

GPS/GNSS Symposium 2010

**QZSS LEXによるリアルタイムPPP実験と
その拡張**

Real-Time PPP Experiment via QZSS LEX and its Extension



Tokyo University of Marine Science and Technology

Tomoji TAKASU

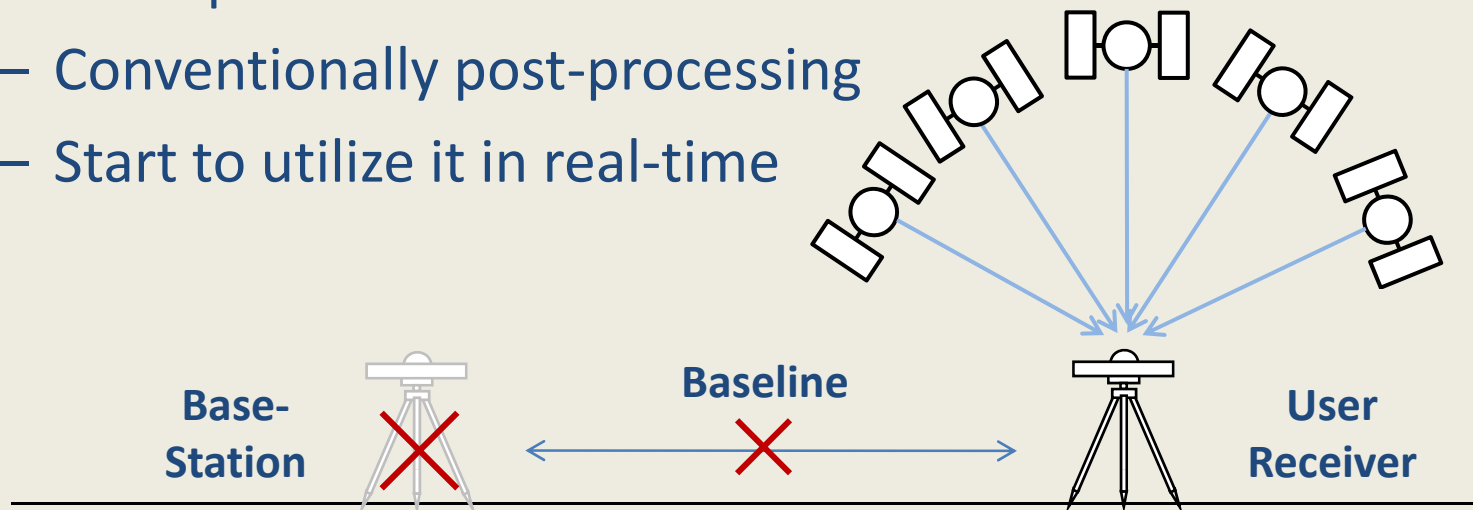
Outline

- What is PPP?
- Real-Time PPP Experiment via QZSS LEX
- Real-Time PPP Client Implementation
- Preliminary Performance Evaluation
- Future Extension of QZSS LEX PPP
- Summary

What is PPP?

PPP: Precise Point Positioning

- Carrier-Based Single Positioning with GNSS
 - Dm to mm-level accuracy
 - No need base-station and baseline
 - Global coverage world-wide
 - Need precise orbit and clock
 - Conventionally post-processing
 - Start to utilize it in real-time

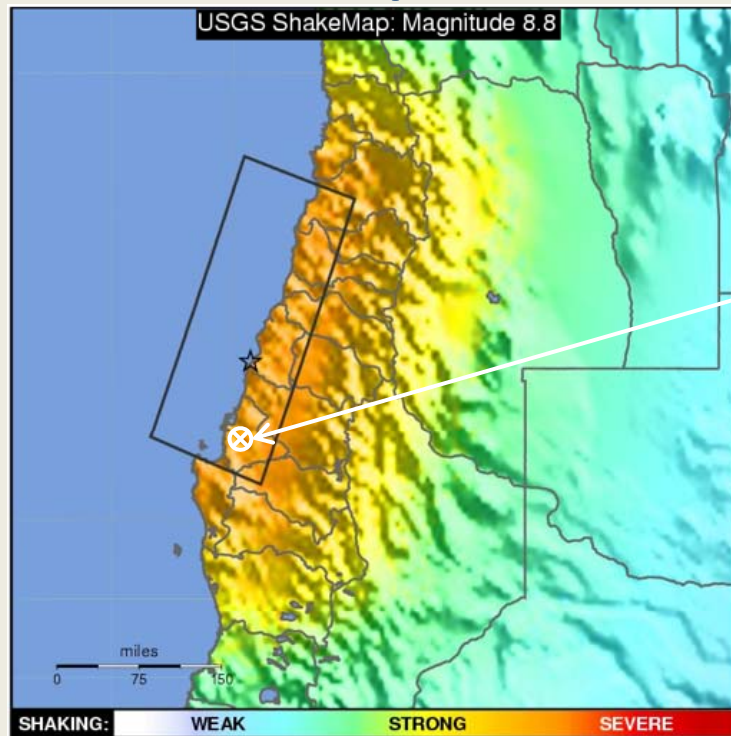


Comparison of RTK and RT-PPP

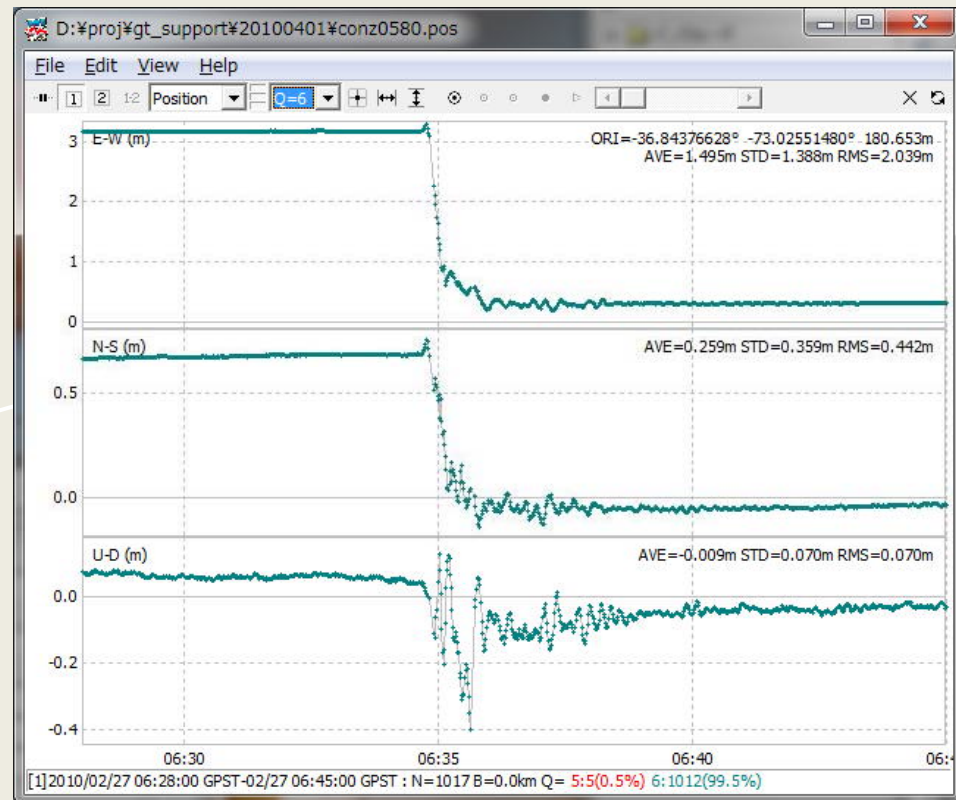
	RTK/Network-RTK	Real-Time PPP
Coverage	<100 km from Base	Global
Accuracy	2 cm HRMS	<10 cm HRMS
Convergence	< 30 s	30 min
Ionosphere	Eliminated by DD	Dual-Frequency
Ambiguity	Fixed	Float
Orbit/Clock	Broadcast	Precise
Communication	Point To Point	Satellite, Internet

Example of PPP AP (1/2)

2010/1/27 M8.8 Chilean Earthquake

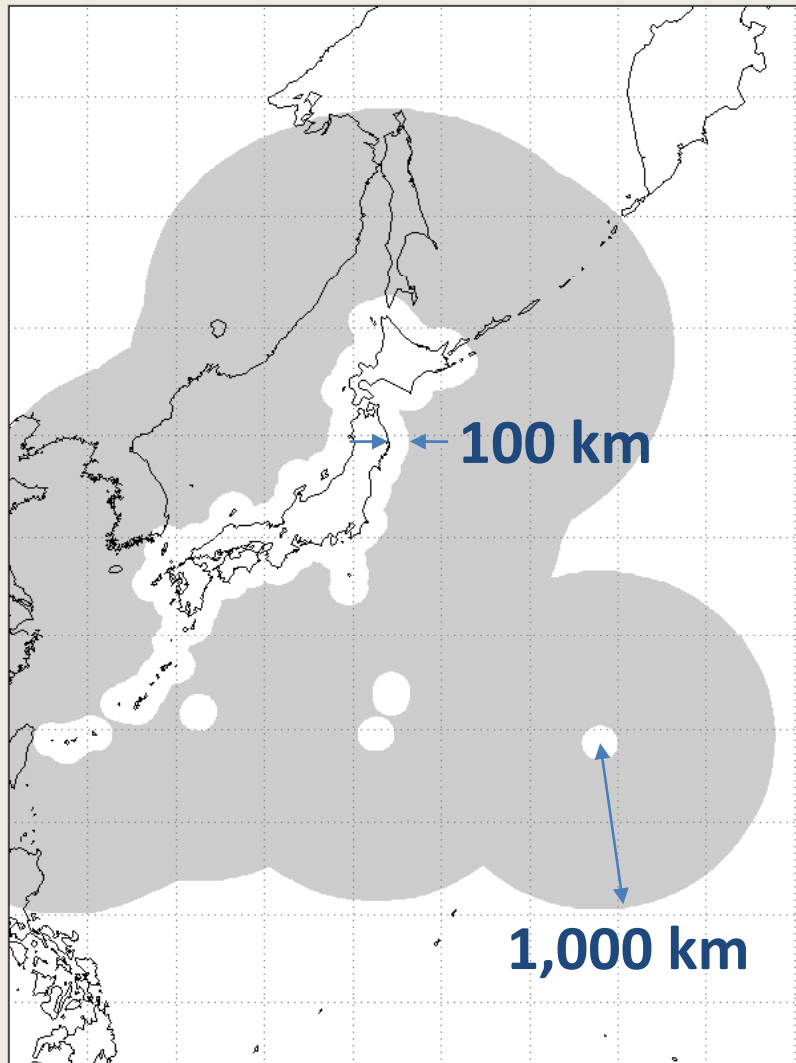


<http://earthquake.usgs.gov/earthquakes>



IGS CONZ, Orbit/Clock: CODE/CODE-5 s
2010/2/27 6:28-6:45 1 Hz, RTKPOST 2.4.0,
Mode: Kinematic PPP + Combined, GPS

Example of PPP AP (2/2)



**GPS Tsunami
Monitoring System
(Currently ~20 km off-shore)**

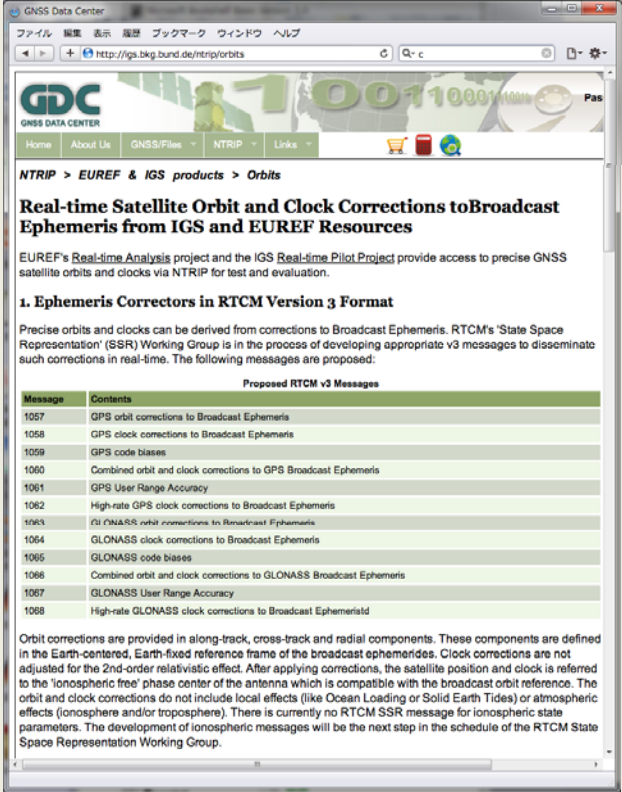
<http://www.tsunamigps.com>

Commercial RT-PPP Service

Provider	Service	Coverage	Broad- cast	Ref. Stations	Orbit/ Clock	Engine	Accuracy
NavCom	StarFire	World- wide	3 GEO L-band	60	1 min/ 1-2 s	JPL RTG	<10 cm H <15 cm V (1 sigma)
Fuguro	OmniSTAR XP/HP+	World- wide (Land)	6 GEO L-band	100	1 min/ 10 s	Fuguro	dm-class
	SeaSTAR XP/G2	World- wide (Sea)	6 GEO L-band	100	1 min/ 10 s	Fuguro/ ESOC (G2)	dm-class
VERIPOS	VERIPOS Ultra/Apex	World- wide	7 GEO L-band	80	30 s/ 30 s	JPL/ ESOC	10 cm H 20 cm V (95%)

IGS RT Orbit/Clock

- Developed by IGS RTPP
 - Corrections to broadcast ephemeris
 - RTCM v.3 MT1057-1068 (SSR)
 - NTRIP stream via Internet
 - Interval: 10 s, Latency: 5 - 10 s
 - Free of charge
- Provided by several ACs
 - Orbit: fixed to IGU or estimated
 - Clock: estimated with IGS real-time tracking network



The screenshot shows a web browser window displaying the IGS Data Center website. The page title is "NTRIP > EUREF & IGS products > Orbits". The main heading is "Real-time Satellite Orbit and Clock Corrections to Broadcast Ephemeris from IGS and EUREF Resources". Below the heading, there is a paragraph explaining the project and a section titled "1. Ephemeris Correctors in RTCM Version 3 Format". This section includes a table of proposed RTCM v3 messages and a detailed description of the corrections provided.

Message	Contents
1057	GPS orbit corrections to Broadcast Ephemeris
1058	GPS clock corrections to Broadcast Ephemeris
1059	GPS code biases
1060	Combined orbit and clock corrections to GPS Broadcast Ephemeris
1061	GPS User Range Accuracy
1062	High-rate GPS clock corrections to Broadcast Ephemeris
1063	GLONASS orbit corrections to Broadcast Ephemeris
1064	GLONASS clock corrections to Broadcast Ephemeris
1065	GLONASS code biases
1066	Combined orbit and clock corrections to GLONASS Broadcast Ephemeris
1067	GLONASS User Range Accuracy
1068	High-rate GLONASS clock corrections to Broadcast Ephemeris

Orbit corrections are provided in along-track, cross-track and radial components. These components are defined in the Earth-centered, Earth-fixed reference frame of the broadcast ephemerides. Clock corrections are not adjusted for the 2nd-order relativistic effect. After applying corrections, the satellite position and clock is referred to the 'ionospheric free' phase center of the antenna which is compatible with the broadcast orbit reference. The orbit and clock corrections do not include local effects (like Ocean Loading or Solid Earth Tides) or atmospheric effects (ionosphere and/or troposphere). There is currently no RTCM SSR message for ionospheric state parameters. The development of ionospheric messages will be the next step in the schedule of the RTCM State Space Representation Working Group.

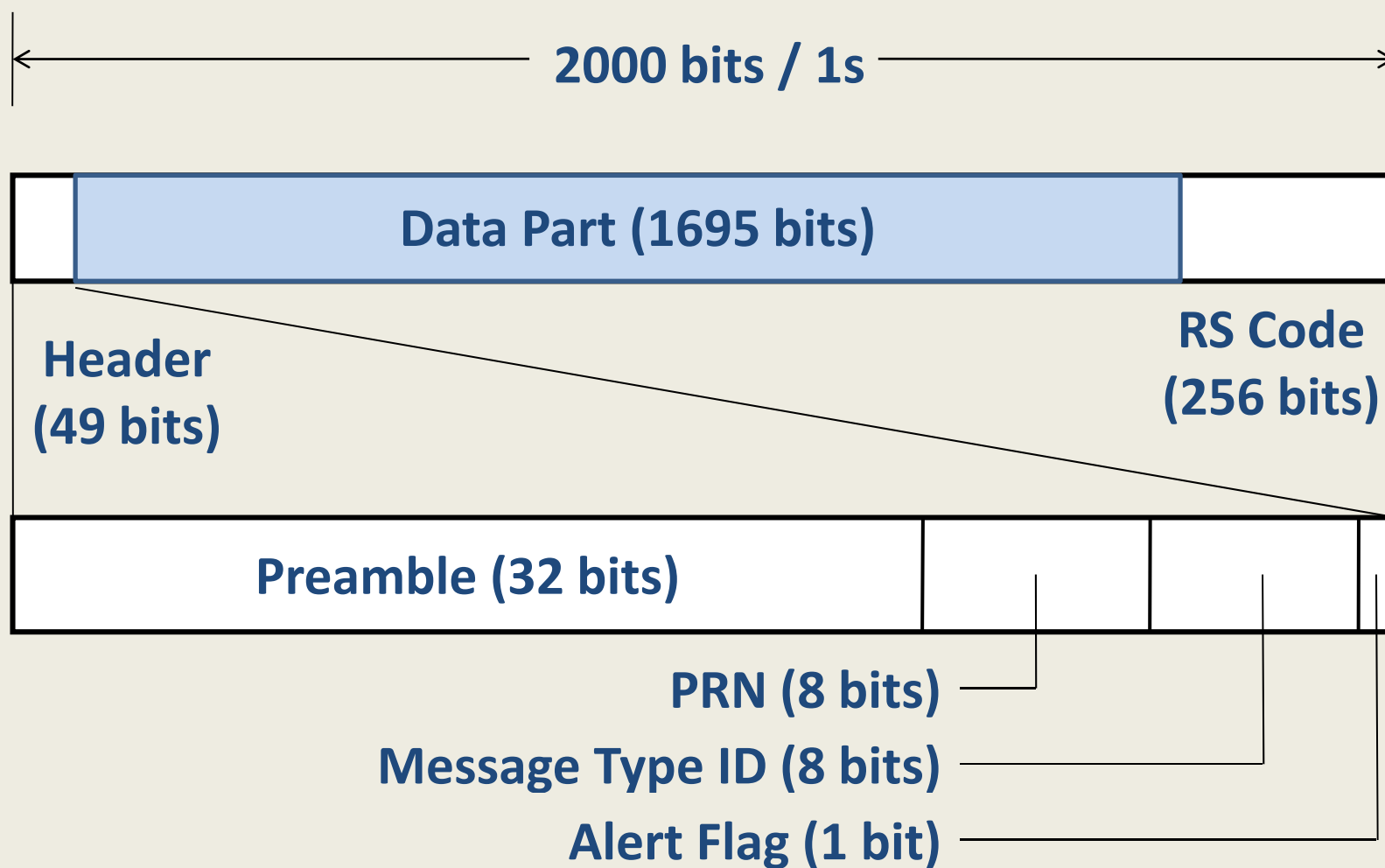
<http://igs.bkg.bund.de>

Real-Time PPP Experiment via QZSS LEX

QZSS LEX Signal

		Specification
Frequency		1278.75MHz (= Galileo E6 CS)
Bandwidth		42.0MHz
Signal Power		-155.7dBW (Min)
Modulation		BPSK (5) , Short-Kasami-Sequence
Spreading Code	Short	Period: 4ms, Length: 10,230 chips
	Long	Period: 410ms, Length: 1,048,575 chips
Navigation Data		2000 bits/frame, 1 frame/s

QZSS LEX Message



QZSS LEX Message Type ID

MT	Contents
0-9	Reserved
10-19	JAXA Experiment
10	Signal Health (35 Satellites) Ephemeris and SV Clock (3 Satellites)
11	Signal Health (35 Satellites) Ephemeris and SV Clock (2 Satellites) Ionosphere Correction
12-19	Reserved
20	GSI Experiment
21-255	Other Experiment

JAXA Experiment (1/2)

- Signal Health
 - 32 GPS + 3 QZSS, L1, L2, L5, L1C, LEX
- Ephemeris and SV Clock
 - 32 GPS + 3 QZSS satellites
 - 3rd order coefficients of ECEF position and URA
 - Clock bias/drift and DCB
- Ionosphere Correction
 - 2nd/1st order coefficients of vertical delay
 - Regional coverage near Japan

JAXA Experiment (2/2)

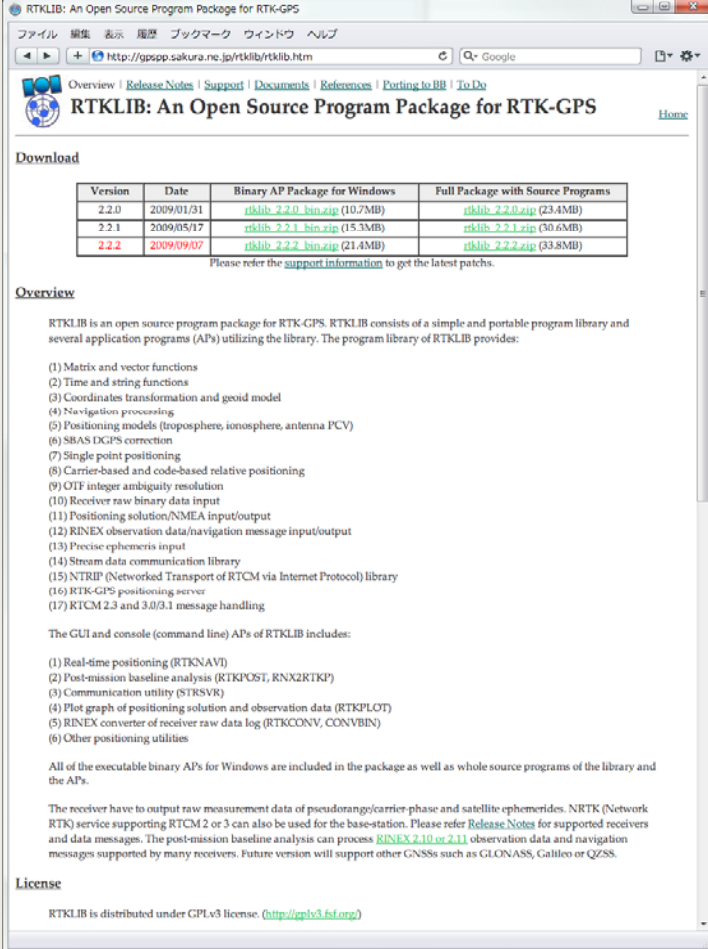
Message Interval (Nominal)

Message	Broadcast	Update	Effective Period
Signal Health	1 s	1 s	-
Ephemeris	12 s	3 min	6 min
SV Clock	12 s	3 min	6 min
Ionosphere	12 s	30 min	-

Real-Time PPP Client Implementation

RTKLIB

- Open Source Program Package for GNSS Positioning
 - Whole source codes are freely available
 - License: GPLv3
 - >10,000 downloads (Total)
- Portable Library + Several APs
 - ANSI C + socket/pthread ...
 - Portable command-line APs
 - GUI APs for Windows



The screenshot shows the RTKLIB website with the following content:

Download

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)

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

Overview

RTKLIB is an open source program package for RTK-GPS. RTKLIB consists of a simple and portable program library and several application programs (APs) utilizing the library. The program library of RTKLIB provides:

- (1) Matrix and vector functions
- (2) Time and string functions
- (3) Coordinates transformation and geoid model
- (4) Navigation processing
- (5) Positioning models (troposphere, ionosphere, antenna PCV)
- (6) SBAS DGPS correction
- (7) Single point positioning
- (8) Carrier-based and code-based relative positioning
- (9) OTF integer ambiguity resolution
- (10) Receiver raw binary data input
- (11) Positioning solution/NMEA input/output
- (12) RINEX observation data/navigation message input/output
- (13) Precise ephemeris input
- (14) Stream data communication library
- (15) NTRIP (Networked Transport of RTCM via Internet Protocol) library
- (16) RTK-GPS positioning server
- (17) RTCM 2.3 and 3.0/3.1 message handling

The GUI and console (command line) APs of RTKLIB includes:

- (1) Real-time positioning (RTKNAVI)
- (2) Post-mission baseline analysis (RTKPOST, RNX2RTKP)
- (3) Communication utility (STRSVK)
- (4) Plot graph of positioning solution and observation data (RTKPLOT)
- (5) RINEX converter of receiver raw data log (RTKCONV, CONVBIN)
- (6) Other positioning utilities

All of the executable binary APs for Windows are included in the package as well as whole source programs of the library and the APs.

The receiver have to output raw measurement data of pseudorange/carrier phase and satellite ephemerides. NRTK (Network RTK) service supporting RTCM 2 or 3 can also be used for the base-station. Please refer [Release Notes](#) for supported receivers and data messages. The post-mission baseline analysis can process [RINEX 2.10 or 2.11](#) observation data and navigation messages supported by many receivers. Future version will support other GNSSs such as GLONASS, Galileo or QZSS.

License

RTKLIB is distributed under GPLv3 license. (<http://gpv3.fsf.org/>)

<http://www.rtklib.com>

RTKLIB APs

The image displays a collection of software windows from the RTKLIB suite. The windows are arranged in a grid-like fashion, with some overlapping. The main windows shown are:

- STRSVR ver.2.2.0**: A window showing stream configuration with columns for Stream, Type, Opt. Ord, Bytes, and Ops. It lists (0) Input as NTRIP Client and (1) Output as Serial.
- RTKCONV ver.2.2.0**: A window for converting observation files, showing Time Start (GPST), Time End (GPST), Interval, and Receiver Log File paths.
- Ntrip Source Table Browser**: A window displaying a table of NTRIP sources. The table has columns for Mountpoint, ID, Format, Format-Details, Cn, and New-System/Network. The table lists various stations like ADCS0, ADCS1, ALB10, etc.
- RTKNAVI ver.2.2.0**: A navigation window showing a solution for SBAS, including coordinates (N: 35° 52' 22.7486", E: 138° 23' 22.7875", H: 961.418 m) and a bar chart of rover SNR.
- RTKPOST ver.2.2.0**: A window for post-processing, showing Observation Data, Navigation Messages, Base Station Observation Data, and Output File paths.
- RTKPLOT**: A window showing a 2D plot of a trajectory. The plot has a vertical axis from -4000 to 1350 and a horizontal axis from -20 to 100. A green line shows a path that starts near the origin, moves up and right, then curves sharply down and left, ending near the origin. The plot includes a scale bar (10 m) and coordinate information at the bottom.

Overlaid on the windows are labels for each software component: STRSVR, RTKCONV, NTRIPBROWS, RTKNAVI, and RTKPOST. At the bottom of the image, there are several 'About' dialog boxes for the software, each containing the RTKLIB logo and copyright information: Copyright (C) 2007-2009 by T. Takasu. All rights reserved.

RTKLIB Features

- Standard and precise positioning algorithms with:
 - GPS, GLONASS, SBAS (and Galileo, QZSS)
- Various positioning modes:
 - 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, ...
- External communication via:
 - Serial, TCP/IP, NTRIP and file streams

RTKLIB 2.4.0

- Released on August 8, 2010
- New Features:
 - PPP-Kinematic or PPP-Static mode for both of real-time and post-processing
 - Long baseline RTK up to 1,000 km
 - Supports RTCM v.3 MT1057-1068 (SSR) for real-time orbit and clock corrections
 - Supports RINEX 3.0 for multi-GNSS processing
 - Ready to support new GNSS (QZSS, Galileo, ...)
 - Real-time and remote visualization by RTKPLOT

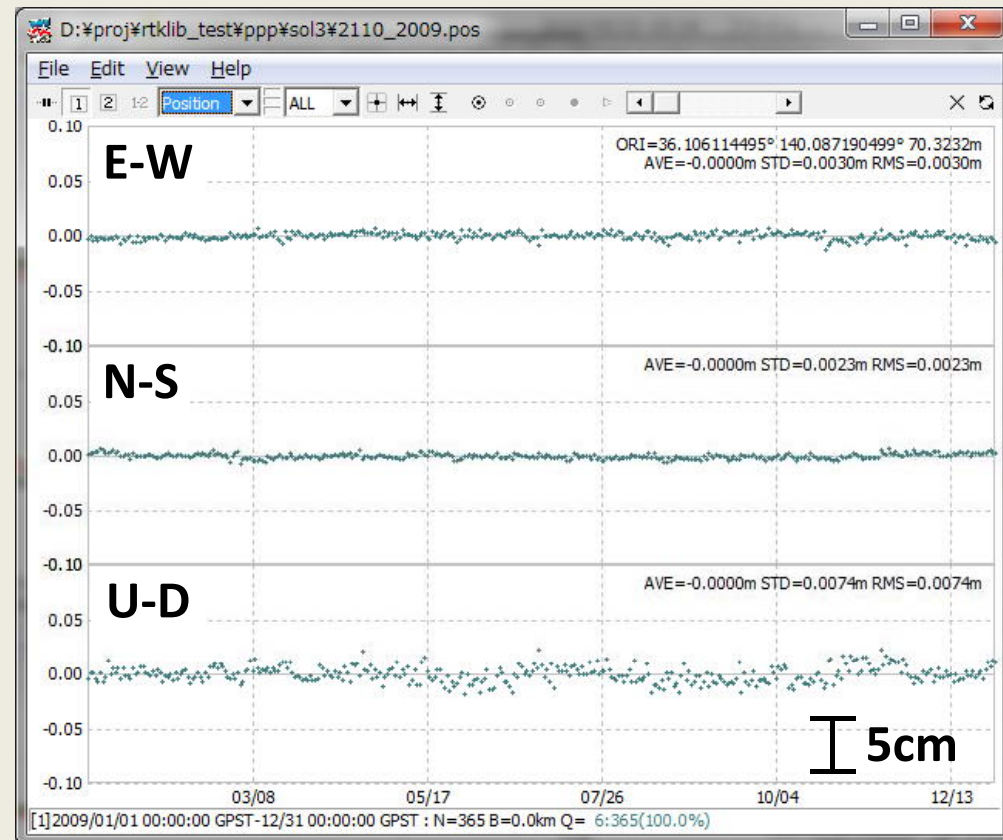
PPP Features in RTKLIB 2.4.0

- Kalman-Filter Based Parameter Estimator
 - PPP-Kinematic or PPP-Static mode
- Atmosphere Corrections:
 - Only L3-LC with dual-frequency for Ionosphere
 - ZTD and gradient estimation with NMF
- Solid Earth Tide Model by IERS 2003 (subset)
- Satellite and Receiver Antenna PCV models
 - ANTEX (IGS05.ATX) or NGS
- Antenna Wind-up Correction for Phase

Static 24H PPP with IGS Final

Geonet Station	Repeatability after Linear Fitting (mm)		
	E-W	N-S	U-D
0601	6.5	3.4	10.7
0837	4.4	2.9	10.8
0369	3.3	2.4	8.1
0579	3.1	2.2	8.6
0586	4.4	3.1	9.4
0241	3.3	2.3	8.4
0324	3.6	2.4	8.8
0174	3.7	2.7	8.9
3023	3.3	2.7	7.8
0905	3.7	2.8	8.1

GEONET2110: 2009/1/1-12/31



STD E/N/U: 3.0 2.3 7.4 mm

RT-PPP with IGS RT Orbit/Clock

NovAtel, 2010/10/1 -10/14 1Hz with GSOC/DLR: CLK20



RMS E/N/U: 4.9, 5.6, 10.1 cm

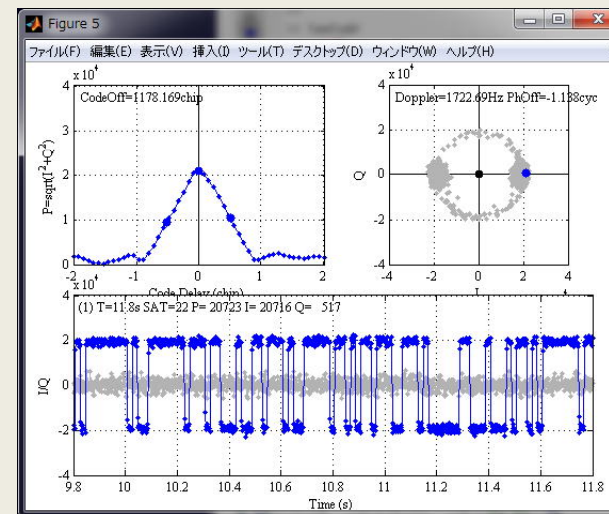
50cm

QZSS Extension for RTKLIB

- Support for QZSS satellites
 - Single, DGPS, RTK and PPP with QZSS
 - RINEX 2.2, RINEX 3.0, SP3, ANTEX and RTCM for QZSS
- Support for LEX MT 10 and 11
 - LEX message handling
 - Ephemeris and SV clock model
 - Ionosphere correction model
 - Single-Frequency PPP
- Support for LEX receiver proprietary message
- Utility for post-processing

Future Plan of RTKLIB

- v. 2.4.1: End of 2010
 - Fix problems and bugs
- v. 2.5.0: Spring or Summer 2011
 - SDR front end for GPS/GLONASS/QZSS (L1)
 - Support of Galileo/QZSS
 - Single-Frequency PPP
 - Improvement of PPP
 - Add supported formats
 - ...



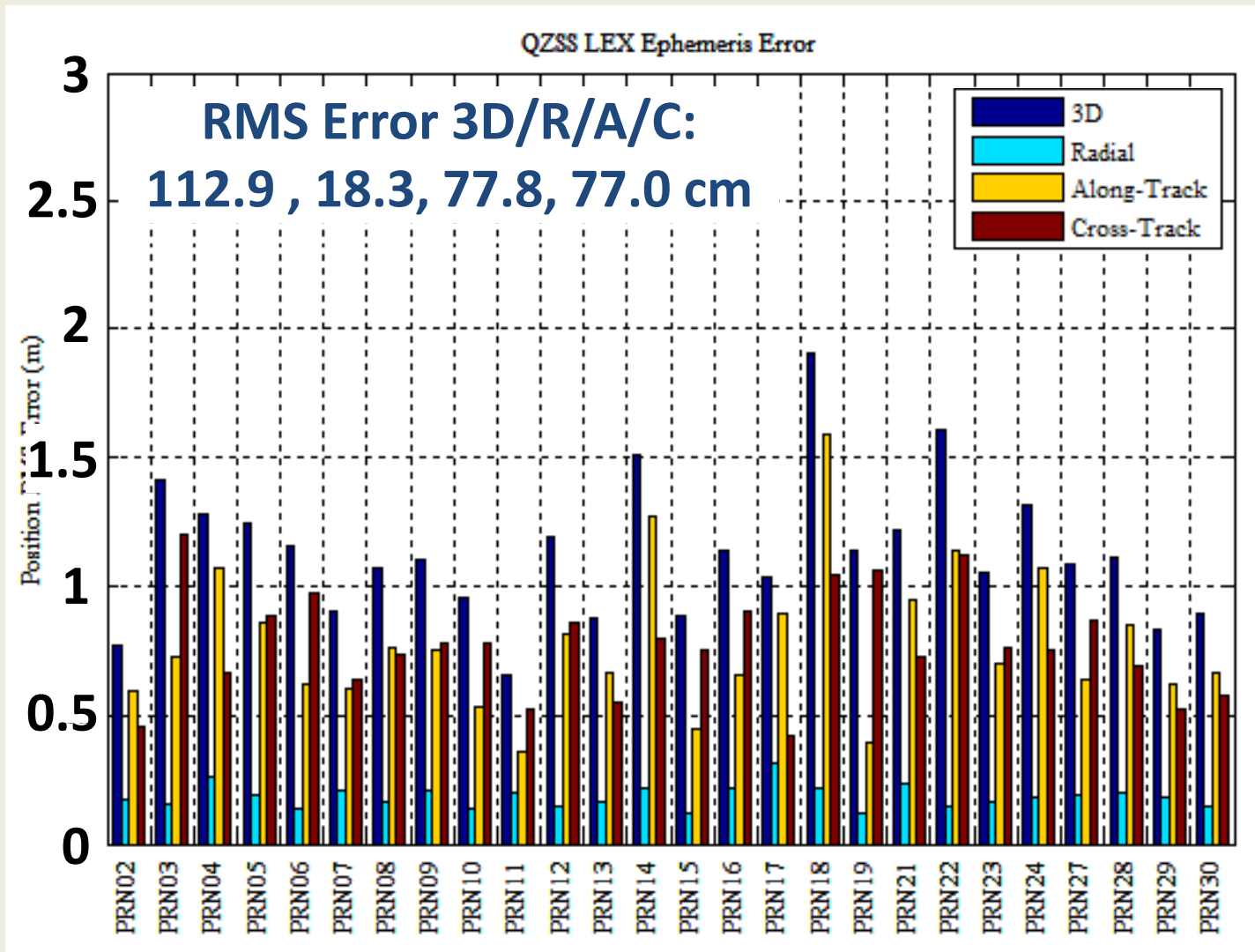
SDR prototype for RTKLIB 2.5.0

Preliminary Performance Evaluation

Preliminary Evaluation

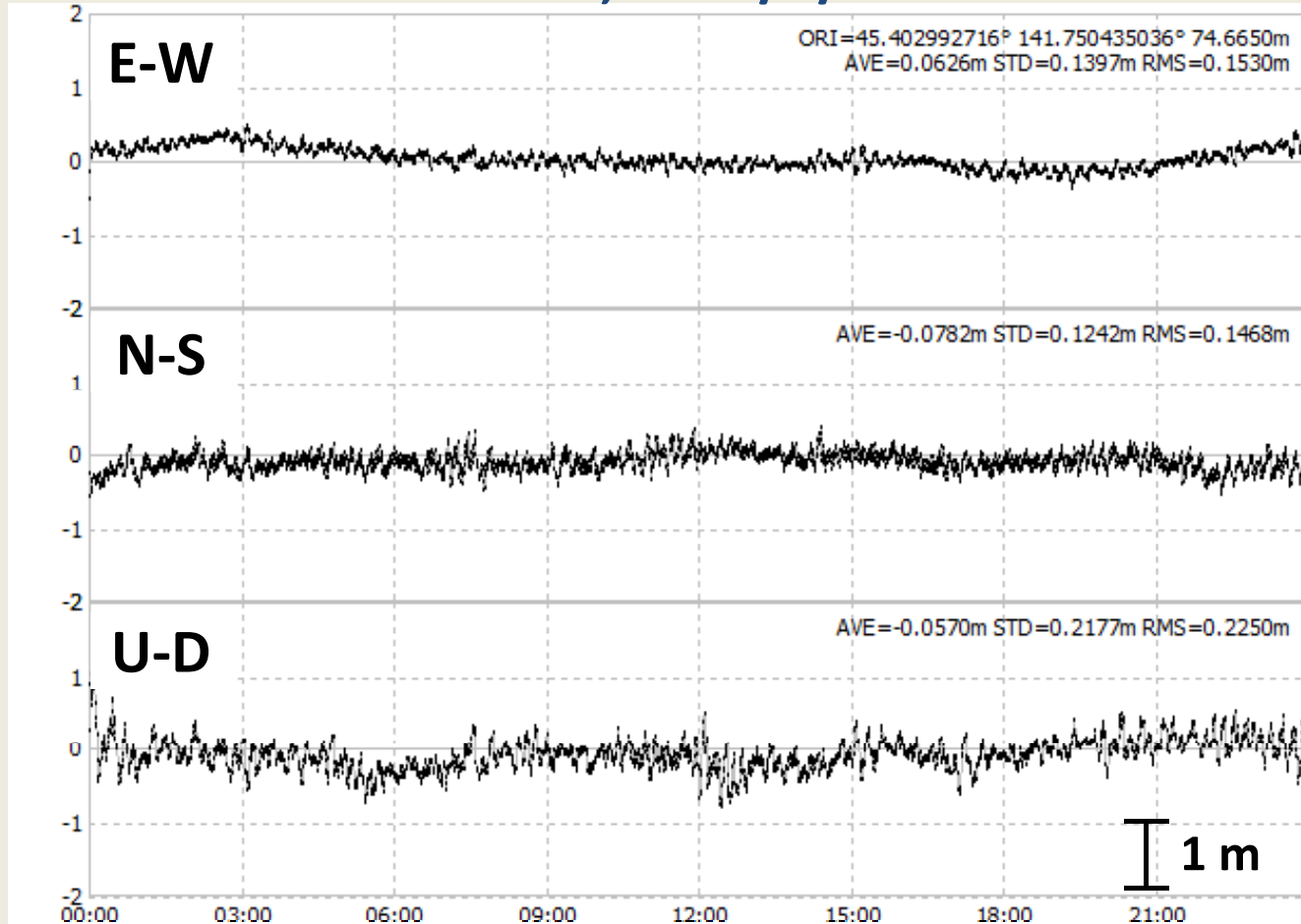
- LEX Data for JAXA Experiment
 - 2010/08/03 0:00:00-23:59:59 24H
 - Generated in ground system Integration test
 - LEX MT 10, 11 only corrections for GPS
 - 13 Monitor Stations
- Post-processing PPP Test
 - RTKPOST 2.4.0 + LEX extension
 - 4 GEONET stations 30 s x 24 H
- Positioning Mode
 - Kinematic PPP with L1/L2 and L1 only

LEX GPS Orbit Accuracy



Kinematic PPP with LEX Correction

GEONET 0001 Wakkanai, 2010/8/3 0:00:00-23:59:30



RMS E/N/U: 15.2, 14.2, 21.6 cm

LEX Experiment Plan

- January - March 2011
- Evaluation of LEX PPP Performance
 - Dual-freq/Single-freq PPP
 - Convergence Time of PPP
 - Stationary and moving receiver
- Evaluation of LEX Orbit and Clock
 - GPS orbit and clock
 - QZSS orbit and clock
- Evaluation of LEX Ionospheric Correction

Future Extension of QZSS LEX PPP

Future LEX PPP

- Real-time PPP with multi-GNSS
 - Real-time orbit and clock for all GNSS available
 - Uniform time and coordinate among different GNSS
- PPP-AR (ambiguity resolution)
 - Satellite-side carrier-phase bias correction
 - Need more precise orbit and clock (< 3 cm)
- Regional precise atmospheric corrections
 - STEC instead of VTEC for ionosphere
 - ZTD/MF or 3D NWM for troposphere
- Bandwidth Limitation vs. Target User/AP

Summary

Summary

- What is PPP?
 - Applications
 - Real-Time PPP
- RT PPP Experiment via QZSS LEX
- RT PPP Client Implementation with RTKLIB
- Preliminary Evaluation Result
- Future Enhancement of LEX PPP