM 3 | 1004(1),1006(15),1008(15),1012(1),1033(15) | 2 | GPS+GLO+GAL | IGS | CZE 49.91 | 14.79 | 0 | 0 | 0 | Leica GRX1200+GNSS | none | B | N | 3000 |
| GOP61 | Pecny-MGEX | RTCM 2 | 1(1),3(15),18(1),19(1),22(15),23(15),24(15) | 2 | GPS+GLO+GAL | IGS | CZE 49.91 | 14.79 | 0 | 0 | 0 | Leica GRX1200+GNSS | none | B | N | 3000 |
| GOP62 | Pecny-MGEX | LB2 | | 2 | GPS+GLO+GAL | IGS | CZE 49.91 | 14.79 | 0 | 0 | 0 | Leica GRX1200+GNSS | none | B | N | 3000 |
| GRAC1 | Grasse IGN | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLONASS | RGP,REGIN, | FRA 43.75 | 6.92 | 0 | 1 | 0 | Leica GR25 | none | B | N | 2400 |
| GRAS1 | Grasse CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO | RGP,EPN,IG | FRA 43.75 | 6.92 | 0 | 1 | 0 | Trimble NetR5 | none | B | N | 2400 |
| HARB1 | Harb CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO+GAL | REGINA,IGS | FRA -25.53 | 27.42 | 0 | 0 | 0 | Trimble NetR9 | none | B | N | 2400 |
| HOB27 | Hobart (TAS) | RTCM 3.2 | 1006(15),1008(15),1013(60),1019(60),1020(60),2 | 2 | GPS+GLO+GAL | ARGN | AUS -42.8047 | 147.4387 | 0 | 0 | 0 | SEPT POLARX5 | none | B | N | 9600 |
| JOG20 | Yogyakarta | RTCM3.0 | 1004(1),1006(10),1007(10),1012(1),1019(120),1 | 2 | GPS+GLO+GAL | Misc | IDN -7.50 | 107.25 | 0 | 1 | 0 | JAVAD TRE_G3TH DELT. | none | B | N | 3000 |
| KAT17 | Katherine (NT) | RTCM 3.2 | 1006(15),1008(15),1013(60),1019(60),1020(60),2 | 2 | GPS+GLO+GAL | ARGN | AUS -14.3760 | 132.1532 | 0 | 0 | 0 | SEPT POALRX5 | none | B | N | 9600 |
| KERG1 | Kerguelen CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO+GAL | REGINA,IGS | FRA -49.21 | 70.15 | 0 | 0 | 0 | Trimble NetR9 | none | B | N | 2400 |
| KIR14 | Betio | RTCM 3.2 | 1006(15),1008(15),1013(15),1019(60),1020(60),2 | 2 | GPS+GLO+GAL | SPRGN | KIR 1.35458 | 172.9228 | 0 | 0 | 0 | TRIMBLE NETR9 | none | B | N | 9600 |
| KIT30 | Kitab | RTCM 3.0 | 1004(1),1006(10),1007(10),1012(1),1019(120),1 | 0 | GPS+GLO+GAL | IGS | UZB 38.94 | 66.88 | 0 | 0 | 0 | JAVAD TRE_G3TH DELT. | none | B | N | 3000 |
| KITG1 | Kitab CNES | RTCM 3.1 | 1004/1012(1),1006/1008/1013/1033(10),1019/1 | 2 | GPS+GLO+GAL | REGINA,IGS | UZB 39.8 | 66.53 | 0 | 0 | 0 | Trimble NetR9 | none | B | N | 2400 |

source table received

RTCM 3.3 OBS, MSM, NAV, ANT

| 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 | 1042 | - |
| 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* | 1258* | 1252* |
| Clock Corr. | 1058 | 1064 | 1241* | 1247* | 1259* | 1253* |
| Code Bias | 1059 | 1065 | 1242* | 1248* | 1260* | 1254* |
| Combined | 1060 | 1066 | 1243* | 1249* | 1261* | 1255* |
| URA | 1061 | 1067 | 1244* | 1250* | 1262* | 1256* |
| HR-Clock | 1062 | 1068 | 1245* | 1251* | 1263* | 1257* |
| Antenna Info | 1005 | 1006 | 1007 | 1008 | 1033 | |

* draft

3 RTK Practice

Receiver and Antenna

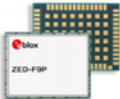
Product Summary
ZED-F9P

u-blox F9 high precision GNSS module

Multi-band receiver delivers centimeter-level accuracy in seconds

- Concurrent reception of GPS, GLONASS, Galileo and BeiDou
- Multi-band RTK with fast convergence times and reliable performance
- High update rate for highly dynamic applications
- Centimeter accuracy in a small and energy-efficient module
- Easy integration of RTK for fast time-to-market

17.0 x 22.0 x 2.4 mm



Product description


The ZED-F9P positioning module features the new u-blox F9 receiver platform, which provides multi-band GNSS to high volume industrial applications in a compact form factor. ZED-F9P is a multi-band GNSS module with integrated u-blox multi-band RTK technology for centimeter-level accuracy. The module enables precise navigation and automation of moving industrial machinery by means of a small, surface mounted module.

The ZED-F9P module is designed for easy integration and low design-in costs with minimal e-BOM. It is well-suited for mass market adoption, thanks to its small package size, light weight, and small power consumption.

ZED-F9P ensures the security of positioning and navigation information by using secure interfaces and advanced jamming and spoofing detection technologies.

ZED-F9P offers support for a range of correction services allowing each application to optimize performance according to the application's individual need. ZED-F9P comes with built-in support for standard RTCM corrections, supporting centimeter-level navigation from local base stations or from virtual reference stations (VRS) in a Network RTK setup. The module can be upgraded to support future SSR-type correction services suitable for mass market penetration.

u-blox modules are manufactured in ISO/TS 16949 certified sites and are fully tested on a system level. Qualification tests are performed as stipulated in the ISO 16750 standard: "Road vehicles – Environmental conditions and testing for electrical and electronic equipment".




Standard

Professional

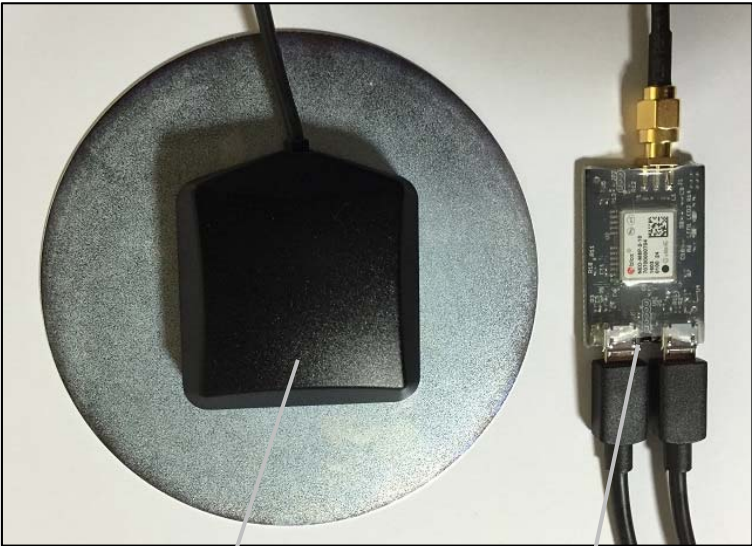
Automotive

| | ZED-F9P |
|----------------------------------|---------|
| Grade | |
| Automotive | |
| Professional | • |
| Standard | |
| GNSS | |
| GPS / QZSS | • |
| GLONASS | • |
| Galileo | • |
| BeiDou | • |
| Number of concurrent GNSS | 4 |
| Multi-band | • |
| Interfaces | |
| UART | 2 |
| USB | 1 |
| SPI | 1 |
| DDC (I ² C compliant) | 1 |
| Features | |
| Programmable (Flash) | • |
| Data logging | • |
| Carrier phase output | • |
| Additional SAW | • |
| RTC crystal | • |
| Oscillator | Y |
| RTK rover | • |
| RTK base station | • |
| Moving base | • |
| Survey-in and fixed mode | • |
| Timepulse | 1 |
| Power supply | |
| 2.7 V – 3.6 V | • |

T = TCXO



UBX-17005151 - R05



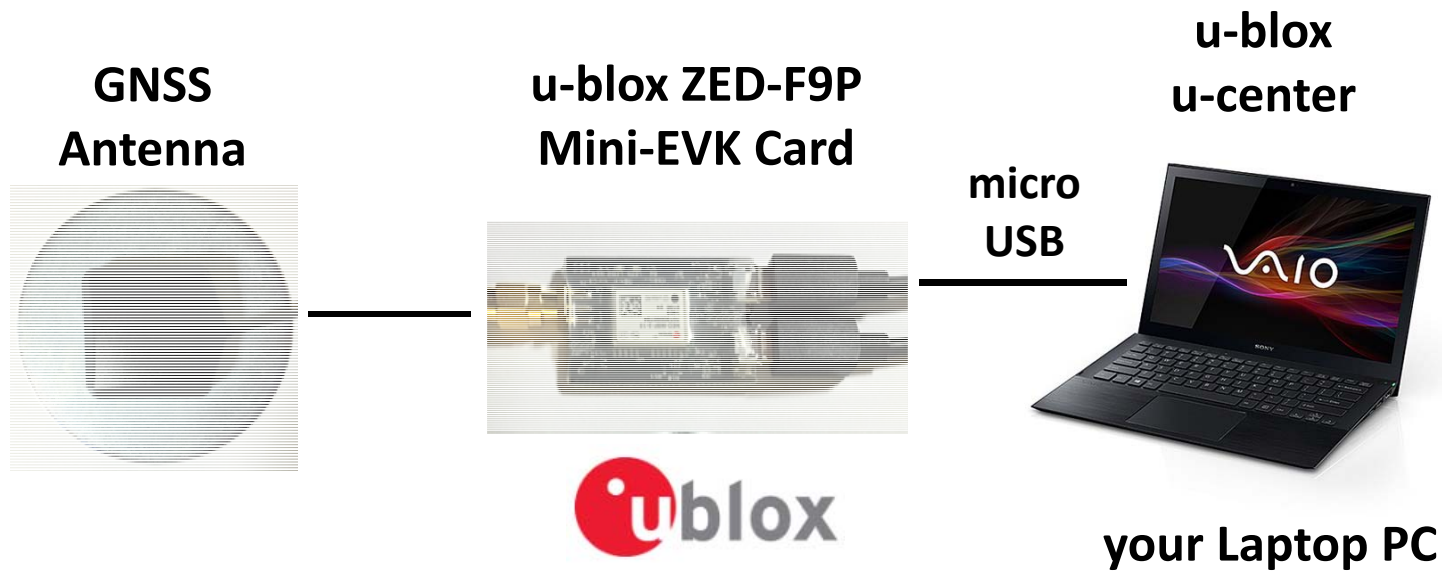
**GNSS
Antenna**

**u-blox ZED-F9P
Mini-EVK Card**

Receiver Modules are provided by  .

Setup u-blox Receiver/u-center

- **Install u-center 19.04 to your laptop PC**
 - seminar_2019¥ublox¥u-centersetup_v19.04.zip



u-center 19.04

The screenshot displays the u-center 18.06 software interface with several key components:

- Connect Button:** A callout box points to the 'Connect' button in the top-left toolbar.
- Message View:** A window titled 'UBX - NAV (Navigation) - PVT (Navigation PVT Solution)' showing a table of parameters:

| Param | Value | Units |
|---|---------------------------------|---------------|
| GPS Time Tag | 364447.000 | [s] |
| UTC Date and Time | 26/ 7/ 2018 05:13:49 +000091624 | |
| UTC Date and Time Confirmation Status | n/a | |
| UTC Time Accuracy | 3 | [ns] |
| Position Fix Type | -- -- | |
| Fix Flags | | |
| PSM state | | |
| Position Latitude | 138.3896653, 1004.2. 9... | [deg,deg,m,m] |
| Position Accuracy | | [m,m] |
| Velocity North, E |), -0.013 | [m/s,m/s,m/s] |
| Velocity, Heading | | [m/s,deg] |
| Speed over Ground | 0.015 | [m/s] |
| Heading of Motion, Heading of Vehicle | 0.0, n/a | [deg,deg] |
| Magnetic Declination, Declination Accuracy Estim... | n/a, n/a | [deg,deg] |
| PDOP | 1.17 | |
- Docking Windows - Data:** A window showing various accuracy and status metrics:

| | |
|-------------|-------------|
| Altitude | 1004.162 m |
| TTFF | |
| Fix Mode | 3D |
| 3D Acc. [m] | 1.74 |
| 2D Acc. [m] | 0.75 |
| PDOP | 1.2 |
| HDOP | |
| Satellites | [Bar chart] |
- Satellite Position:** A circular diagram showing the positions of various satellites (e.g., E1, B13, B8, G2, E3, G10, B2, B10, B7, B17, B4, G43, B7, B8, G9) around a central point.
- Satellite Level:** A bar chart showing the signal strength or level for each satellite, with values ranging from approximately 10 to 50.
- Configuration View:** A window titled 'UBX - CFG (Config) - ANT (Antenna Settings)' with several checked options:
 - Enable supply voltage control signal
 - Enable short circuit detection
 - Enable short circuit power down logic
 - Enable auton
 - Enable open
 Control Signal settings:
 - Short Circuit Detection: 15
 - Open Circuit Detection: 14

The bottom status bar shows: Ready, u-blox M8/8, COM15 9600, No file open, UBX, 00:02:0 [05:13:4].

Configure u-blox Receiver

- **GNSS (GNSS Config)**
GPS, Galileo, BeiDou, QZSS, GLONASS: Enabled
- **MSG (Messages)**
02-15 RXM-RAWX: USB - ON (raw observation data)
02-13 RXM-SFRBX: USB - ON (navigation data)
01-07 NAV-PVT: USB - ON (optional)
01-35 NAV-SAT: USB - ON (optional)
Others: USB - OFF
- **CFG (Configuration)**
Save current configuration

UBX-RXM-RAWX

COM15 - u-center 18.06 - [Messages - UBX - RXM (Receiver Manager) - RAWX (Multi-GNSS Raw Measurement Data)]

File Edit View Player Receiver Tools Window Help

UBX - RXM (Receiver Manager) - RAWX (Multi-GNSS Raw Measurement Data) 54 s

Local Time: 2011:374006.010000000 [s]

Leap seconds: 18 (VALID) [s] Clock reset

| SV | Sign... | G... | Pseudo Range [m] | Carrier Phase [c... | Dopple... | Lock T... | SNR | PR Std... | CP Std... | DD Std... | P... |
|-----|---------|------|------------------|---------------------|-----------|-----------|-----|-----------|-----------|-----------|------|
| B20 | B1D1 | - | 27272669.41 | 142015916.06 | -2305.2 | 64500 | 44 | 0.32 | 0.004 | 0.512 | Y |
| B29 | B1D1 | - | 26057302.70 | 135687172.39 | -2147.4 | 64500 | 46 | 0.32 | 0.004 | 0.512 | Y |
| G06 | L1C/A | - | 23308321.52 | 122486037.90 | 788.9 | 64500 | 50 | 0.32 | 0.004 | 0.512 | Y |
| G23 | L1C/A | - | 26014279.91 | 136705949.34 | -1730.5 | 64500 | 44 | 0.32 | 0.004 | 0.512 | Y |
| G09 | L1C/A | - | 23780294.56 | 124966274.89 | -30.8 | 64500 | 48 | 0.32 | 0.004 | 0.512 | Y |
| G19 | L1C/A | - | 23566247.83 | 123841458.78 | -1299.0 | 64500 | 48 | 0.32 | 0.004 | 0.512 | Y |
| G05 | L1C/A | - | 26488704.18 | 139199076.00 | 3143.5 | 64500 | 45 | 0.32 | 0.004 | 0.512 | Y |
| E08 | E1C | - | 26000644.20 | 136634284.88 | -1642.3 | 64500 | 43 | 0.32 | 0.004 | 0.512 | Y |
| E07 | E1C | - | 26209520.70 | 137731951.71 | 918.3 | 64500 | 45 | 0.32 | 0.004 | 0.512 | Y |
| E26 | E1C | - | 24894493.44 | 130821453.22 | 1591.8 | 64500 | 46 | 0.32 | 0.004 | 0.512 | Y |
| B08 | B1D1 | - | 38872908.20 | 202421412.88 | 895.2 | 64500 | 45 | 0.32 | 0.004 | 0.512 | Y |
| B01 | B1D2 | - | 39969065.33 | 208129362.18 | 327.0 | 64500 | 44 | 0.32 | 0.004 | 0.512 | Y |
| B04 | B1D2 | - | 40527998.69 | 211039892.20 | 348.3 | 64500 | 41 | 0.32 | 0.004 | 0.512 | Y |
| B13 | B1D1 | - | 39986160.58 | 208218403.54 | 1077.2 | 64500 | 45 | 0.32 | 0.004 | 0.512 | Y |
| B03 | B1D2 | - | 40763929.75 | 212268443.87 | 395.4 | 64500 | 41 | 0.32 | 0.004 | 0.512 | Y |
| I02 | B1D2 | - | 42331098.24 | 220429101.74 | 395.6 | 64500 | 36 | 0.64 | 0.004 | 0.512 | Y |
| B06 | B1D1 | - | 41061337.63 | 213817123.08 | 1494.5 | 64500 | 37 | 0.64 | 0.004 | 0.512 | Y |
| B09 | B1D1 | - | 43123520.45 | 224555440.89 | 1646.2 | 23000 | 31 | 1.28 | 0.008 | 0.512 | Y |
| B12 | B1D1 | - | 27368786.61 | 142516424.99 | 3237.6 | 64500 | 40 | 0.32 | 0.004 | 0.512 | Y |
| B22 | B1D1 | - | 26182123.85 | 136337206.70 | 2462.4 | 64500 | 46 | 0.32 | 0.004 | 0.512 | Y |
| Q01 | L1C/A | - | 41099852.20 | 215981182.49 | -321.9 | 64500 | 46 | 0.32 | 0.004 | 0.512 | Y |
| G07 | L1C/A | - | 28367339.25 | 149071398.91 | 2633.6 | 64500 | 37 | 0.64 | 0.004 | 0.512 | Y |
| E14 | E1C | - | 31162480.74 | 163759935.65 | -3933.8 | 64500 | 34 | 0.64 | 0.004 | 0.512 | Y |
| G17 | L1C/A | - | 24521334.47 | 128860472.88 | -2270.9 | 64500 | 46 | 0.32 | 0.004 | 0.512 | Y |
| G12 | L1C/A | - | 26896834.52 | 141343824.13 | -815.2 | 64500 | 41 | 0.32 | 0.004 | 0.512 | Y |
| G02 | L1C/A | - | 25732372.17 | 135224561.05 | 2724.7 | 64500 | 44 | 0.32 | 0.004 | 0.512 | Y |
| B19 | B1D1 | - | 24509092.65 | 127625243.96 | 598.0 | 64500 | 48 | 0.32 | 0.004 | 0.512 | Y |

Right Panel 1: Longitude 138.38966490, Latitude 35.87300570, Altitude 1003.334 m, TTFF, Fix Mode 3D, 3D Acc. [m] 1.65, 2D Acc. [m] 0.86, PDOP 1.3, HDOP 0.7, Satellites (bar chart)

Right Panel 2: Satellite constellation diagram showing SV positions relative to North (N), East (E), South (S), and West (W).

Right Panel 3: Signal strength bar chart for various satellites, with values ranging from approximately 10 to 50.

Bottom Status Bar: Ready | u-blox M8/8 | COM15 9600 | No file open | UBX | 02:42:1 07:54:C

UBX-RXM-SFRBX

COM15 - u-center 18.06 - [Messages - UBX - RXM (Receiver Manager) - SFRBX (Subframe Data NG)]

File Edit View Player Receiver Tools Window Help

RTCM3
 UBX
 [+] ACK (Acknowledge)
 [+] AID (GPS Aiding)
 [+] CFG (Config)
 [+] ESF (External Sensor Fusion)
 [+] HNR (High Navigation Rate)
 [] INF (Information)
 [+] LOG (Data Logger)
 [+] MGA (Multiple GNSS Assistance)
 [+] MON (Monitor)
 [+] NAV (Navigation)
 [] RXM (Receiver Manager)
 [] ALM (Almanac)
 [] EPH (Ephemeris)
 [] IMES (IMES Status)
 [] MEASX (Measurement Data)
 [] PMREQ (Power Mode Request)
 [] RAW (Raw Measurement Data)
 [] RAWX (Multi-GNSS Raw Meas...)
 [] RLM (Return Link Message)
 [] RTCM (RTCM input status)
 [] SFRB (Subframe Data)
 [] SFRBX (Subframe Data NG)
 [] SVS (SV Status Info)
 [] SEC (Security)
 [] TIM (Timing)
 [] UPD (Firmware Update Messages)
 [] ??-?? (Unknown)
 [] ??-?? (Custom)
 UNKNOWN
 CUSTOM

UBX - RXM (Receiver Manager) - SFRBX (Subframe Data NG) 0 s

denotes data received on subChn Strip Parity Bits

| SV | MSG | DATA [* denotes invalid words] |
|----------------|--------|---|
| BDS 1 B1D2 0 | 4 | 389045B5 16880020 00000000 00000000 00000000 0000150A 1555554B 1555554B 1555554B |
| BDS 2 B1D2 0 | 3 | 389035BE 1689E02C 00090133 0F7777DA 1DDDD0DE 3717F915 1BC4CB1E 206901DC 0001 |
| BDS 3 B1D2 0 | 4 | 389045B5 16880020 00000000 00000000 00000000 0000150A 1555554B 1555554B 1555554B |
| BDS 4 B1D2 0 | 4 | 389045B5 16880020 00000000 00000000 00000000 0000150A 1555554B 1555554B 1555554B |
| BDS 6 B1D1 0 | 3 | 389035BE 1671A850 1C4CF249 14E87F2A 371FFF2F 104A005D 02837525 3635867D 255528C |
| BDS 8 B1D1 0 | 3 | 389035BE 1671A850 1C52FB15 39BC7FD3 3937FFBF 13DDFE81 25DCDF67 0B793000 2F446 |
| BDS 9 B1D1 0 | 4/12 | 389045B5 08F03289 2514868D 002229CF 11DCACCA 2099F892 368A378B 3F69A6C1 3A95FF |
| BDS 12 B1D1 0 | 3 | 389035BE 1671A850 1C503510 06E87F8A 3F27FD49 29FC0089 00FF0F79 28EC0079 0854DC |
| BDS 13 B1D1 0 | 3 | 389035BE 1671A850 1C4FC44E 0CCFFFCF 2F37FFFF 1265FFD2 298D7F0C 2B683DFB 2A00C0 |
| BDS 16 B1D1 0 | 3 | 38903158 1E900080 00000000 00000000 00000000 00000000 00000000 00000000 00000000 |
| BDS 19 B1D1 0 | 3 | 389035BE 16732454 084F2B7F 35DEFFB0 3C7FFD79 2003FF96 3A5DE82E 2A2978EC 065EE! |
| BDS 20 B1D1 0 | 3 | 389035BE 1671A850 1C4E4A4E 167E806A 03EFFDC9 2DD600A4 0143AE17 3389BDF4 0BCE! |
| BDS 22 B1D1 0 | 3 | 389035BE 1671A850 1C4E3845 2A760004 009FFD09 2D89FF4B 34039DAD 338CA2FB 134F0! |
| BDS 29 B1D1 0 | 3 | 389035BE 1671A850 1C4E4D47 15558048 05AFFDE9 218E0054 0B3E78B2 28D820DA 22B1F |
| GAL 7 E1B 0 | E2 | 021BA4EC D4DF4983 384F33C6 57B74000 95C24000 0000002A AAAAA48CF CF7F4000 |
| GAL 8 E1B 0 | E2 | 021BA4D4 6E3209C2 B616F64C 96DC4000 85EC4000 0000002A AAAAA44CD BEFF4000 |
| GAL 14 E1B 0 | E2 | 021B8FB7 AB7D48FB 369F8DE2 28130000 BF914000 0000002A AAAAA6A7E EB7F4000 |
| GAL 26 E1B 0 | E2 | 021A1585 78D869F0 FA245720 7E420000 BC844000 0000002A AAAAA7B79 203F4000 |
| GPS 2 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 5 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 6 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 7 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 9 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 12 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 17 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 19 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| GPS 23 L1C/A 0 | 5/23/1 | 22C3DB36 9E73AD38 15D9EA1C 24001888 3F4E8007 2843638F 2EE50271 A82D7AEB 256FA |
| QZSS 1 L1S 0 | 49 | 53C7FFD0 000C648C 126C980E C20006A1 7A000000 00000000 00000001 AA1A02A6 |
| QZSS 1 L1C/A 0 | 5/0/3 | 22C0AA24 1E73A508 302AAA86 AAAAAA95 AAAAAA95 AAAAAA95 AAAAAA95 AAAAAA95 AAAAAA95 AA |

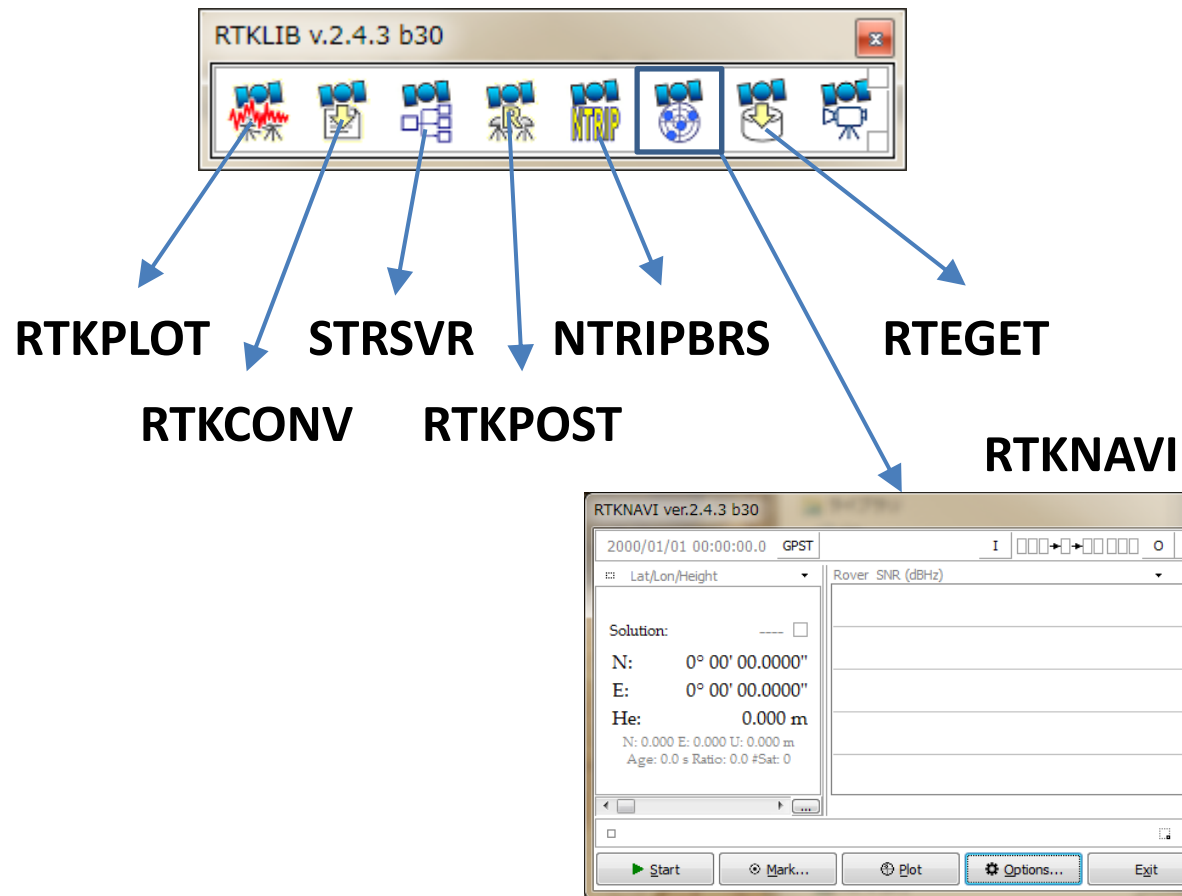
Longitude 138.38965950
 Latitude 35.87300510
 Altitude 1003.690 m
 TTFF
 Fix Mode 3D
 3D Acc. [m] 11.69
 2D Acc. [m] 0.86
 PDOP 1.3
 HDOP 10.7
 Satellites

u-blox M8/8 COM15 9600 No file open UBX 02:44:3 | 07:56:1

Start RTKLIB

- **RTKLAUNCH (RTKLIB AP launcher)**

seminar_2019¥rtklib_2.4.3b32¥bin¥rtklaunch.exe



RTKNAVI

RTKNAVI ver.2.4.3 b30

2018/07/26 08:30:11.0 GPST

Lat/Lon/Height

Solution: **SINGLE**

N: 35° 52' 22.8149"
 E: 138° 23' 22.7484"
 He: 1003.754 m
 N: 2.750 E: 3.498 U: 6.565 m
 Age: 0.0 s Ratio: 0.0 #Sat:16

Rover SNR (dBHz)

GEJ C

(1) COM15

Buttons: Stop, Mark..., Plot, Options..., Exit

Input Streams

| Input Stream | Type | Opt_Cmd | Format | Opt |
|---|------------|---------|--------|-----|
| <input checked="" type="checkbox"/> (1) Rover | Serial | ... | u-blox | ... |
| <input type="checkbox"/> (2) Base Station | TCP Client | ... | BINEX | ... |
| <input type="checkbox"/> (3) Correction | TCP Client | ... | RTCM 3 | ... |

Transmit NMEA GPGGA to Base Station
 OFF 0.000000000 0.000000000 0.000 ...

Reset Cmd Max Baseline 10 km

Input File Paths
 S:\Users\ttaka\Desktop\LHAPLUS\log\log_raw_from_flexpack\from_park ...
 S:\Users\ttaka\Desktop\LHAPLUS\log\log_raw_from_3L\from_park_sec ...

Time x1 +0

Serial Options

Port: COM15 Parity: None

Bitrate (bps): 115200 Stop Bits: 1 bit

Byte Size: 8 bits Flow Control: None

Output Received Stream to TCP Port

Buttons: OK, Cancel

Start

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode: Single

Frequencies / Filter Type: L1+L2 Forward

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

Rec Dynamics / Earth Tides Correction: OFF OFF

Ionosphere Correction: Broadcast

Troposphere Correction: Saastamoinen

Satellite Ephemeris/Clock: Broadcast

Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr

Excluded Satellites (+PRN: Included)

GPS GLO Galileo QZSS SBAS BeiDou IRNSS

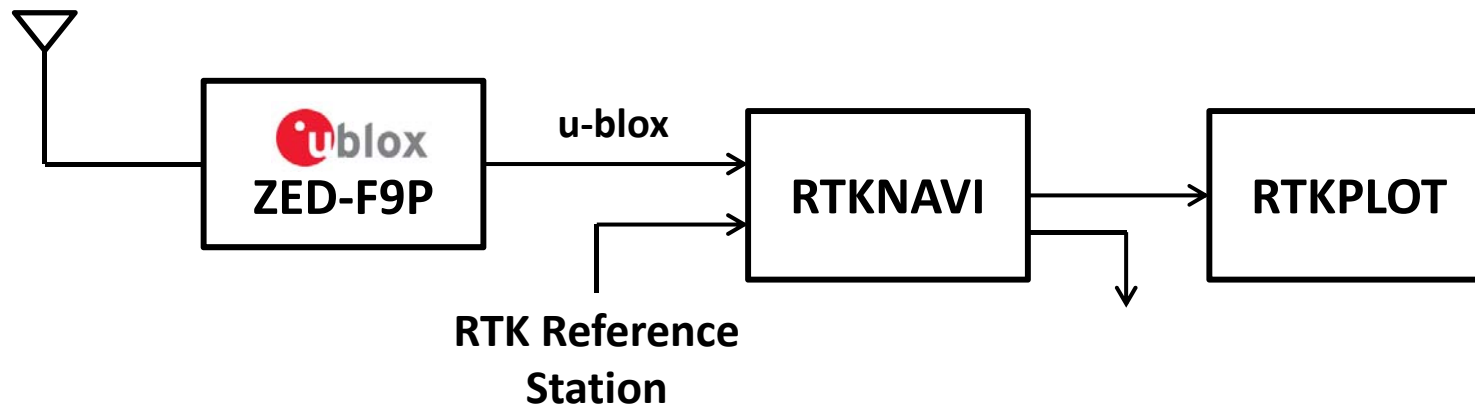
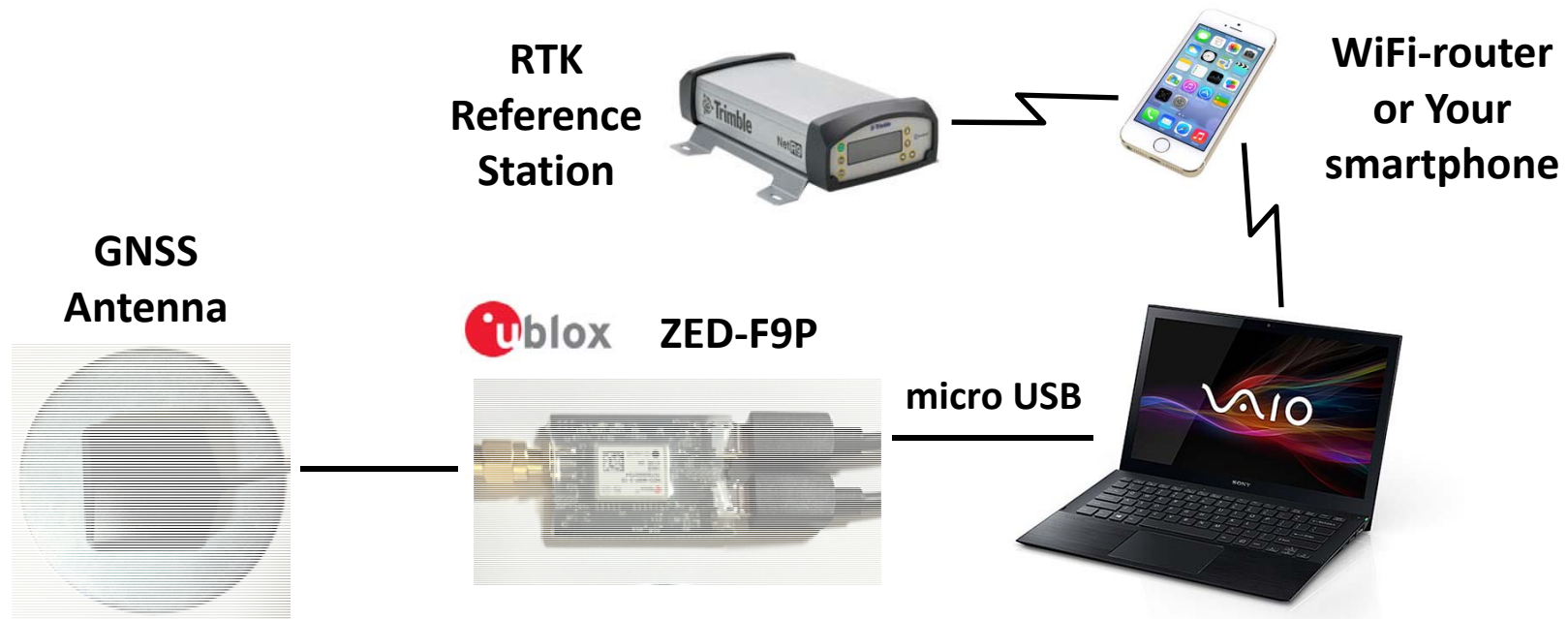
Buttons: Load, Save, OK, Cancel

RTKNAVI - RTK Monitor

The screenshot displays the RTKNAVI software interface with several overlapping windows. The main window shows the date and time '2018/07/26 08:30:11.0' and a 'Stop' button. Overlaid windows include:

- RTKNAVI ver.2.4.3 b30: RTK Monitor (Obs Data):** A table with columns: Trcv (GPST), SAT, RCV, P1 (m), P2 (m), P5 (m), L1 (cycle), L2 (cycle), L5 (cycle), D1 (Hz), D2 (Hz), D5 (Hz), S1, S2, S5, I, I, I, C1, C2. Data row: 2018/07/26 08:31:28.996, G02 1, 20685118.147, 0.000, 0.000, 108701037.500, 0.000, 0.000, 2523.388, 0.000, 0.000, 46.0, 0.0, 0.0, 0, 0, 0, LIC.
- RTKNAVI ver.2.4.3 b30: RTK Monitor (Nav GPS):** A table with columns: SAT, PRN, Statu, IODE, IODC, Acci, Heal, Toe, Toc, Ttrans, A (m), e, i0 (deg), OMEGA0 (d omega (deg), M0 (deg), deltan (deg/s), OMEGAdot. Data row: G01 1, -, 65, 65, 1, 00, 2018/07/24 02:00:00, 2018/07/24 02:00:00, -, 26560338.513, 0.00801718, 55.70287, 145.15680, 38.14650, -21.65601, 2.3429E-07, -4.520E-07.
- RTKNAVI ver.2.4.3 b30: RTK Monitor (Streams):** A table with columns: Stream, Type, Format, Mode, State, Input (bytes), Input (bps), Output (byte), Output (bps), Path, Message. Data row: Input Rover, Serial, u-blox, R/W, OK, 421353, 17731, 72, 0, COM15:115200:8:n:1:off, COM15.
- RTKNAVI ver.2.4.3 b30: RTK Monitor (Log):** A list of log entries such as 'UBX RXM-SFRBX (56): sys=3 prn= 1', 'UBX 0x01 0x07 (100)', and 'UBX RXM-RAWX (984): time=2018/07/26 08:33:21.00 nsat=30'.

Configure RTK with RTKLIB and u-blox



RTK Reference Station

Receiver:
Trimble NetR9



IP-Addr : 153.121.xx.xx
Port : 2101 or 80
MountP : xxxxx
USER-ID : xxxxxx
PW : xxxxxx
Format : RTCM3 (GPS+GLO+GAL+QZS+BDS)

IP-Addr : 153.121.xx.xx
Port : 2101 or 80
MountP : xxxxx
USER-ID : xxxxxx
PW : xxxxxx
Format : BINEX (GPS+GLO+GAL+QZS+BDS)



Lat: 35.66633444
Lon: 139.79220107
Height: 59.746

RTKNAVI Options for RTK

The image displays four screenshots of the RTKNAVI Options dialog box, arranged in a 2x2 grid. Each window has a title bar with 'Options' and a close button (X). The tabs are 'Setting1', 'Setting2', 'Output', 'Statistics', 'Positions', 'Files', and 'Misc'.

- Top-Left Screenshot (Positioning Mode):** Shows 'Kinematic' selected in the Positioning Mode dropdown. Frequencies / Filter Type is 'L1+L2' and Forward. Elevation Mask is '15'. Rec Dynamics / Earth Tides Correction is 'OFF'. Ionosphere Correction is 'Broadcast'. Troposphere Correction is 'Saastamoinen'. Satellite Ephemeris/Clock is 'Broadcast'. Excluded Satellites (+PRN: Included) includes GPS, GLO, Galileo, QZSS, SBAS, BeiDou, and IRNSS.
- Top-Right Screenshot (Integer Ambiguity Res):** Shows 'Continu' selected in the Integer Ambiguity Res (GPS/GLO/BDS) dropdown. Min Ratio to Fix Ambiguity is '3.0'. Min Confidence / Max FCB to Fix Amb is '0.9999' / '0.20'. Min Lock / Elevation (°) to Fix Amb is '0' / '0'. Min Fix / Elevation (°) to Hold Amb is '10' / '0'. Outage to Reset Amb / Slip Thres (m) is '5' / '0.050'. Max Age of Diff (s) / Sync Solution is '30.0' / 'OFF'. Reject Threshold of GDOP/Innov (m) is '30.0' / '30.0'. Max # of AR Iter/# of Filter Iter is '1' / '1'. Baseline Length Constraint (m) is '0.000' / '0.000'.
- Bottom-Left Screenshot (Solution Format):** Shows 'Lat/Lon/Height' selected in the Solution Format dropdown. Output Header / Output Processing Options is 'OFF' / 'OFF'. Time Format / # of Decimals is 'hh:mm:ss GPST' / '3'. Latitude Longitude Format / Field Separator is 'ddd.ddddddd'. Output Single if Sol Outage / Max Sol Std (m) is 'OFF' / '0'. Datum / Height is 'WGS84' / 'Ellipsoidal'. Geoid Model is 'Internal'. Solution for Static Mode is 'All'. NMEA Interval (s) RMC/GGA, GSA/GSV is '0' / '0'. Output Solution Status / Output Debug Trace is 'OFF' / 'OFF'.
- Bottom-Right Screenshot (Rover/Base Station):** Shows 'RTCM Antenna Position' selected in the Rover dropdown. Rover coordinates are '90.00000000', '0.00000000', '-6335367.6285'. Base Station coordinates are '35.872989422', '138.389669681', '1003.9509'. Both sections have 'Antenna Type (*: Auto)' set to '0.0000', '0.0000', '0.0000'.

4 PPP Basics

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

PPP Applications



Automated Farming



Tsunami Warning



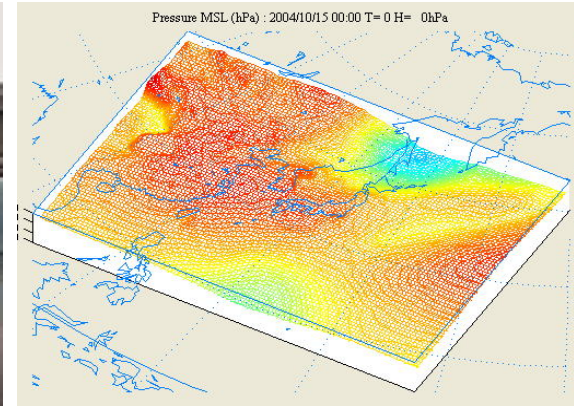
Mining Machine Control



Offshore Construction



Autonomous Driving



Weather Forecast

RTK vs. PPP

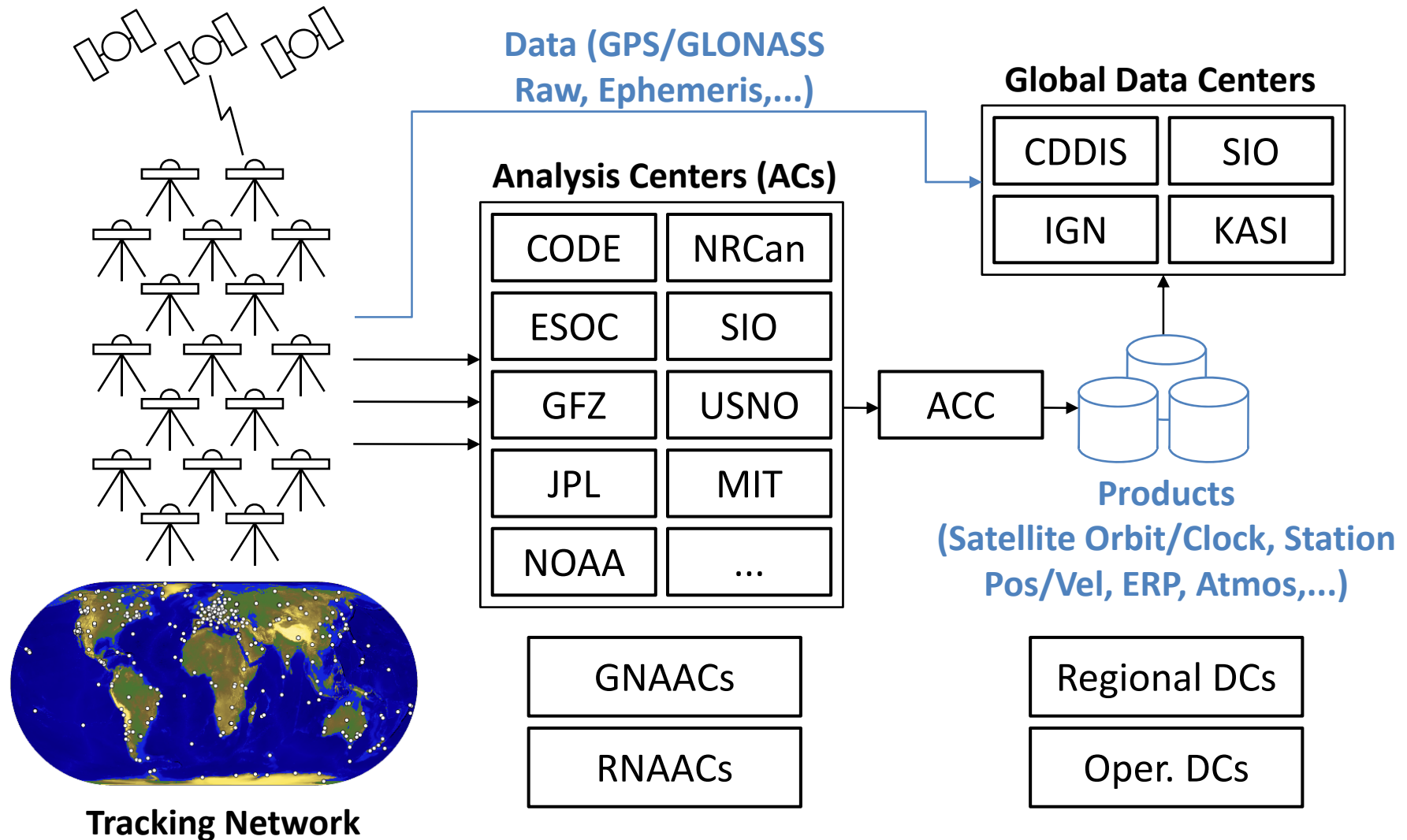
| | RTK | Real-Time PPP |
|------------------------|---|--|
| Coverage | Local/Regional ($< 1000\text{km}$) | Global |
| Typical Accuracy | 1-3 cm HRMS | 2-10 cm, much depending on orbit/clock quality |
| Effect of Ref Movement | Hard to separate ref and user movement | Less effect by distributed ref stations |
| System Complexity | Simple, at least one ref station | Complicated, need many ref stations |
| Latency of Corrections | $\sim 1\text{ s}$ | 5 \sim 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.**

Precise Ephemeris

- **Precise Satellite Orbit and Clock**
 - By Post-Processing or in Real-time
 - Observation Data of Tracking Stations World-Wide
- **Format:**
 - Orbit: NGS SP3
 - Clock: NGS SP3 or RINEX Clock Extension
- **Contents:**
 - Orbit: ECEF-Positions of Satellite Mass Center
 - Clock: Clock-biases wrt Time Scale Aligned to GPS Time

IGS: International GNSS Service

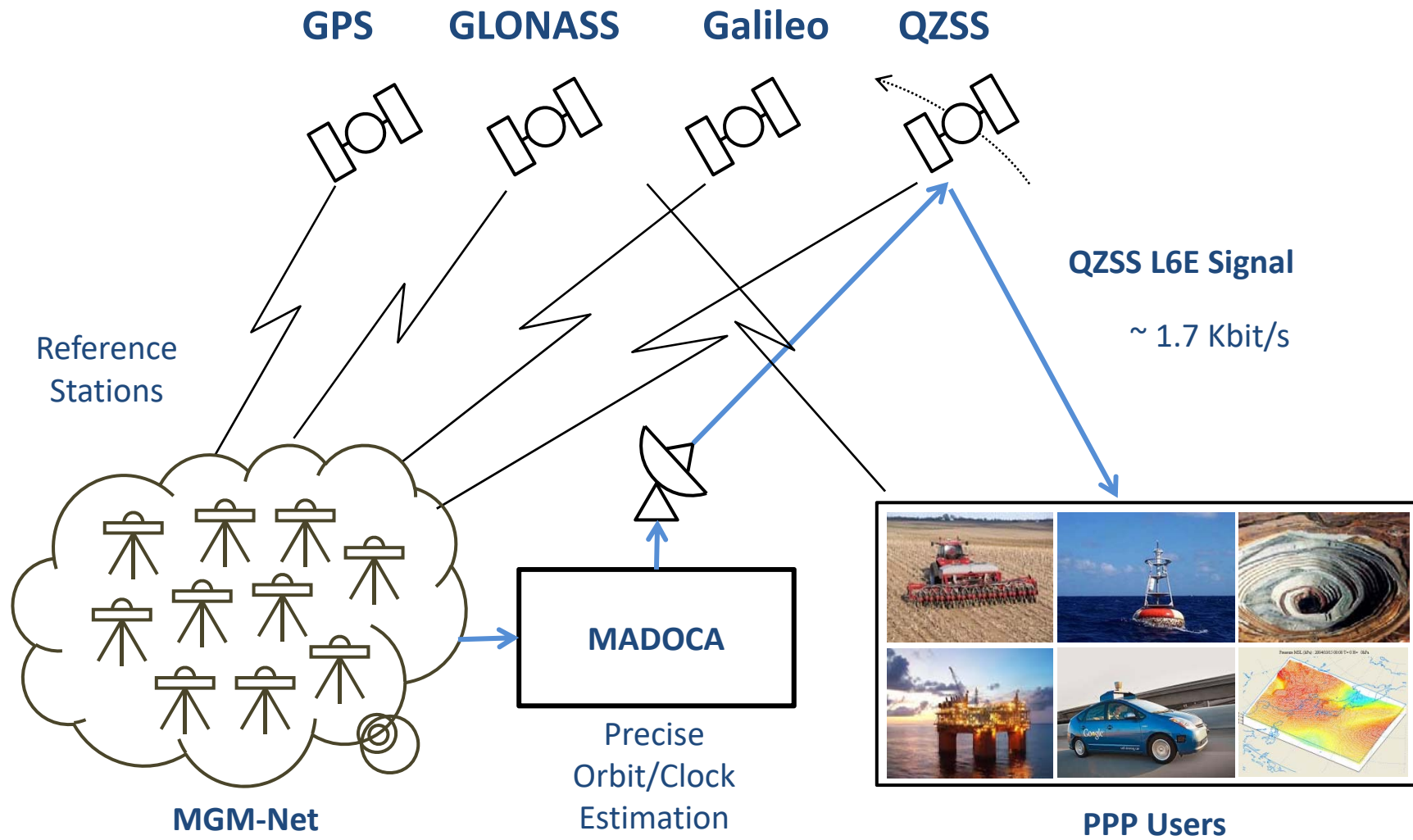


IGS Products

| | | Final (IGS) | Rapid (IGR) | Ultra-Rapid (IGU) | | Broadcast |
|-----------------|-------|------------------------|------------------------|-------------------------|------------------------|------------------------|
| | | | | Observed | Predicted | |
| Accuracy | Orbit | ~2.5cm | ~2.5cm | ~3cm | ~5cm | ~100cm |
| | Clock | ~75ps RMS ~20ps STD | ~75ps RMS ~25ps STD | ~150ps RMS ~50ps STD | ~3ns RMS ~1.5ns STD | ~5ns RMS ~2.5ns STD |
| Latency | | 12-18 days | 17-41 hours | 3-9 hours | realtime | realtime |
| Updates | | every Thursday | at 17 UTC daily | at 03, 09, 15, 21 UTC | at 03, 09, 15, 21 UTC | - |
| Sample Interval | Orbit | 15min | 15min | 15min | 15min | daily |
| | Clock | Sat: 30s Stn: 5min | 5min | 15min | 15min | daily |

(<http://www.igs.org/>)

MADOCA-PPP (1)

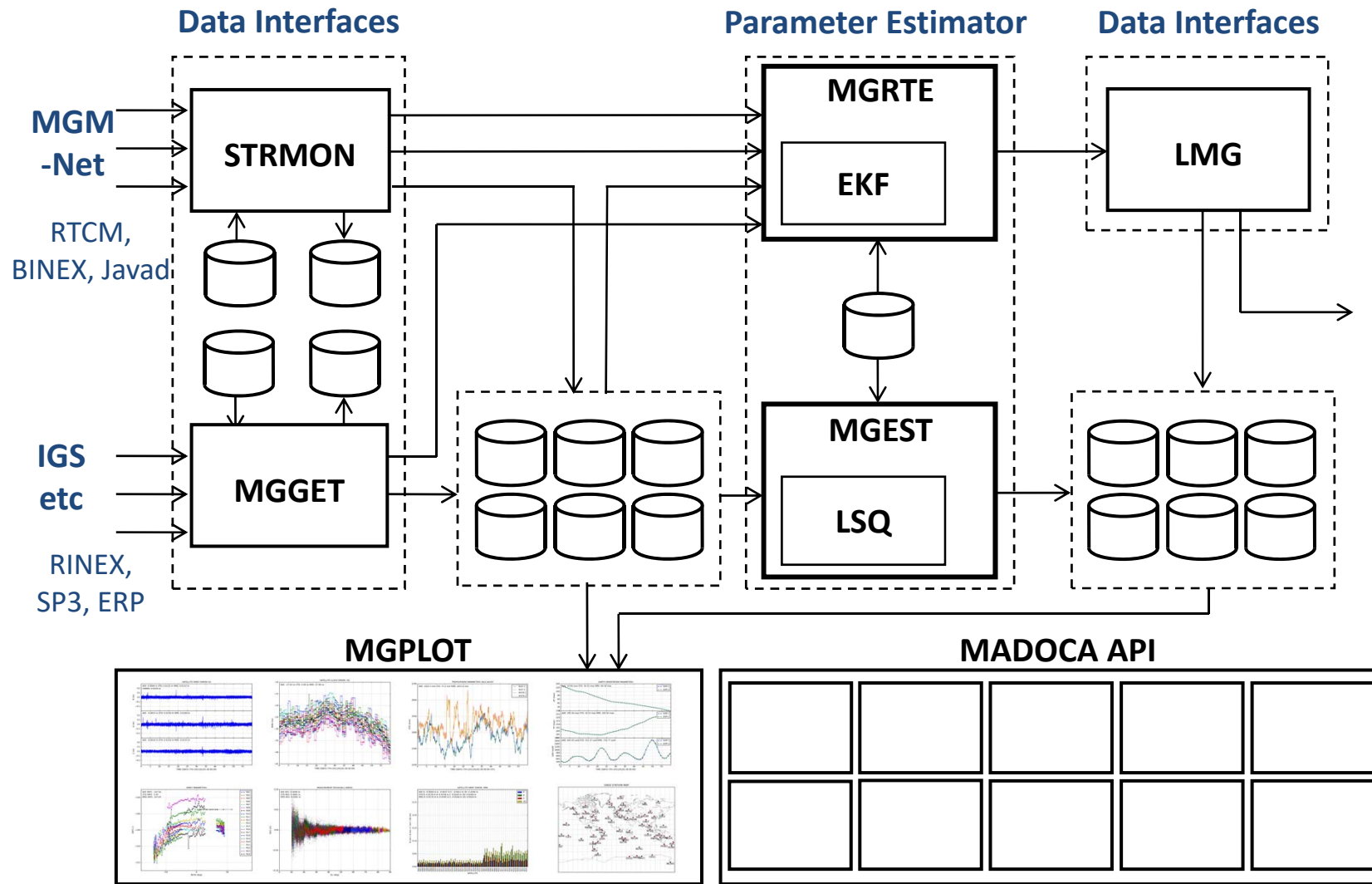


MADOCA-PPP (2)

Multi-GNSS Advanced Demonstration tool for Orbit and Clock Anlalysis

- **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-PPP (3)



MADCOCA-PPP (4)

MADCOCA: Real Time Products

Overview | Survey(NTRIP,CDDIS) | Products(MGU,MGR,MGF,LOCAL) | Monitor(MGU,MGR,MGF,LOCAL) | PPP(MGU,MGR,MGF,LOCAL) | PPP-AR(MGF) | Network | RT-Products | Availability | RT-Monitor(MGRT,MDC) | RT-PPP | LEX-PPP | QZS Orbit

Real-time Products:

- Analysis software: MGRT1:MADCOCA v.0.7.2 p1, MGRT2:MADCOCA v.0.7.2
- Observation data: MGM-net + QZSS MS + IGS/MGEX ([map](#))
- Option Settings: [mgrte1.conf](#), [mgrte2.conf](#), [mgrte_def.conf](#), [inpstr_rte.conf](#) and [outstr_rte.conf](#)
- Station File: MGRT1/MGTR2
- Updates: every 30 s for orbit, clock and URA, every 1 s for high-rate clock (latency: 3 - 5 s)

History:

- 2015-07-01 02:52 : MGRT1/MGRT2 excluded Satellite(G08).(Ref.#177)
- 2015-07-01 02:52 : Started MGRT1/MGRT2,SSR STOP for leap second.(Ref.#289)
- 2015-07-01 02:45 : Stopped MGRT1/MGRT2.(Ref.#289)
- 2015-06-23 02:40 : Changed station info file(MGRT1/MGRT2)(before after).(Ref.#280).
- 2015-06-19 09:25 : MGRT1 excluded Satellite(G08).(Ref.#177) ([more](#))

Contents:

- [Estimation Stations](#)
- [SSR Status](#)
System: [MGRT1_GPS](#) [MGRT1_GLONAS](#) [MGRT1_QZSS](#) [MGRT2_GPS](#) [MGRT2_GLONAS](#) [MGRT2_QZSS](#)
- [Direct Links to Product Files](#)

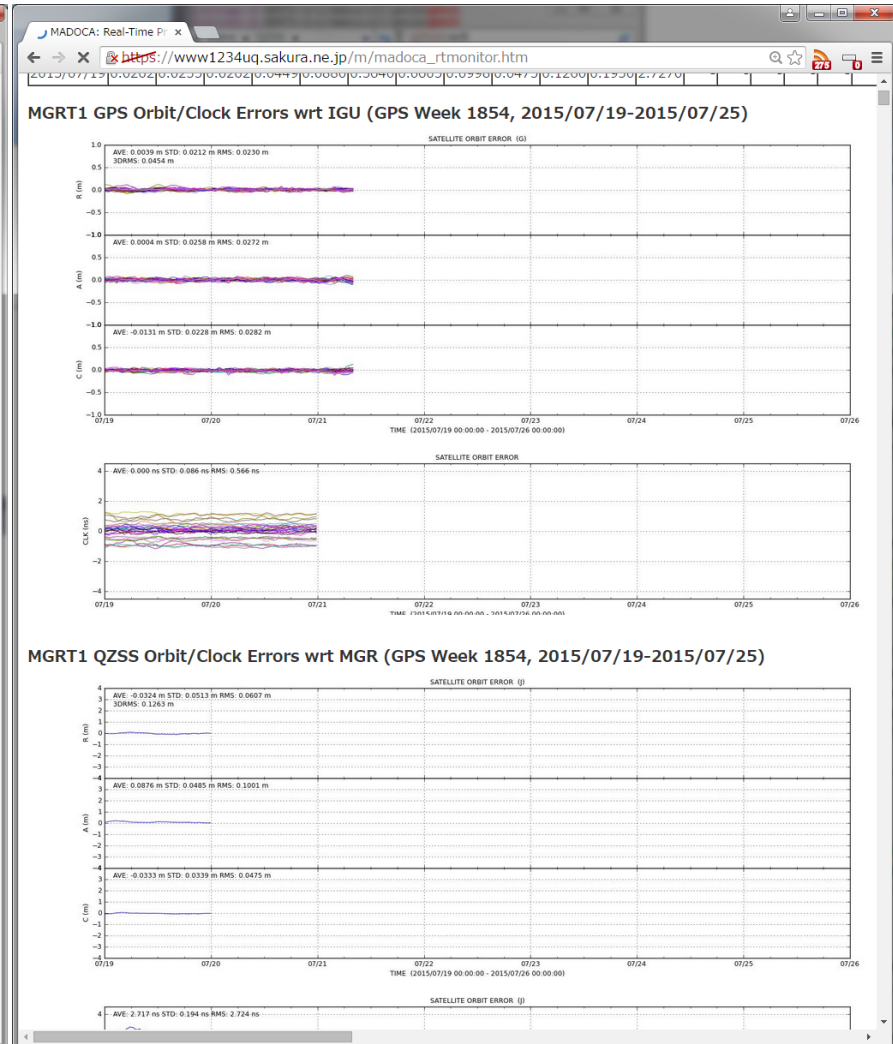
Product Stream:

- NTRIP Caster: , Port: 2101 or 80
- User-ID: MADCOCA , Password: MADCOCA

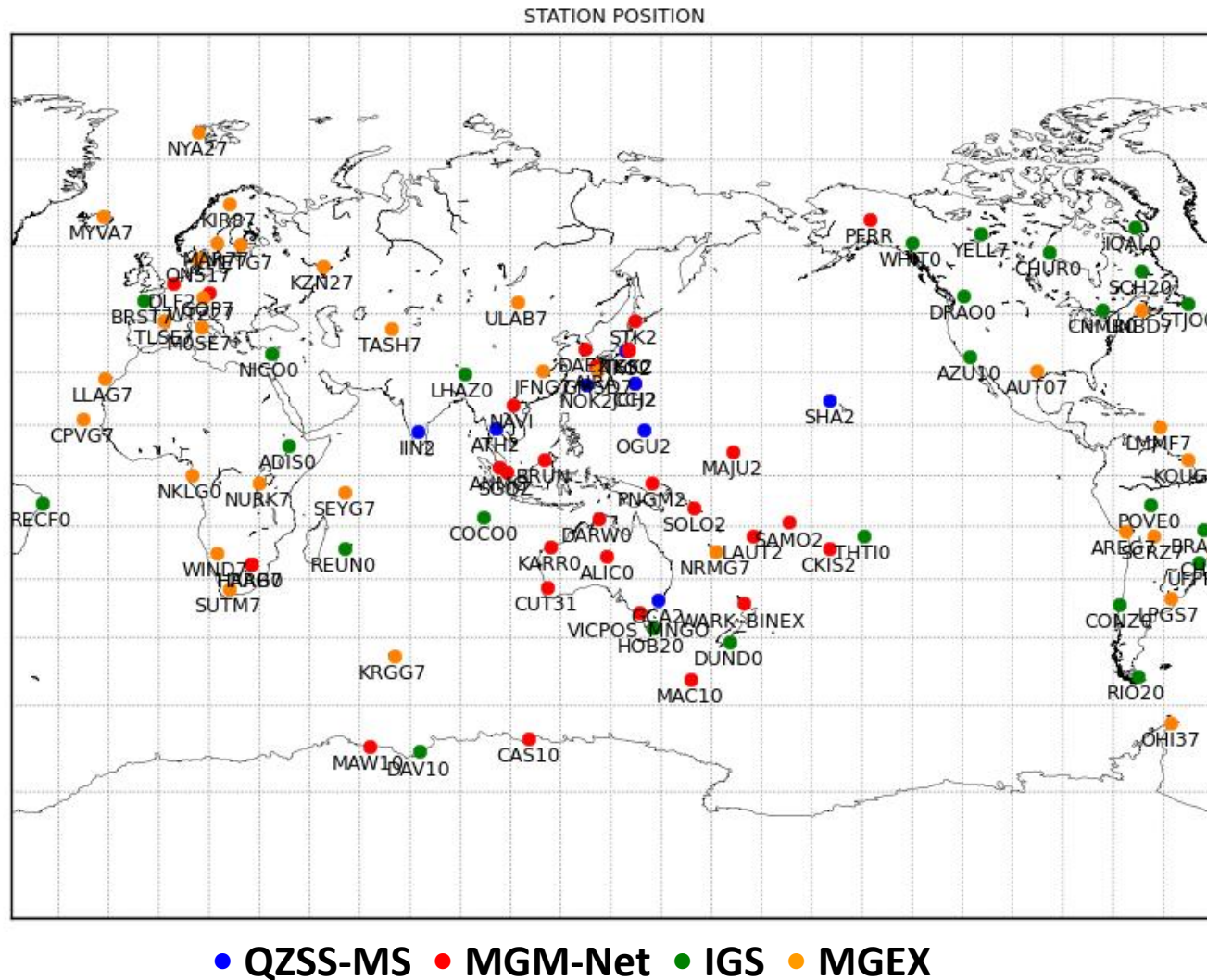
Product Messages:

| Mount Point | Products | RTCM Message Type | | | | Update Interval | Notes |
|---------------|-----------------|-------------------|---------|--------|---------|-----------------|---|
| | | GPS | GLONASS | QZSS | Galileo | | |
| MADCOCA_SSR1 | Satellite Orbit | 1057 | 1063 | 1246 * | 1240 * | 30 s | APC, ITRF2008, igs08.atx ** |
| | Satellite Clock | 1058 | 1064 | 1247 * | 1241 * | 30 s | - |
| | Code Bias | - | - | - | - | 30 s | - |
| | URA | 1061 | 1067 | 1250 * | 1244 * | 30 s | - |
| MADCOCA_SSR2 | High-rate Clock | 1062 | 1068 | 1251 * | 1245 * | 1 s | - |
| same as above | | | | | | | Test and backup stream |

URL of Product Files

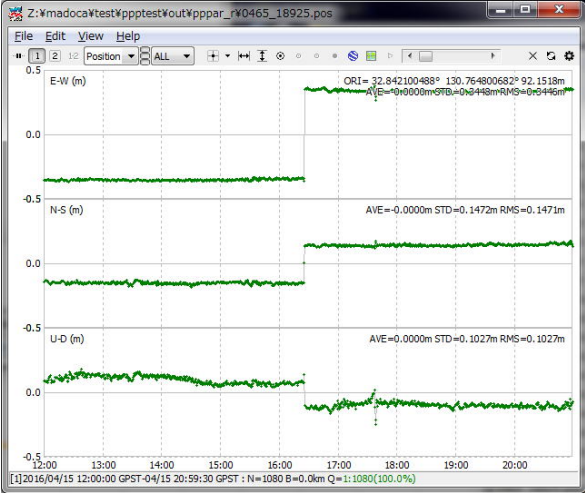


MADOCA-PPP (5)

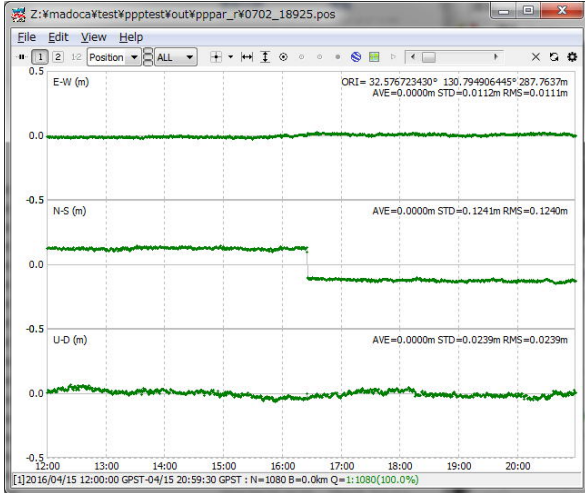


MADOCA PPP (6)

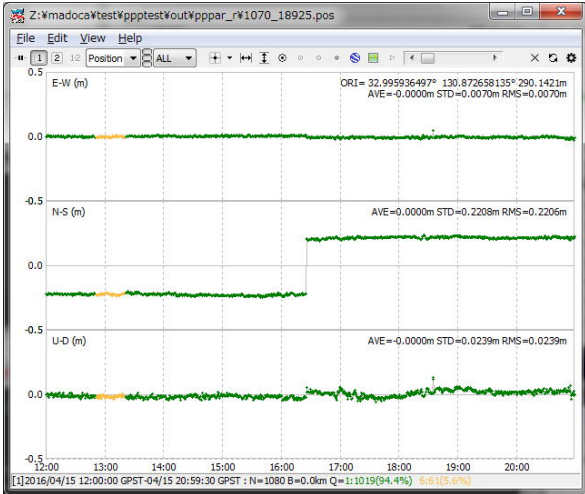
Kumamoto
(0465)



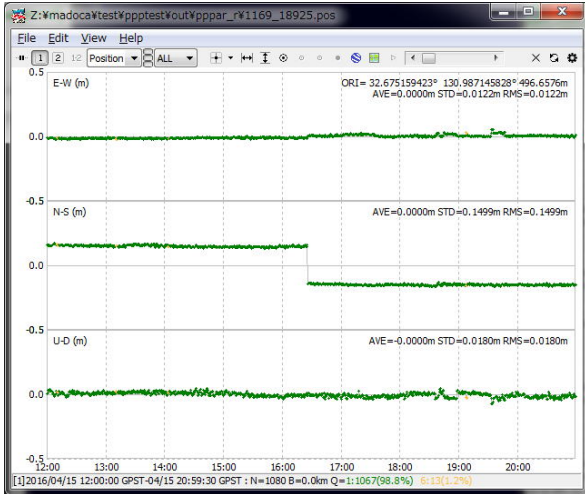
Izumi
(0702)



Kikuchi
(1070)



Yabe A
(1169)



2016/4/15 16:25 GPST PPP Analysis of Kumamoto-EQ. by MADOCA-PPP
(RTKLIB 2.4.3 b9, Kinematic-PPP-AR, MADOCA Final Products)

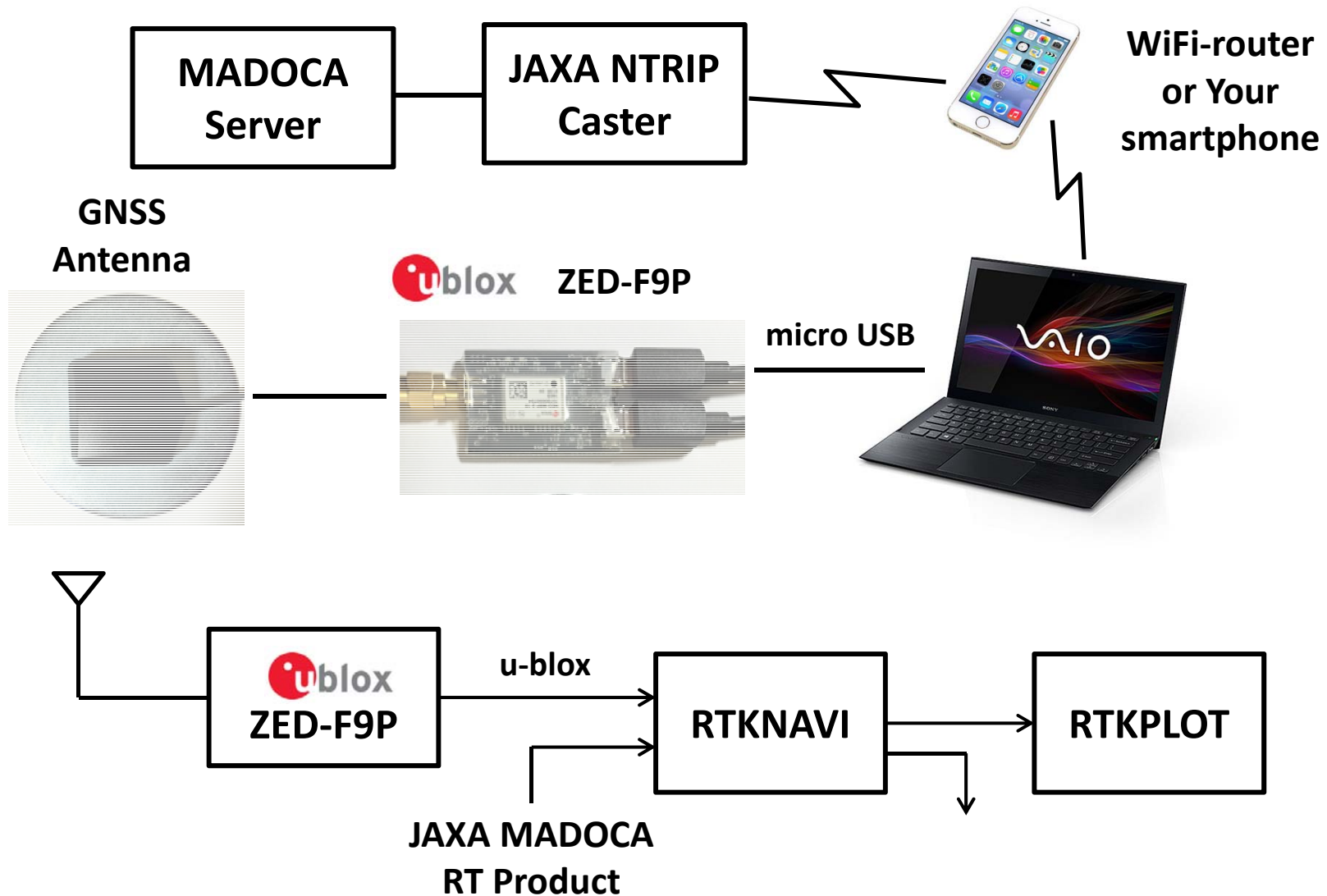
RTCM 3.3 SSR

| 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 | 1042 | - |
| 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* | 1258* | 1252* |
| Clock Corr. | 1058 | 1064 | 1241* | 1247* | 1259* | 1253* |
| Code Bias | 1059 | 1065 | 1242* | 1248* | 1260* | 1254* |
| Combined | 1060 | 1066 | 1243* | 1249* | 1261* | 1255* |
| URA | 1061 | 1067 | 1244* | 1250* | 1262* | 1256* |
| HR-Clock | 1062 | 1068 | 1245* | 1251* | 1263* | 1257* |
| Antenna Info | 1005 | 1006 | 1007 | 1008 | 1033 | |

* draft

5 PPP Practice

Configure PPP with RTKLIB and u-blox



JAXA MADOCA RT Product

JAXA NTRIP Caster

IP-Addr : madoca.ntrip-mgm.net
Port : 2101
MountP : MDC0, MDC1 or MDC2
USER-ID : xxxxxx
PW : xxxxxx
Format : RTCM3 SSR

USER-ID and PW are only for the seminar (temporal)

MADOCA Products

https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html

QZSS : Quasi-Zenith Satellite System

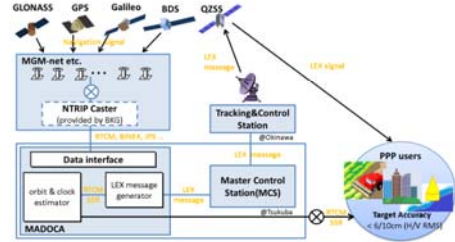
MADOCA Real-Time Products

MADOCA | NEWS | MESSAGE | PRODUCTS | APPLICATION | ARCHIVE

Real-Time PPP Service

JAXA conducts real-time precise point positioning (PPP) experiments using the L-band experimental(LEX) signal from "Michibiki(QZS-1)". PPP is a technique to calculate accurate user positions using precise orbit and clock of GNSS without any reference stations.

Our Real-Time PPP Service allows to obtain a centimeter accuracy positioning.



What's MADOCA?

For this service, JAXA has developed Multi-GNSS orbit and clock estimator called "MADOCA (Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis)". This basic requirements are as follows;

- (1) Multi-GNSS Support (GPS, GLONASS, Galileo and QZSS)
- (2) Both of Offline and Real-Time Estimator
- (3) Precise Estimation using latest models
- (4) Reduction of Processing Time by Multi-threading
- (5) Maintainability and Portability which can run on note PC

System: GPS, GLONASS and QZS (Galileo and BeiDou are under construction..)
 Goal: Real-Time positioning with less than 10cm accuracy
 Goal of orbit/clock accuracy:

| Product | Offline | | | Real-Time | | |
|---------|---------|--------|-------|-----------|-----|-----|
| | GPS | GLO | QZS | GPS | GLO | QZS |
| OBT | 3cm | 7cm | 6cm | 9cm | | |
| CLK | 0.1ns | 0.25ns | 0.1ns | 0.25ns | | |

Edit Date: 2015/11/26

https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html

RTKNAVI Options for PPP

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Positioning Mode: PPP Kinematic

Frequencies / Filter Type: L1+L2 Forward

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

Rec Dynamics / Earth Tides Correction: OFF Solid

Ionosphere Correction: Iono-Free LC

Troposphere Correction: Estimate ZTD

Satellite Ephemeris/Clock: Broadcast+SSR APC

Sat PCV Rec PCV PhWU Rej Ed RAIM FDE DBCorr

Excluded Satellites (+PRN: Included):

GPS GLO Galileo QZSS SBAS BeiDou IRNSS

Load Save OK Cancel

Options

Setting1 Setting2 Output Statistics Positions Files Misc

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

Min Ratio to Fix Ambiguity: 3.0

Min Confidence / Max FCB to Fix Amb: 0.9999 0.20

Min Lock / Elevation (°) to Fix Amb: 10 0

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

Outage to Reset Amb / Slip Thres (m): 5 0.050

Max Age of Diff (s) / Sync Solution: 30.0 OFF

Reject Threshold of GDOP/Innov (m): 30.0 30.0

Max # of AR Iter/# of Filter Iter: 1 1

Baseline Length Constraint (m): 0.000 0.000

Load Save OK Cancel

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Measurement Errors (1-sigma)

Code/Carrier-Phase Error Ratio L1/L2: 1000.0 100.0

Carrier-Phase Error a+b/sinEl (m): 0.003 0.003

Carrier-Phase Error/Baseline (m/10km): 0.000

Doppler Frequency (Hz): 1.000

Process Noises (1-sigma/sqrt(s))

Receiver Accel Horiz/Vertical (m/s²): 1.00E+01 1.00E+01

Carrier-Phase Bias (cycle): 1.00E-04

Vertical Ionospheric Delay (m/10km): 1.00E-03

Zenith Tropospheric Delay (m): 1.00E-04

Satellite Clock Stability (s/s): 5.00E-12

Load Save OK Cancel

Options

Setting1 Setting2 Output Statistics Positions Files Misc

Rover

Lat/Lon/Height (deg/m):

90.000000000 0.000000000 -6335367.6285

Antenna Type (*: Auto) Delta-E/N/U (m)

NOV703GGG.R2 0.0000 0.0000 0.0000

Base Station

Lat/Lon/Height (deg/m):

35.872988910 138.389670141 1005.5217

Antenna Type (*: Auto) Delta-E/N/U (m)

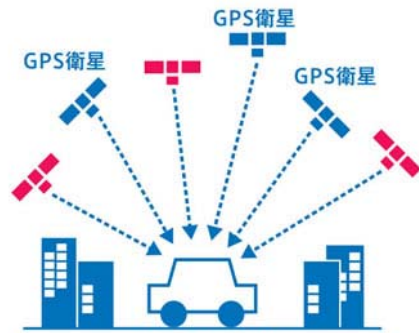
0.0000 0.0000 0.0000

Station Position File

Load Save OK Cancel

6 Advanced Topics of PP

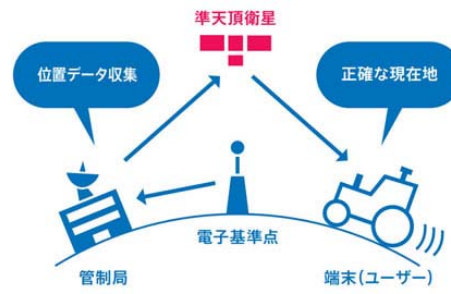
QZSS



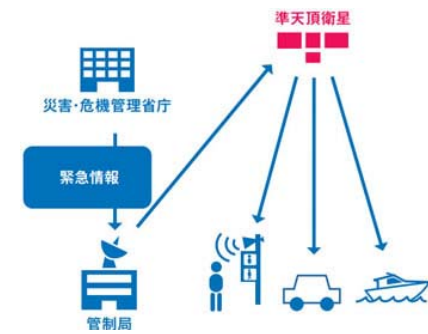
Satellite Positioning, Navigation and Timing Service



Sub-meter Level Augmentation Service (SLAS)



Centimeter Level Augmentation Service (CLAS)

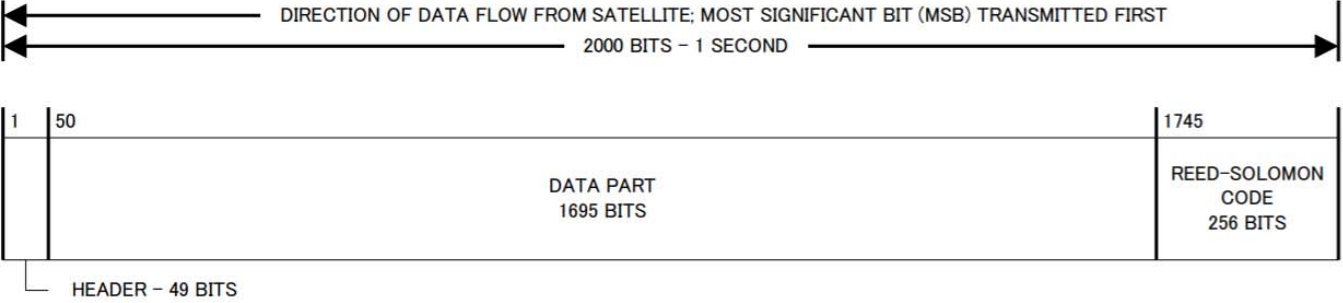


Disaster and Crisis Management (DC) Report Service

| | 2010年度 | 2011年度 | 2012年度 | 2013年度 | 2014年度 | 2015年度 | 2016年度 | 2017年度 | 2018年度 | 2019年度 |
|---------------|------------------------|--------|--------------|--------|---------|--------|--------|-------------|-------------|----------------|
| 衛星 打上げ | ① 初号機打上げ (準天頂軌道) | | | | | | | ② 2号機打上げ | ③ 3号機打上げ | ④ 4号機打上げ |
| システム 構築・整備 | | | | 1機体制 | 基本/詳細設計 | | システム整備 | | 4機体制 | オープンサービス 運用 |
| | | | 技術実証・利用実証・運用 | | | | | | | |

(<http://qzss.go.jp>)

QZSS L6



PRN sig messages

 193-199 L6D CLAS
 203-209 L6E MADOCA PPP

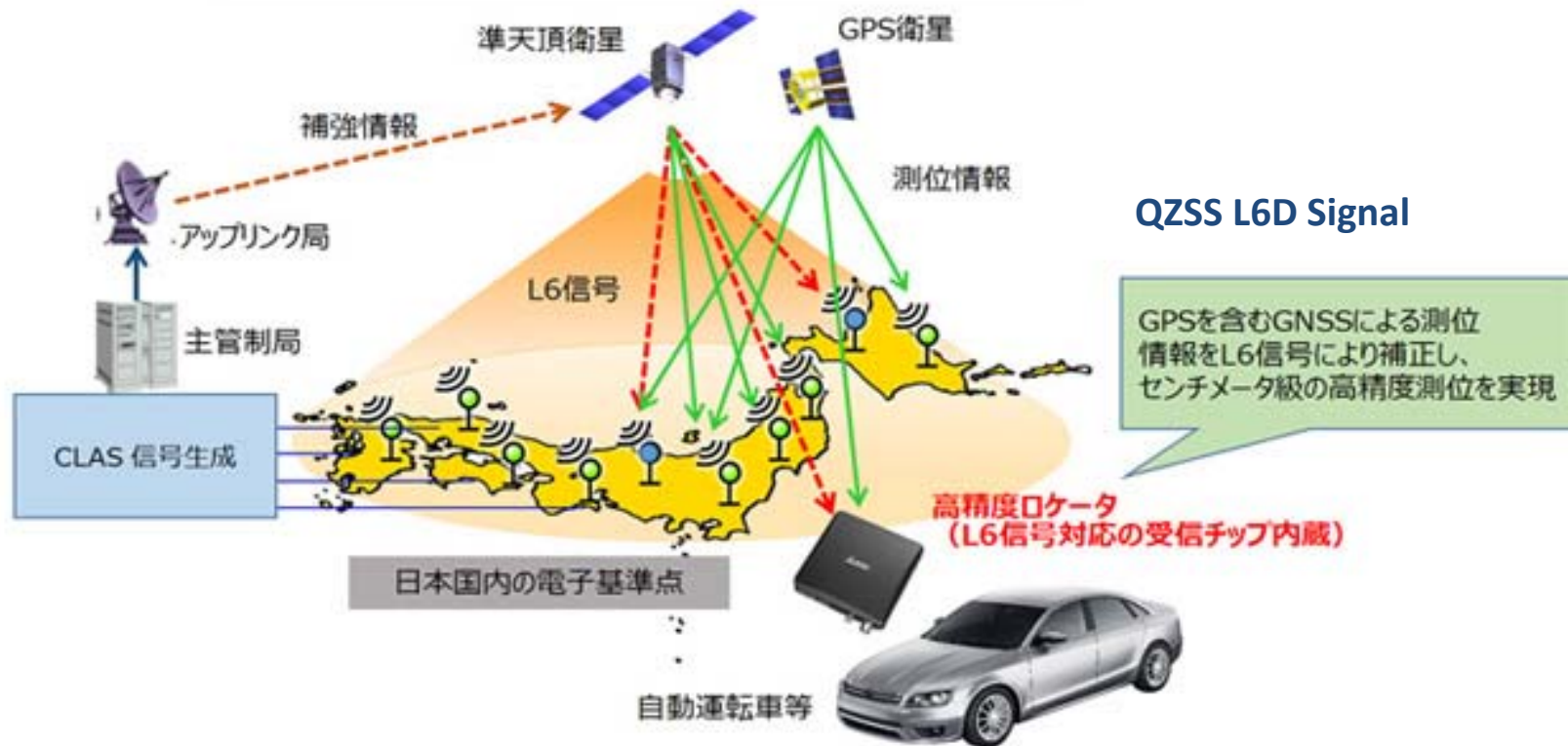
```

2019-05-08 10:39:47, J01, 193, L6D: CLAS FID=0 SF=1 AF=0
1ACFFC1DC1A17F49CA8903F707DFFD2602580578285F5FC1FD3E00001020307FC9BFA6E54480C3FEFFDDBBF3EFE3800D602BC
0E3FFCD00D3FE1FF5CFF5EFE969425033FFB85D683E0C1F160FFB002880754078A03AD089BC638631CB1927F8CEFB537DAAB
FCE67E1900D620AD9EC8C72B93D335E00AFB0C7C143F487F873FBD3860E844682504FE989515047FF768248FCEFE2015A09C
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```

[1] IS-QZSS-L-001 Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service, November 5, 2018

CLAS

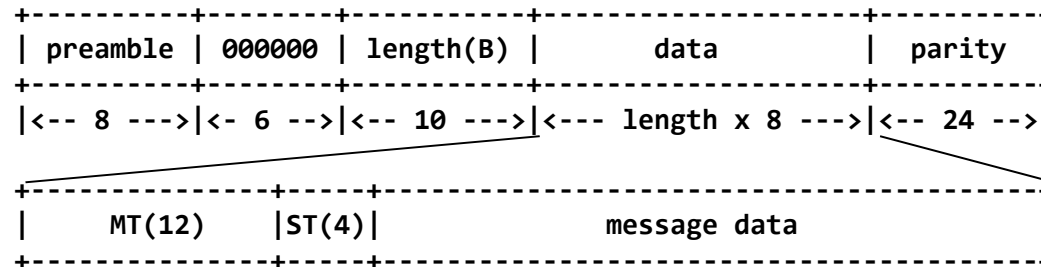
センチメートル級測位補強サービス (CLAS) 概要



GNSS : Global Navigation Satellite System (全地球航法衛星システム)

(<http://www.mitsubishielectric.co.jp>)

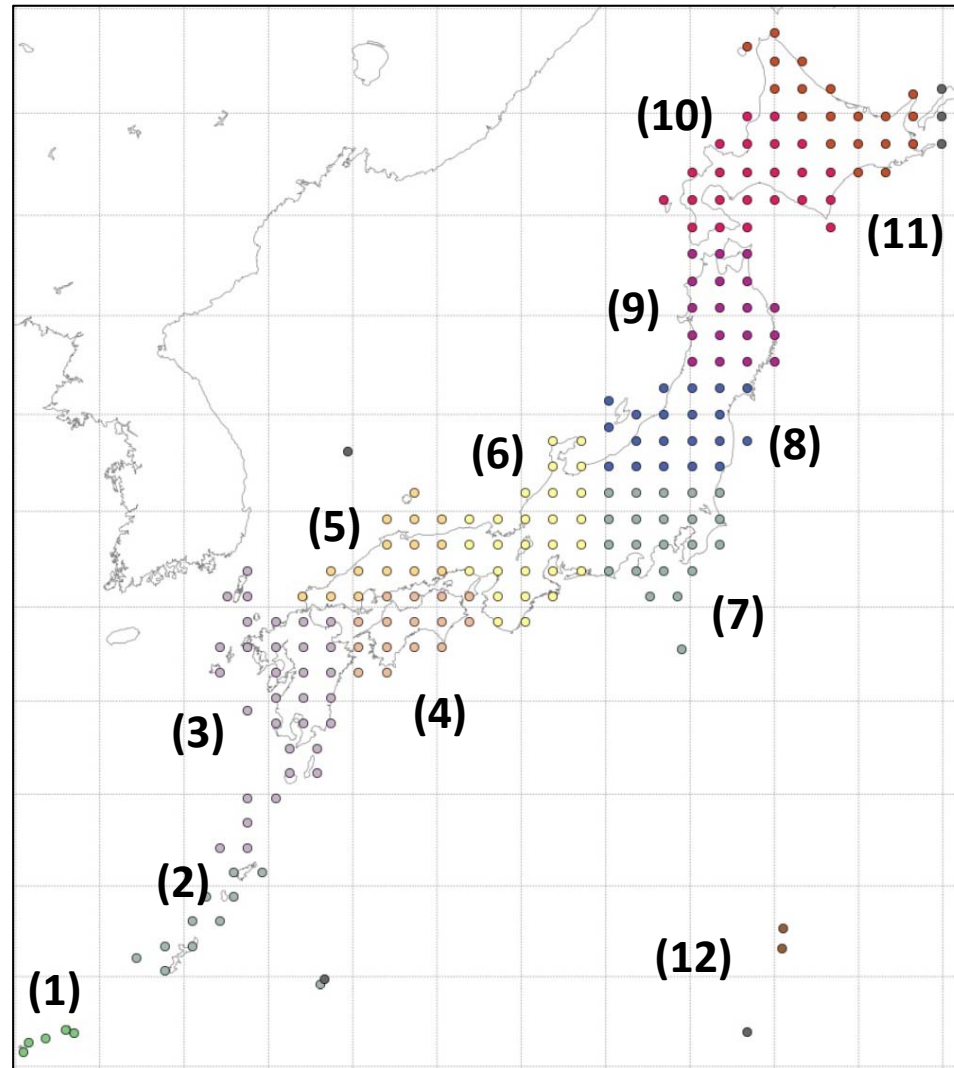
CSSR (Compact SSR)



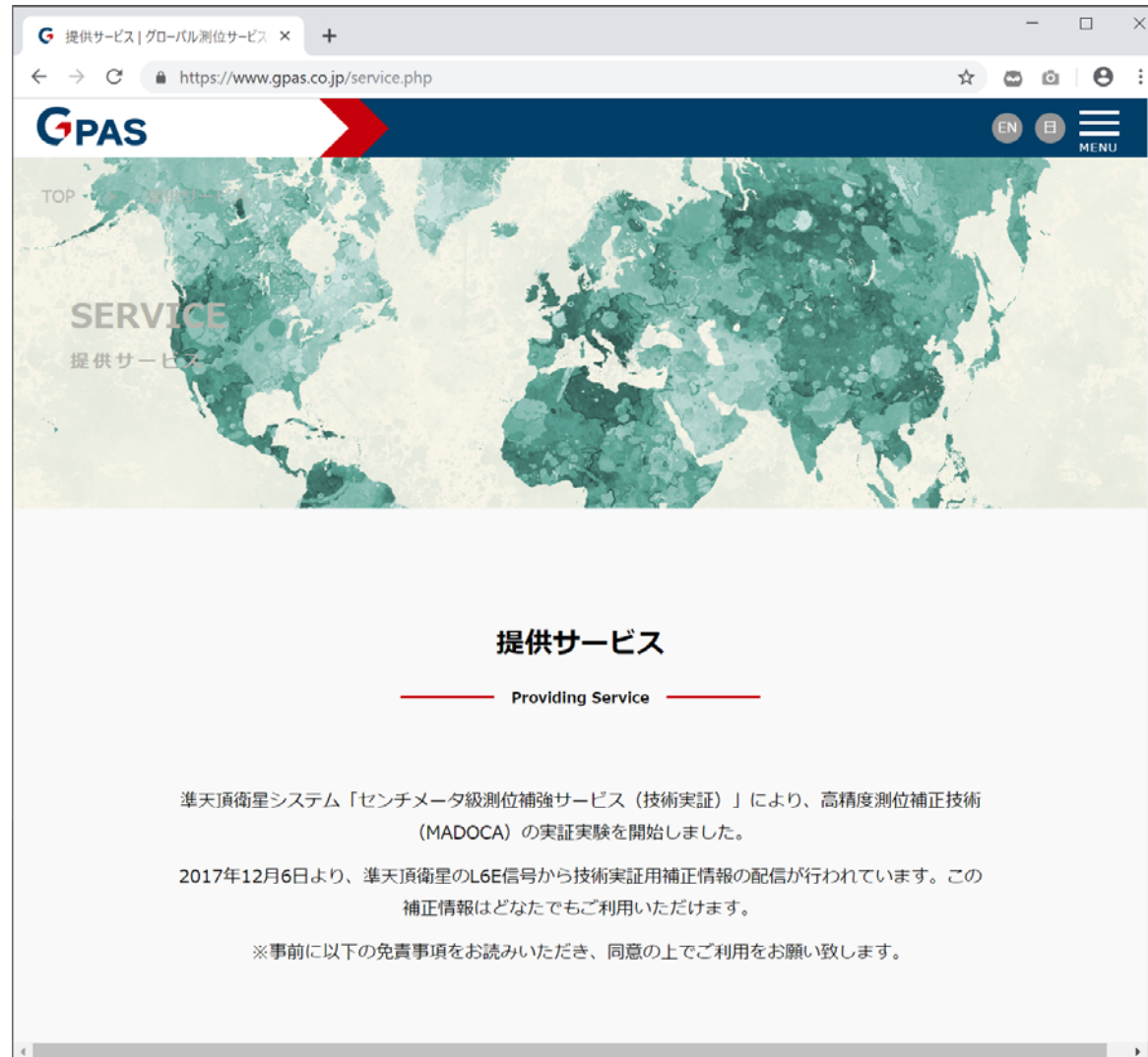
| NO | Message | MT | ST | Format |
|------|--------------------------|------|----|----------------|
| (1) | Compact SSR mask | 4073 | 1 | [1] 4.1.2.2.2 |
| (2) | Compact SSR orbit corr | 4073 | 2 | [1] 4.1.2.2.3 |
| (3) | Compact SSR clock corr | 4073 | 3 | [1] 4.1.2.2.4 |
| (4) | Compact SSR code bias | 4073 | 4 | [1] 4.1.2.2.5 |
| (5) | Compact SSR phase bias | 4073 | 5 | [1] 4.1.2.2.6 |
| (6) | CSSR code and phase bias | 4073 | 6 | [1] 4.1.2.2.7 |
| (7) | Compact SSR URA | 4073 | 7 | [1] 4.1.2.2.8 |
| (8) | Compact SSR STEC corr | 4073 | 8 | [1] 4.1.2.2.9 |
| (9) | Compact SSR gridded corr | 4073 | 9 | [1] 4.1.2.2.10 |
| (10) | Compact SSR combined cor | 4073 | 11 | [1] 4.1.2.2.12 |

[1] IS-QZSS-L-001 Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service, November 5, 2018

CLAS CSSR Grids and Networks



MADOCA PPP



(<https://www.gpas.co.jp>)

Today's Summary

1 Theory of PP (precise positioning)

2 RTK Basics

3 RTK Practice

Lunch Break

4 PPP Basics

5 PPP Practice

6 Advanced Topics of PP