

GPS/GNSSシンポジウム2013 講演会

高精度受信機技術と PPP実用化現状

 東京海洋大学 高須知二

2013-10-29 ~ 31 @東京海洋大学 越中島会館

Contents

- **RTKLIB v. 2.4.2**
- **MADOCA**

References:

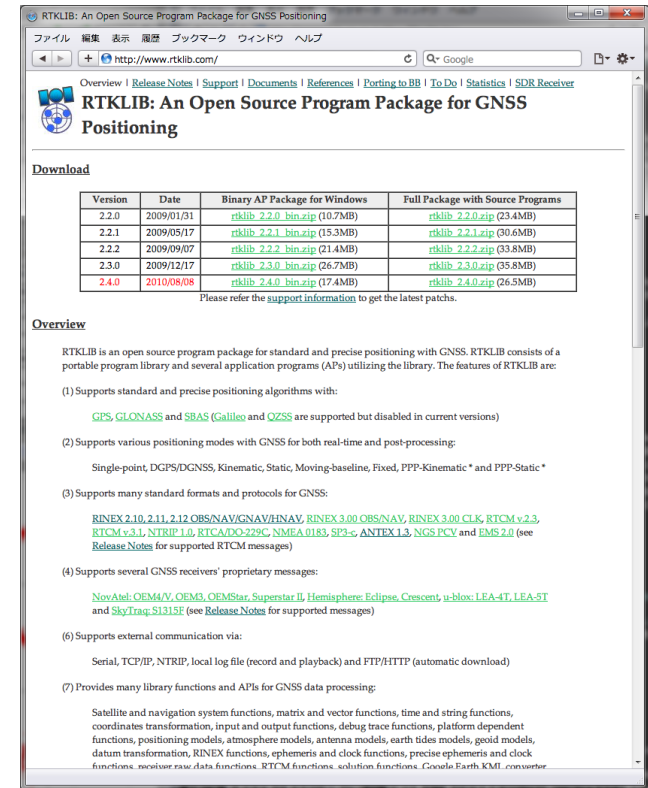
[1] T. Takasu Multiple Constellation PPP with RTKLIB v.2.4.2, GNSS Precise Point Positioning Workshop, June 14-16, 2013, Load Elgin Hotel, Ottawa, Canada

[2] 高須, 安田, 小暮, 中村, 三吉, 河手, 平原, 澤村, 複数GNSS対応高精度軌道時刻推定ツールMADOCAの開発, 第57回宇宙科学技術連合講演会, 2013/10/9-11, 米子コンベンションセンター

RTKLIB v.2.4.2

RTKLIB

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



The screenshot shows the RTKLIB website with a navigation menu and a 'Download' section containing a table of versions. Below the table is an 'Overview' section describing the program's capabilities.

Version	Date	Binary AP Package for Windows	Full Package with Source Programs
2.2.0	2009/01/31	rtklib_2.2.0_bin.zip (10.7MB)	rtklib_2.2.0.zip (23.4MB)
2.2.1	2009/05/17	rtklib_2.2.1_bin.zip (15.3MB)	rtklib_2.2.1.zip (30.6MB)
2.2.2	2009/09/07	rtklib_2.2.2_bin.zip (21.4MB)	rtklib_2.2.2.zip (33.8MB)
2.3.0	2009/12/17	rtklib_2.3.0_bin.zip (26.7MB)	rtklib_2.3.0.zip (35.8MB)
2.4.0	2010/08/08	rtklib_2.4.0_bin.zip (17.4MB)	rtklib_2.4.0.zip (26.5MB)

Please refer the [support information](#) to get the latest patches.

Overview

RTKLIB is an open source program package for standard and precise positioning with GNSS. RTKLIB consists of a portable program library and several application programs (APs) utilizing the library. The features of RTKLIB are:

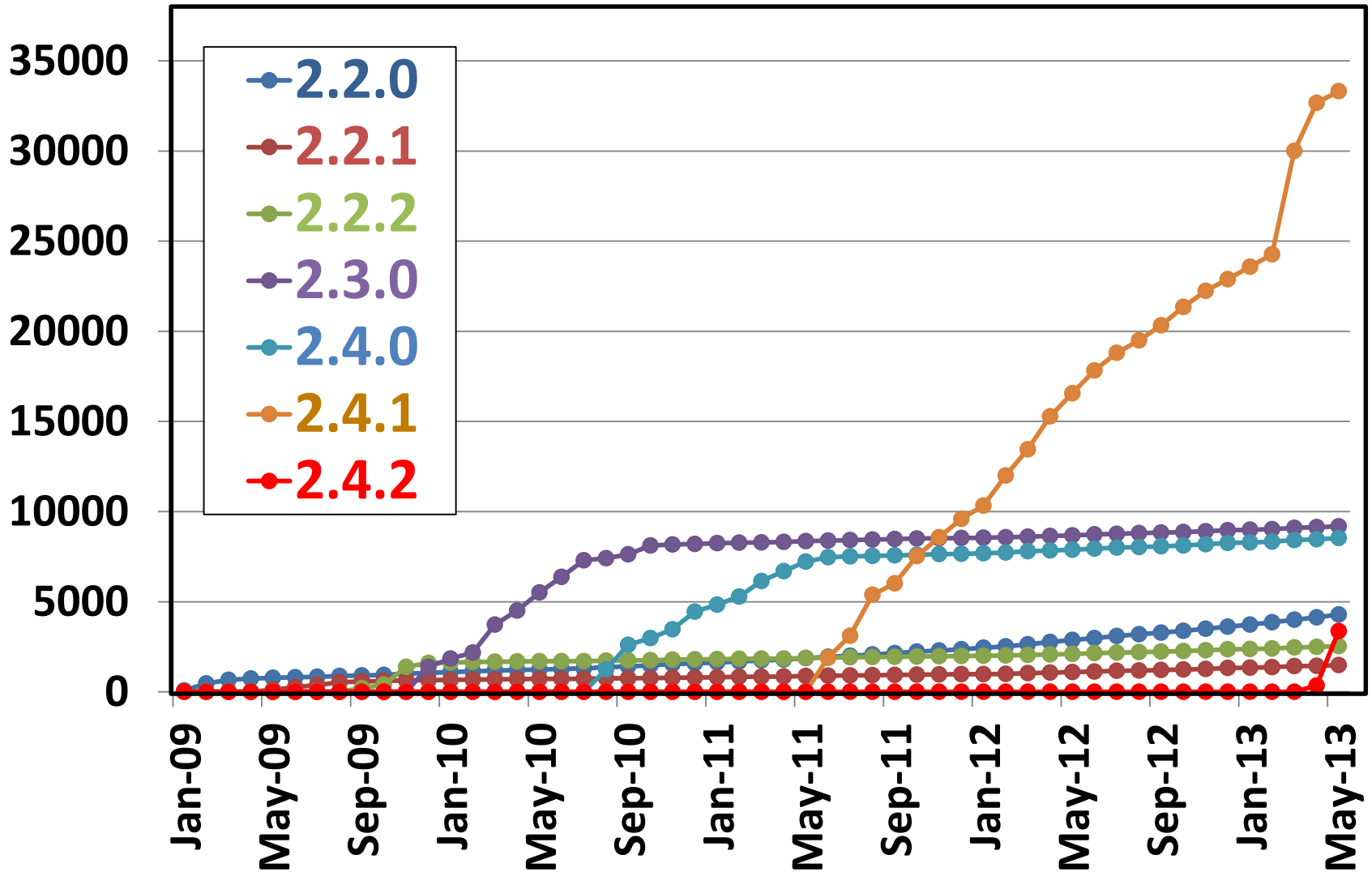
- (1) Supports standard and precise positioning algorithms with:
[GPS](#), [GLONASS](#) and [SBAS \(Galileo\)](#) and [QZSS](#) are supported but disabled in current versions
- (2) Supports various positioning modes with GNSS for both real-time and post-processing:
Single-point, DGPS/DGNSS, Kinematic, Static, Moving-baseline, Fixed, PPP-Kinematic * and PPP-Static *
- (3) Supports many standard formats and protocols for GNSS:
[RINEX 2.10](#), [2.11](#), [2.12 OBSNAV/IGNAV/HNAV](#), [RINEX 3.00 OBSNAV](#), [RINEX 3.00 CLK](#), [RTCM v.2.3](#), [RTCM v.3.1](#), [NTRIP 1.0](#), [RTCA/DO-229C](#), [NMEA 0183](#), [SP3-C](#), [ANTEX 1.3](#), [NGS PCV](#) and [EMS 2.0](#) (see [Release Notes](#) for supported RTCM messages)
- (4) Supports several GNSS receivers' proprietary messages:
[NovAtel: OEM4/V, OEM3, OEMStar, Superstar II](#), [Hemisphere: Eclipse, Crescent](#), [u-blox: LEA-4T, LEA-5T](#) and [SkyTraq: S1313F](#) (see [Release Notes](#) for supported messages)
- (6) Supports external communication via:
Serial, TCP/IP, NTRIP, local log file (record and playback) and FTP/HTTP (automatic download)
- (7) Provides many library functions and APIs for GNSS data processing:
Satellites and navigation system functions, matrix and vector functions, time and string functions, coordinates transformation, input and output functions, debug trace functions, platform dependent functions, positioning models, atmosphere models, antenna models, earth tides models, geoid models, datum transformation, RINEX functions, ephemeris and clock functions, precise ephemeris and clock functions, receiver raw data functions, RTCM functions, solution functions, [Crescent Earth KML converter](#)

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

RTKLIB: Features

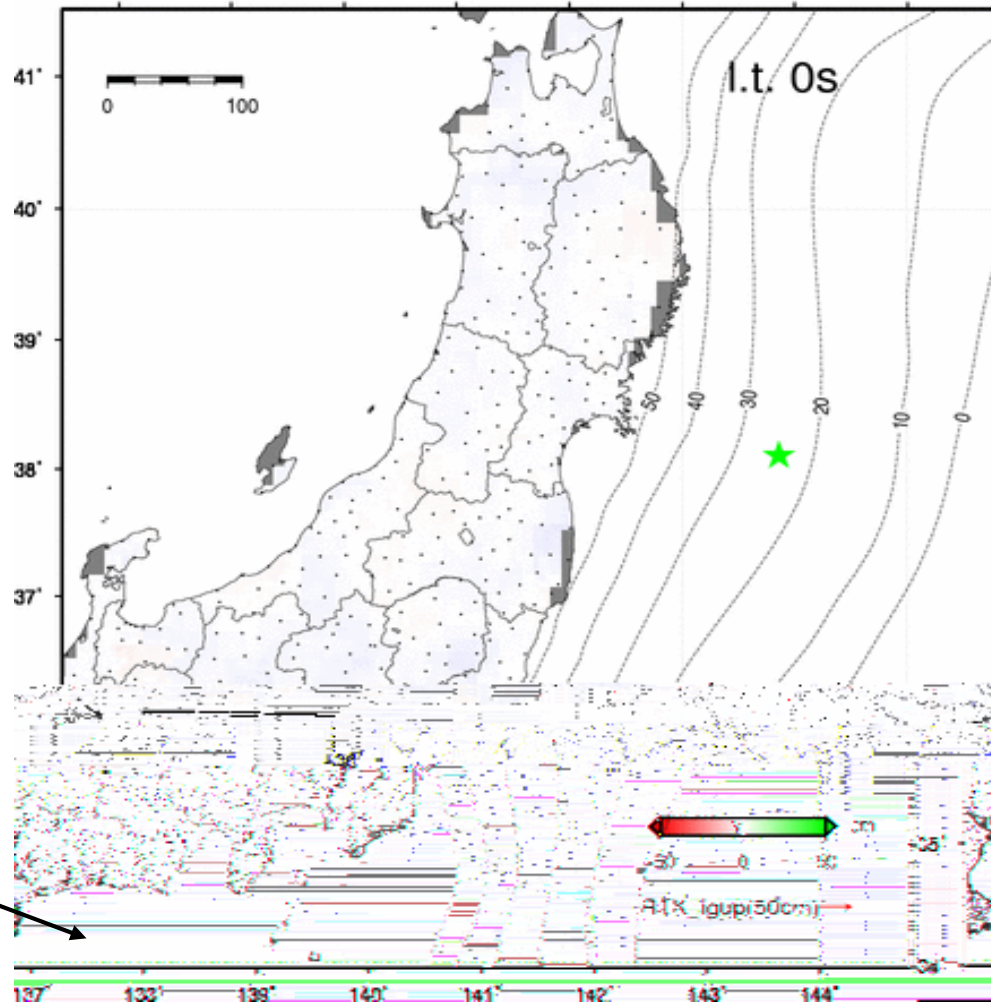
- **Standard and precise positioning algorithms with:**
 - GPS, GLONASS, QZSS, Galileo, BeiDou and SBAS
- **Real-time and post-processing by various modes:**
 - Single, SBAS, DGPS, RTK, Static, Moving-base and PPP
- **Supports many formats/protocols and receivers:**
 - RINEX 2/3, RTCM 2/3, BINEX, NTRIP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

of Downloads



Application of RTKLIB

Ing. lat. dep. len. wld. str. dip. rak. sip. opn.



Reference
Station

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

RTK vs. PPP

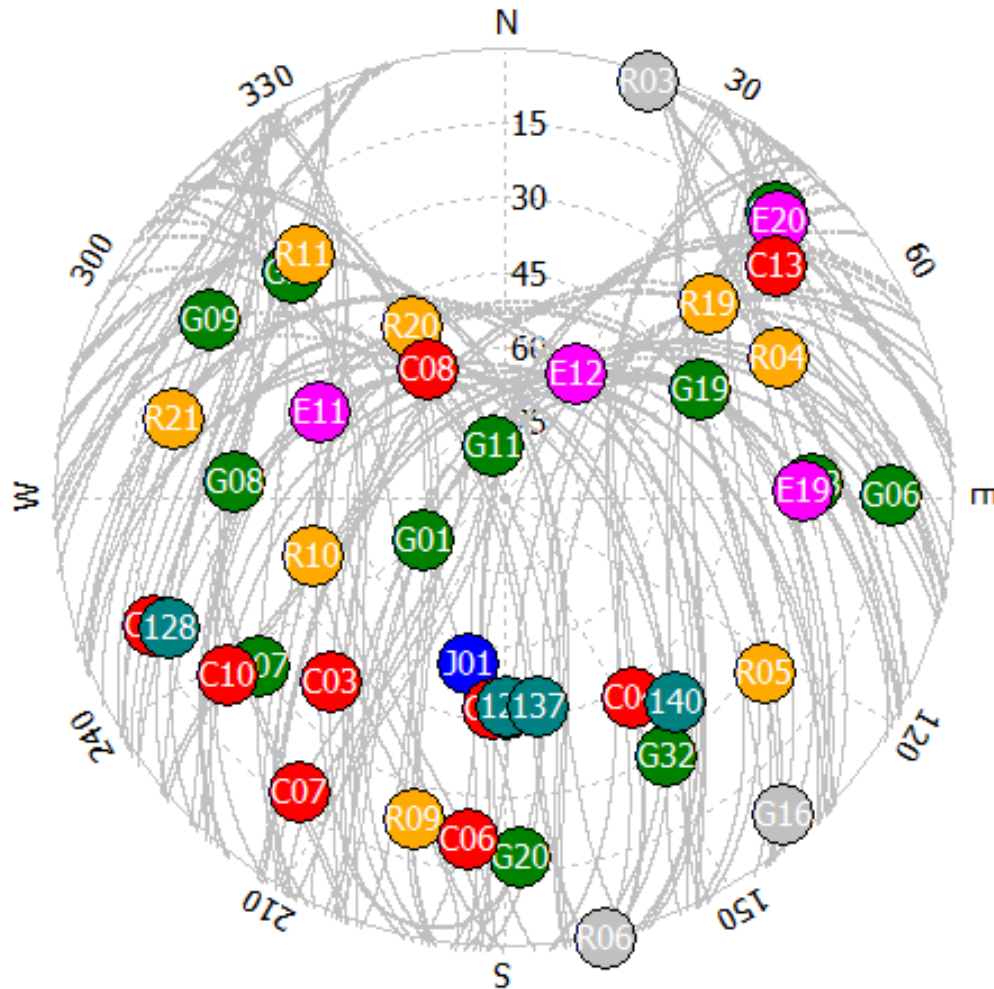
	RTK	Real-Time PPP
Coverage	Local/Regional ($< 1000\text{km}$)	Global
Typical Accuracy	1-3 cm HRMS	2-10 cm, much depending on orbit/clock quality
Effect of Ref Movement	Hard to separate ref and user movement	Less effect by distributed ref stations
System Complexity	Simple, at least one ref station	Complicated,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

New Features by v.2.4.2

- **Galileo and BeiDou supported**
- **Full RINEX 3 compliant, multi-signal supported**
- **RTCM 3.2 MSM and SSR for all GNSSs supported**
- **BINEX, NovAtel OEM6 and NVS supported**
- **Google Earth/Map View by RTKPLOT**
- **Satellite visibility analysis with NORAD TLE**
- **Data downloader AP: RTKGET added**
- **Data format conversion by STRSVR or STR2STR**
- **License Change: GPL v3 -> BSD 2-clause**

Multi-Constellation GNSS



2013-06-12 10:20 GPST

Visibility at Tokyo by RTKPLOT

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

Total (39)
(El>10deg)

RINEX Support

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

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

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

RTCM 3 Support

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

* based on draft, ~ only encode

PPP Models in v.2.4.2

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

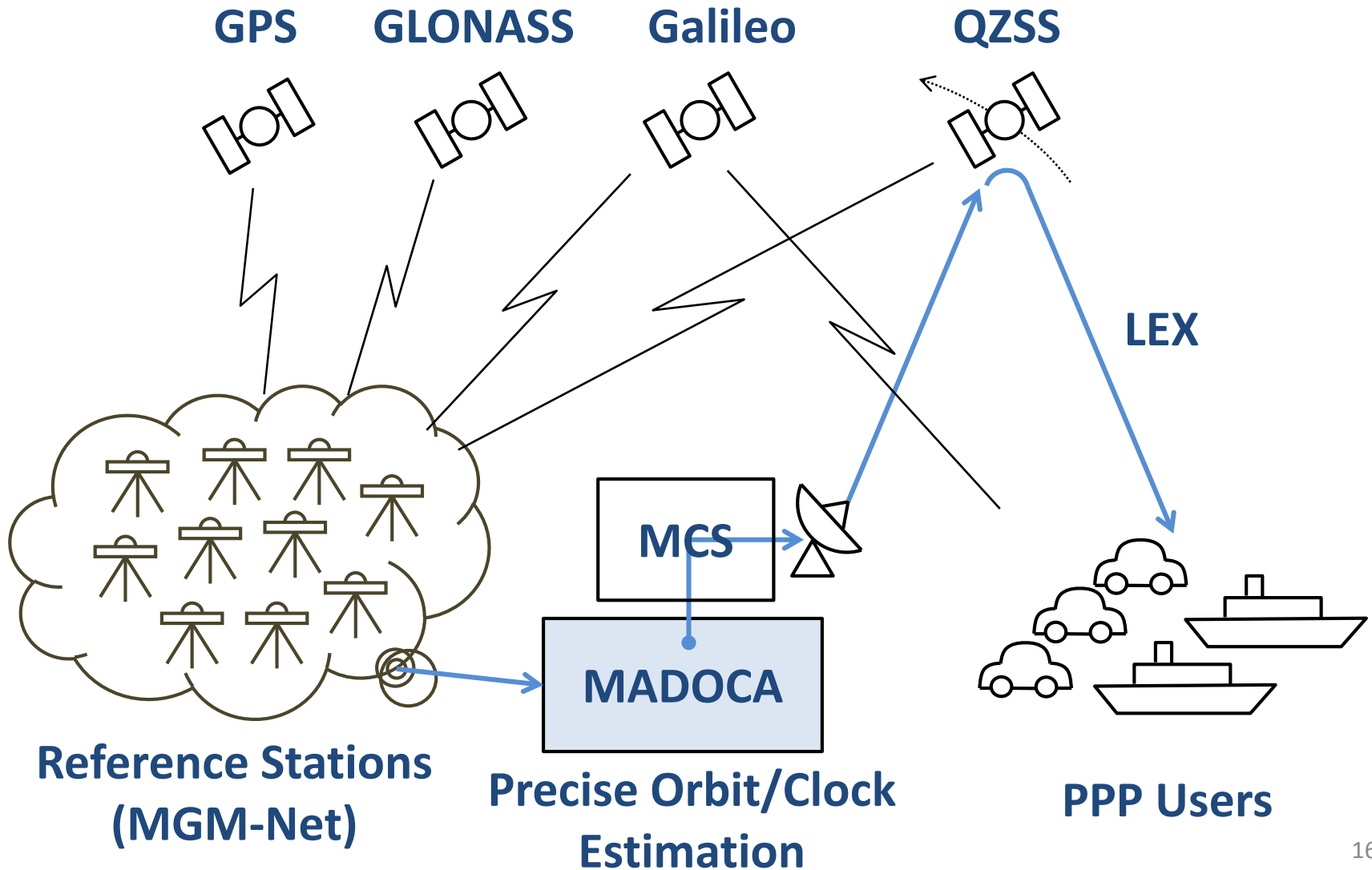
MADOCA

MADOCA

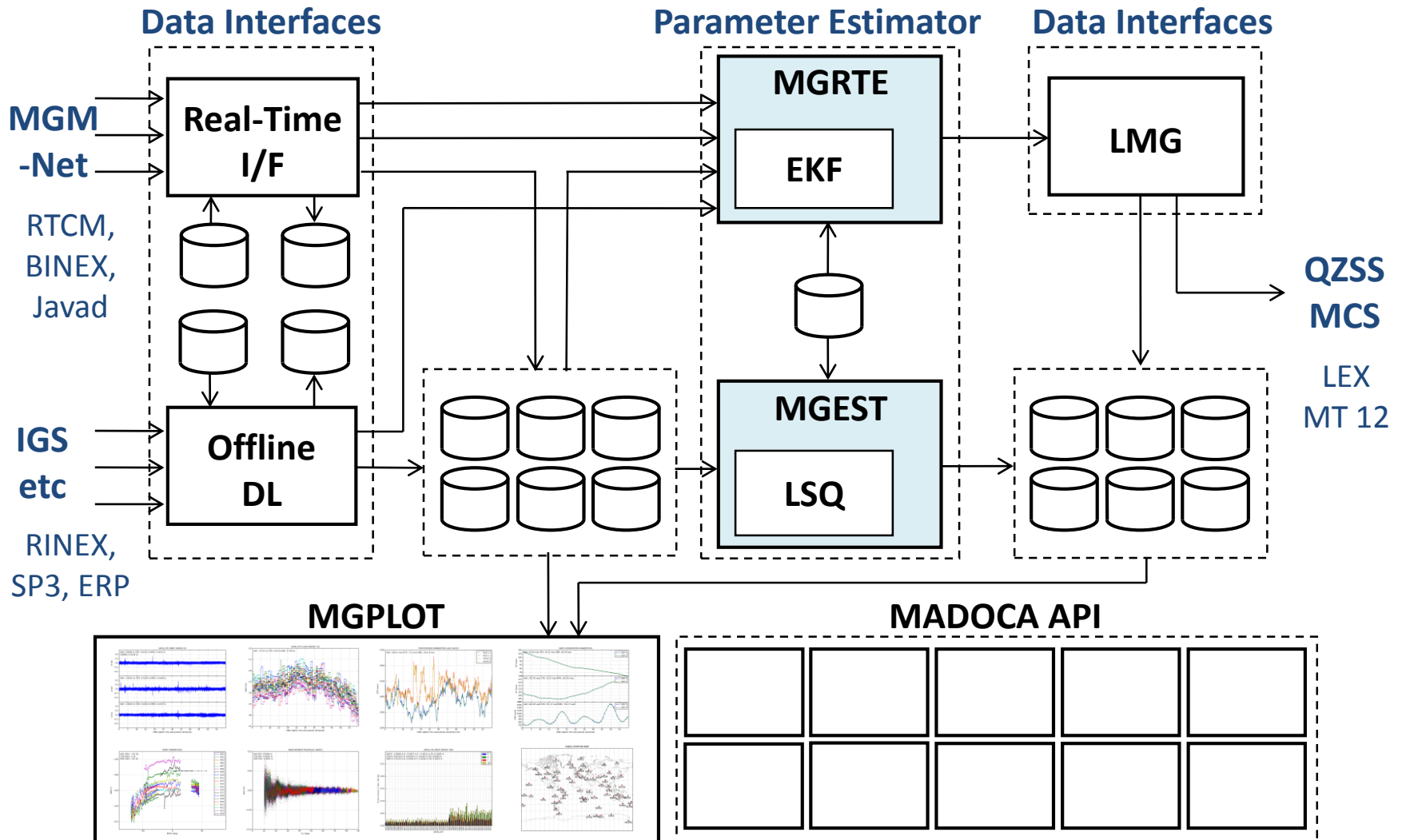
Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

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

Real-Time PPP via QZSS



MADOCA Architecture



Models

- **Satellite Orbit Models**
 - EGM 2008+solid earth tide+FES2004
 - Sun, Moon, Venus and Jupiter with JPL DE421
 - Empirical SRP model, ...
- **Measurement Models**
 - ZD Iono-free phase+ pseudorange, 2nd-order-iono
 - ZTD+gradient estimation with GPT+GMF/VMF1
 - IERS DEHANTIDEINEL+FES2004+pole tide+CMC
- **ECI-ECEF Coordinates Transformation**
 - IAU 2000A/2006 by IAU SOFA

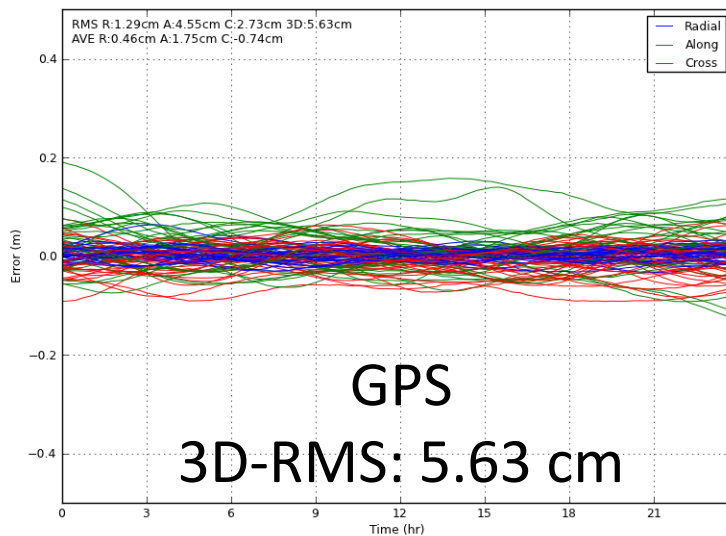
Parameter Adjustment

	Offline	Real-Time
Algorithm	Iterated Weighted LSQ	Dual-Cycle-EKF
Estimated Parameters	Orbit, SRP/Emp-Acc, Clock, Position, ZTD/Grad, Ambiguity, Bias, EOP	
Measurements	ZD Carrier-Phase and Pseudo-range	
Numerical Solver	NEQ by Cholesky Factorization	Numerical Stable EKF
Clock Estimation	Parameter Elimination in NEQ	State as White-Noise or Random-Walk
Integer Ambiguity Resolution	Network AR (Ge., 2005)	Real-Time Network AR

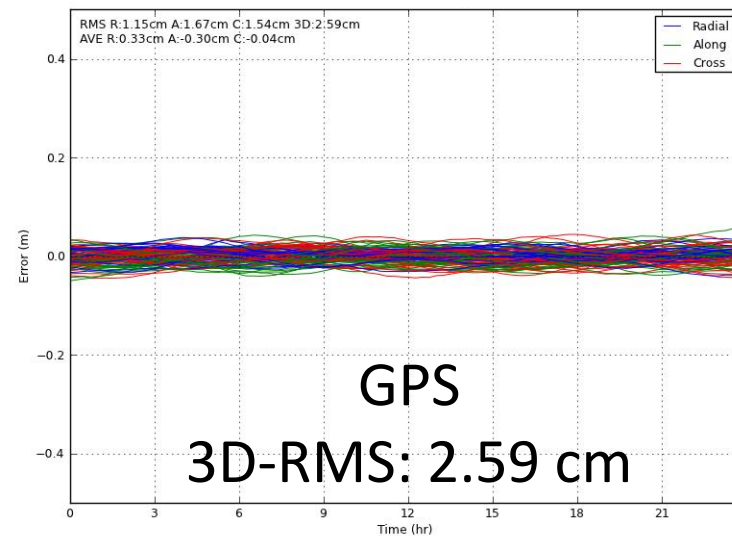
Network AR

- Dynamic baseline selection to convert ZD to DD
- WL and NL DD ambiguities by rounding
- Validation by confidence function and FCB
- For GPS, QZSS and Galileo (no GLONASS)

AR-OFF

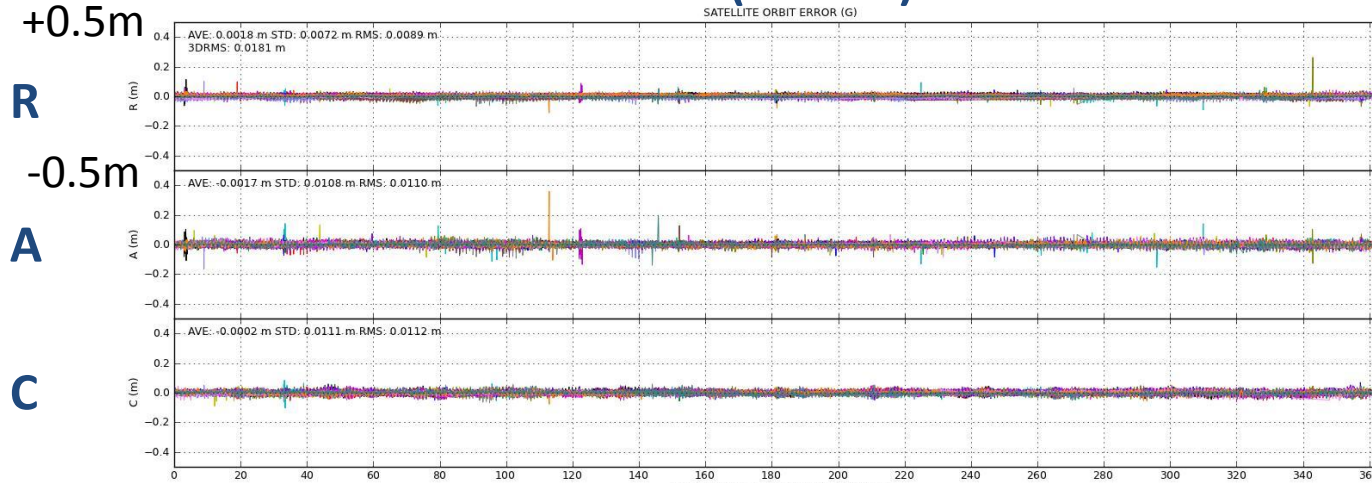


AR-ON



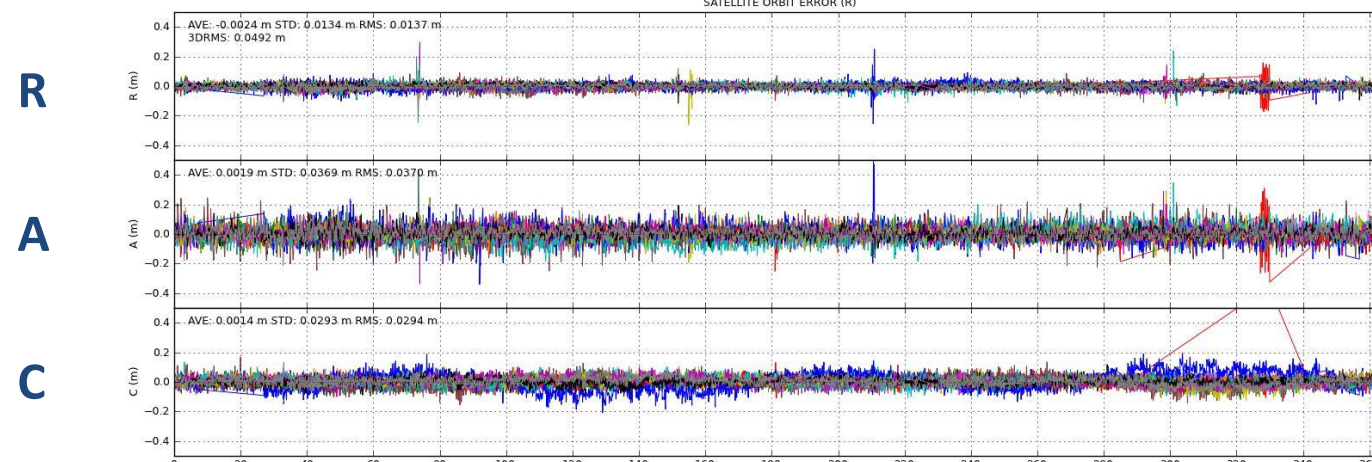
Offline GPS/GLO Orbit

GPS (32 sats)



RMS
R: 0.89 cm
A: 1.10 cm
C: 1.12 cm
3D: 1.81 cm

GLONASS (24 sats)

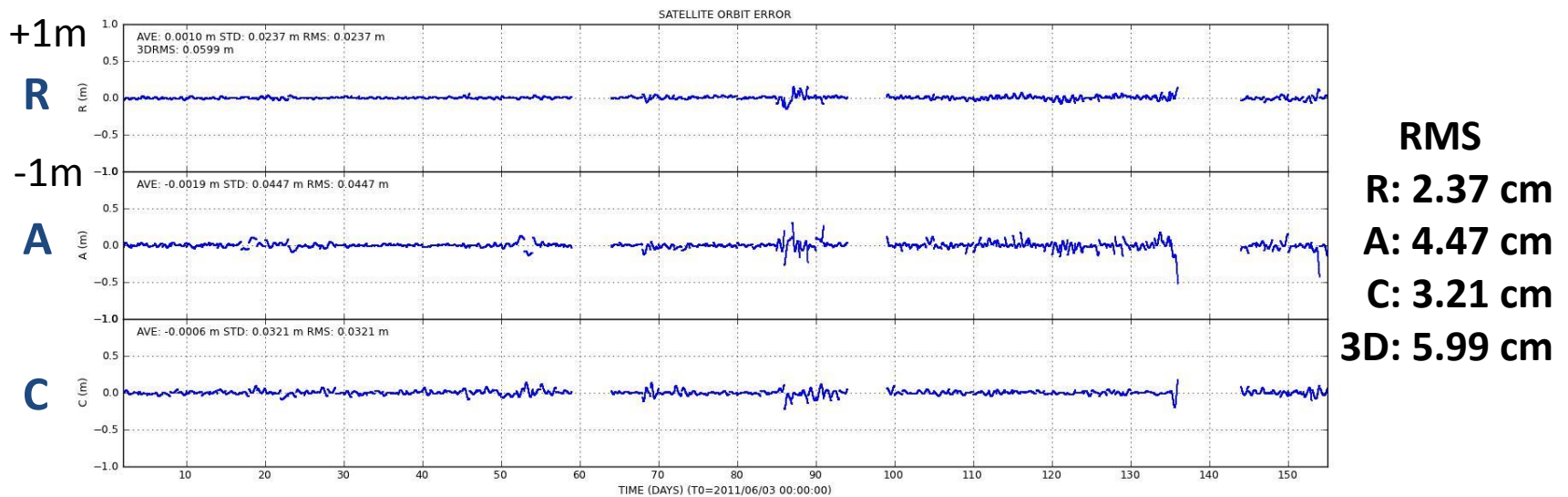


RMS
R: 1.37 cm
A: 3.70 cm
C: 2.94 cm
3D: 4.92 cm

2011/01/01 - 2011/12/31 (365 days), wrt IGS Final

Offline QZSS Orbit

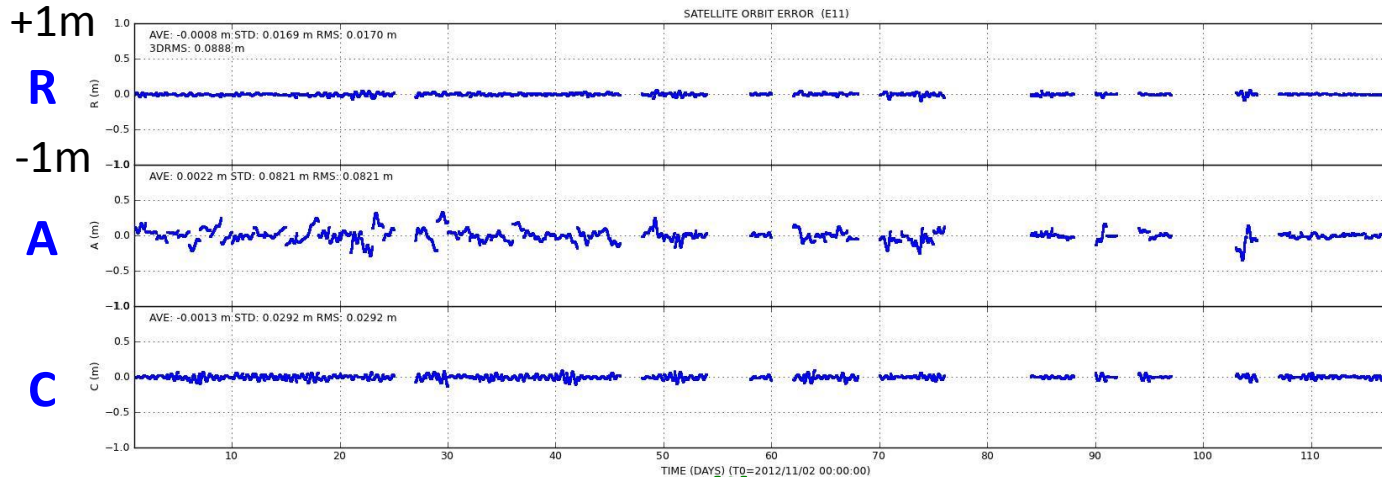
QZSS-1 Michibiki J01



2011/06/04 - 2011/11/03 (153 days), 24 H-overlap

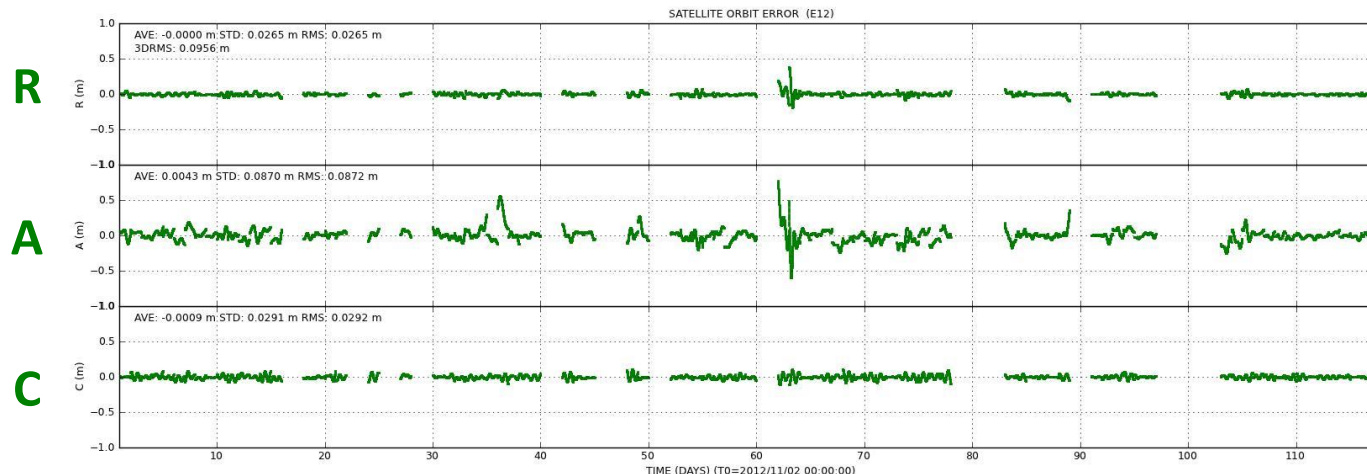
Offline Galileo Orbit

Galileo E11



RMS
R: 1.70 cm
A: 8.21 cm
C: 2.92 cm
3D: 8.88 cm

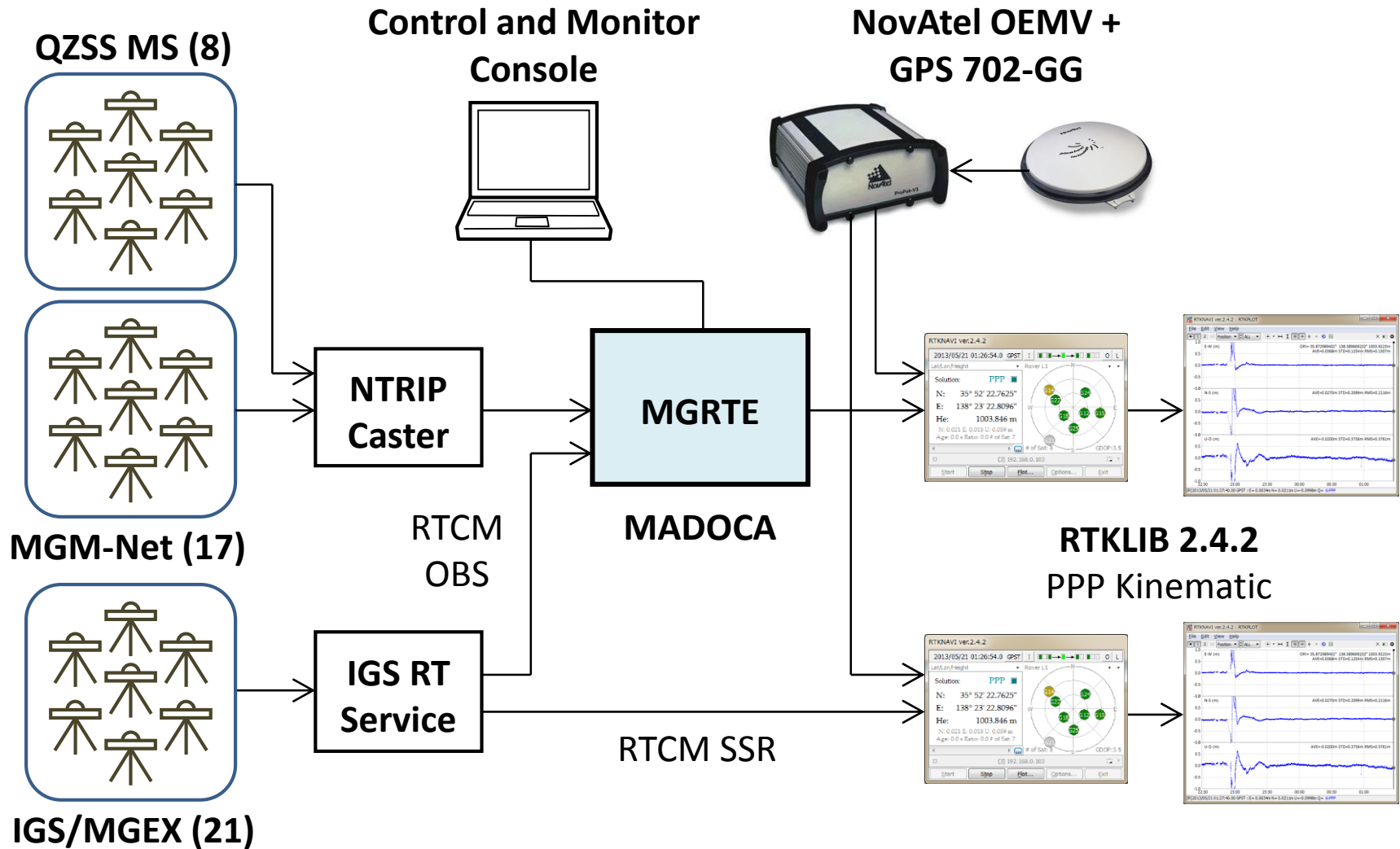
Galileo E12



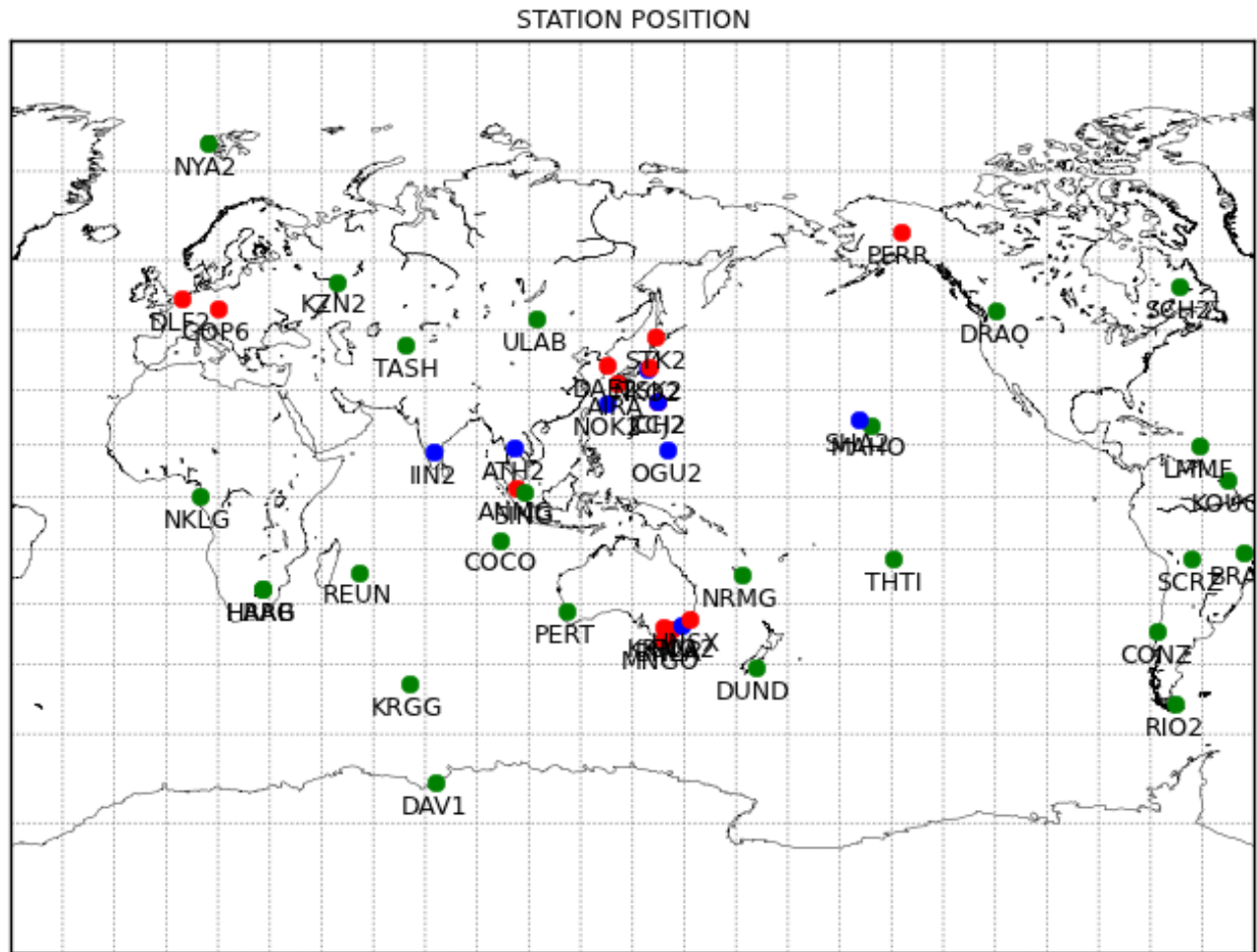
RMS
R: 2.65 cm
A: 8.72 cm
C: 2.92 cm
3D: 9.56 cm

2012/11/2 - 2013/02/27 (117 days), 24H-overlap

Real-Time PPP Test



Reference Station Network



● QZSS-MS (8) ● MGM-Net (17) ● IGS/MGEX (21)

Test Snapshots

Control and Monitor Console of MADOCA MGRTE

Real-time PPP by RTKLIB 2.4.2

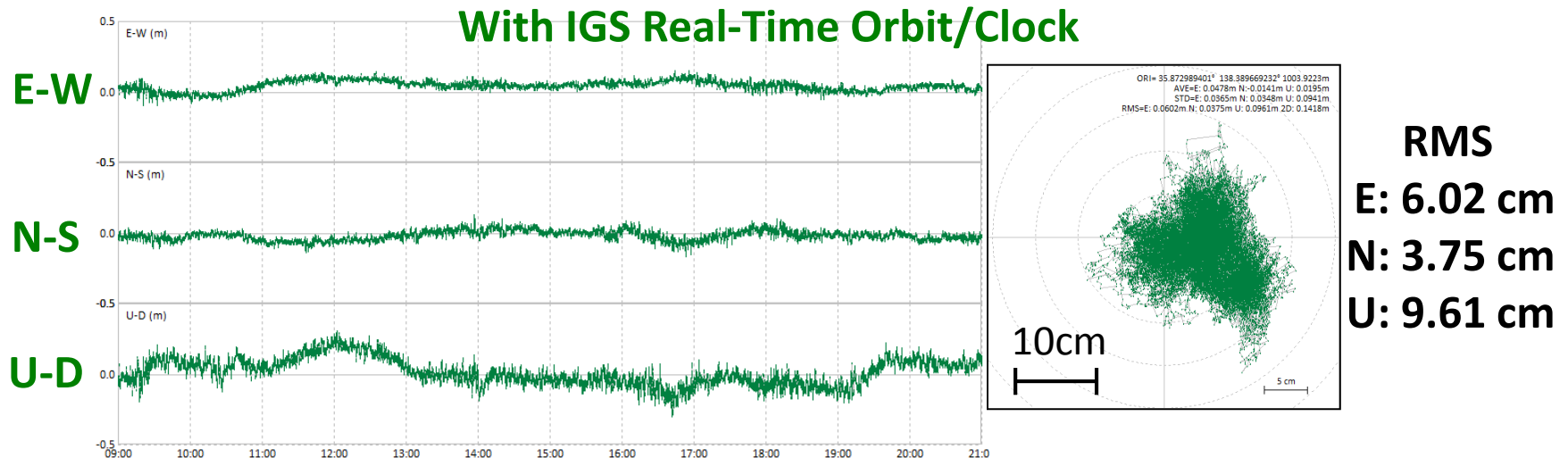
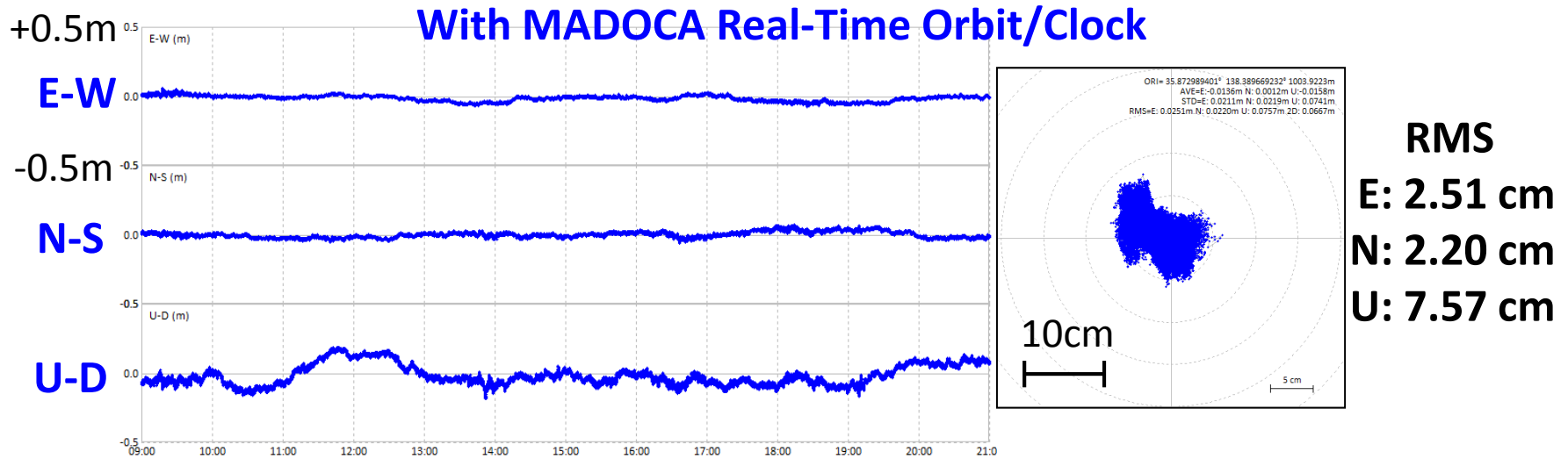
The screenshot displays the MADOCA Control and Monitor interface, which is divided into several sections:

- REAL TIME ESTIMATION STATUS:** Shows the current state (RUNNING), time (2018/05/21 09:22:51.1), and various system parameters like epoch, time, and station coordinates.
- STATION DATA:** Lists 12 stations with their IDs, names, coordinates, and status.
- DATA FEEDER STATUS:** Shows the status of data feeders, including station IDs and coordinates.
- NO. USER LEVEL:** Lists user levels and their corresponding IP addresses.
- NO. EXTERNAL DATA:** Lists external data sources and their coordinates.
- FILE NAMES:** Lists various log and data files.
- SYSTEM PARAMETERS:** Lists system parameters and their values.
- SYSTEM LOGGING:** Lists system logging configurations.
- SYSTEM REPORT:** Lists system reports and their locations.

The screenshot displays the Real-time PPP by RTKLIB 2.4.2 interface, which is divided into several sections:

- Station Status:** Shows the status of the station (PPP), coordinates (N: 39° 52' 22.7629", E: 138° 23' 22.8105"), and height (1003.915 m).
- Real-time Data Plots:** Shows real-time data plots for various parameters, including position, velocity, and acceleration.
- RTKLIB 2.4.2 (2):** Shows the status of the RTKLIB 2.4.2 process, including coordinates (N: 35° 59' 59.3873", E: 139° 47' 32.5434") and height (59.434 m).
- RTKLIB 2.4.2 (3):** Shows the status of the RTKLIB 2.4.2 process, including coordinates (N: 35° 59' 59.3873", E: 139° 47' 32.5434") and height (59.434 m).
- RTKLIB 2.4.2 (4):** Shows the status of the RTKLIB 2.4.2 process, including coordinates (N: 35° 59' 59.3873", E: 139° 47' 32.5434") and height (59.434 m).

Real-Time PPP Test Results



2013/05/20 09:00 - 21:00 (12 h), 1 Hz, only with GPS

Real-Time Experiment

The image displays three overlapping browser windows from the QZ-vision website. The leftmost window shows the main navigation with 'PLAY' and 'READ' buttons. The middle window shows the 'USE' section, featuring an 'Experiment Schedule' table for GPS Week 1761. The rightmost window shows the 'Interface Specifications for QZSS:IS-QZSS' page, which includes a flowchart of the data flow and a download link for the 'MADOCA-LEX Format'.

Experiment Schedule Table (from middle window):

2013	UT	10/6(Sun.)
	L1 C/A	標準コード S
GPS補完信号 Availability Enhancement Signals	L1C	標準コード S
	L2C	標準コード S
	L5	標準コード S
L1-SAIF	ENRF	
	SPAC	
	JAXA-LEX	
	JAXA-LEX (MADOCA)	
	SPAC-LEX	
	アラート及びヘルプフラグ Alert and Health Flags	

Flowchart (from right window):

```

    graph TD
      User[運用者] -- 申請 --> Manager[運用管理者  
製品管理者]
      Manager -- 通知 --> User
      Manager -- 申請 --> Manufacturer[製造販売者]
      Manufacturer -- 型式認定 --> Manager
      Manufacturer -- 販売 --> User
      User -- 調達 --> Manufacturer
  
```

Download Link (from right window):

MADOCA-LEX
MADOCA-LEX Format
ダウンロード

Schedule

LEX Data Format

LEX Data Format (MT12)

- **メッセージタイプ** : JAXA実験用信号としてメッセージタイプ 12 で放送予定
- **メッセージフォーマット** : PPPユーザ向けのRTCM^(*) SSR(State Space Representation)フォーマットに基づき、MADOGAにより生成したプロダクトを格納する。
LEXメッセージのデータ部には、RTCMメッセージの“Variable Length Data Message”のみを先頭から詰めて格納する。
LEXメッセージとRTCMメッセージの関係は、下記のとおり。
(*1)RTCM (Radio Technical Commission for Maritime services)

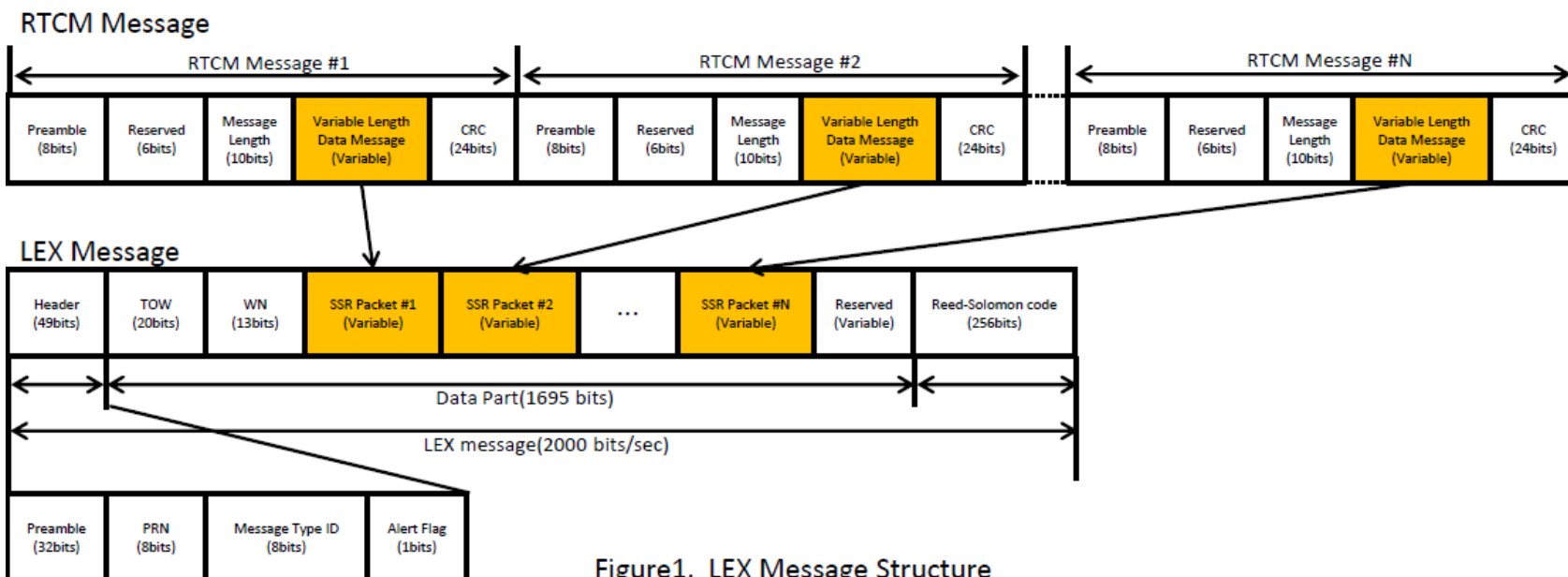


Figure1. LEX Message Structure

MADOCA-RTKLIB-PPP Demos

- **Post-Processing PPP:**
 - GPS, GLONASS and QZSS
 - Orbit/Clock: MADOCA Rapid Products
 - Interval: 30 s
 - PPP kinematic mode
- **Real-Time PPP:**
 - GPS and QZSS (no GLONASS)
 - Orbit/Clock: MADOCA LEX MT12
 - Interval: 1 Hz
 - PPP kinematic mode

Future Plans

- **RTKLIB**

- Full BeiDou support
- Full PPP-AR support
- Local ionosphere/troposphere correction with PPP
- PPP-INS-integration for mobile application
- Porting to SDR-based LEX receiver

- **MADOCA**

- BeiDou support
- Satellite FCB estimation for PPP-AR
- Ionosphere estimation
- Local ionosphere/troposphere products