

# International Symposium on GPS/GNSS 2010

## Development of Real-Time PPP Client for Precise Satellite Orbit and Clock Corrections via NTRIP



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# Outline

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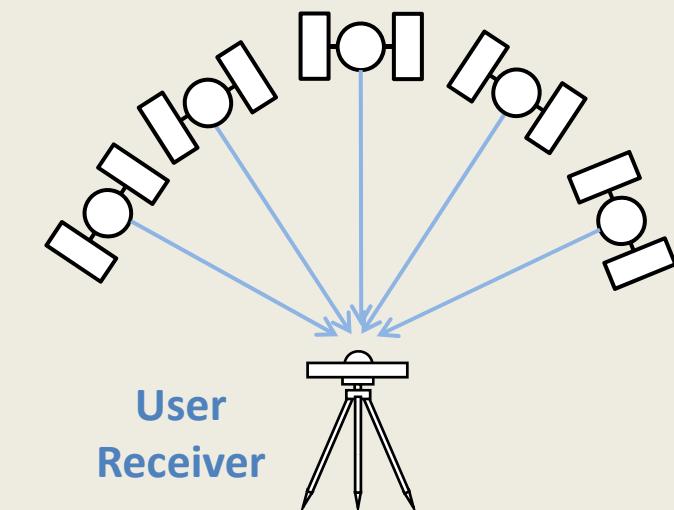
- Background
- Real-Time Precise Orbit and Clock
- Real-Time PPP Client Implementation
- Performance Evaluation
- Future Plan
- Conclusion

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# Background

# PPP: Precise Point Positioning

- Carrier-Based Single Positioning with GNSS
  - Sub-dm - cm-level accuracy by post processing
  - Need precise orbit and clock
  - Need dual-frequency for ionosphere elimination
  - Long TTFF due to float ambiguity (> 30 min)
  - Global coverage world-wide
- Applications
  - Crustal deformation monitoring
  - GPS meteorology
  - POD of LEO satellite



# Real-Time PPP

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- Demand for RT PPP Application
  - Users who can not find nearby reference station
  - Out of coverage of Network-RTK service
  - Marine AP or AP on vast ground
  - Continuous monitoring of natural hazard like Tsunami
- Commercial RT PPP Services via Satellite Links
  - NavCom : StarFire™
  - Fuguro : OmniStar XP/HP+, SeaStar XP/G2
  - VERIPOS : VERIPOS Ultra/Apex
  - Need dedicated receiver and service charge

# Real-Time PPP Issues

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- Lack of RT Precise Orbit and Clock
  - Poor clock accuracy of IGU:  $\sim 3\text{ns}$  ( $\sim 1\text{ m}$ )
  - Proprietary messages by commercial RT PPP service
  - Complicated RT processing to produce orbit and clock
  - Need open and standard RT orbit and clock easily available
- Lack of Receiver or S/W Supporting RT PPP
  - Most of PPP S/W only support post-processing
  - Only few dedicated receivers support RT PPP with commercial RT PPP service
  - Need open and flexible S/W for RT PPP

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# **Real-Time Precise Orbit and Clock**

# IGS RT Orbit/Clock

- Developed by IGS RTPP
  - RTCM v.3 MT1057-1068 (SSR)
  - Corrections to broadcast ephemeris
  - Real-time NTRIP stream via Internet
  - Interval: 10 s, Latency: 5 - 15 s
  - Currently free of charge
- Several ACs
  - Orbit: fixed to IGU or estimated
  - Clock: estimated with IGS real-time tracking network

The screenshot shows a web browser window with the URL <http://igs.bkg.bund.de/ntrip/orbits>. The page is titled "Real-time Satellite Orbit and Clock Corrections to Broadcast Ephemeris from IGS and EUREF Resources". It includes a table titled "Proposed RTCM v3 Messages" with the following data:

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

A note at the bottom states: "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 Representation Working Group."

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

# RTCM v.3 SSR Messages

MT	Contents
1057	GPS Orbit Corrections
1058	GPS Clock Corrections
1059	GPS Code Biases
1060	GPS Combined Orbit and Clock Corrections
1061	GPS URA
1062	High-Rate GPS Clock Corrections
1063	GLONASS Orbit Corrections
1064	GLONASS Clock Corrections
1065	GLONASS Code Biases
1066	GLONASS Combined Orbit and Clock Corrections
1067	GLONASS URA
1068	High-Rate GLONASS Clock Corrections

# IGS RT Orbit/Clock Distribution

AC	Mount Point	GNSS	RTCM MT	Orbit	Analysis S/W
BKG	CLK00, CLK10 * <sup>1</sup>	GPS	1059, 1060	IGU	RTNet + BNS
	CLK01, CLK11, CLK41-45 * <sup>1</sup>	GPS, GLO	1059, 1060 1065,1066	IGU	
GSOC/DLR	CLK20 * <sup>1</sup>	GPS	1059, 1060	IGU	RETICLE
	CLKA1, CLKC1 * <sup>2</sup>	GPS	1059, 1060	IGU	
ESA/ESOC	CLK30, CLK31 * <sup>1</sup>	GPS	1059, 1060	IGU	COMBI+BNS
	CLK50-53 * <sup>1</sup>	GPS	1059, 1060	IGU	RETINA+BNS
TUW	CLK61 * <sup>1</sup>	GPS	1059, 1060	IGU	RTIGSMR+BNS
GFZ	CLK70, CLK71 * <sup>1</sup>	GPS	1059, 1060	IGU	Epos-RT+BNS
GMV	CLK80, CLK81 * <sup>1</sup> GMVAPC, GMVCOM * <sup>3</sup>	GPS	1059, 1060	IGU	magicGNSS+ BNS
	RTCMSSR, RTCMSSR1060 * <sup>4</sup>	GPS, GLO	1057-1060, 1060-1066	Dynamic	

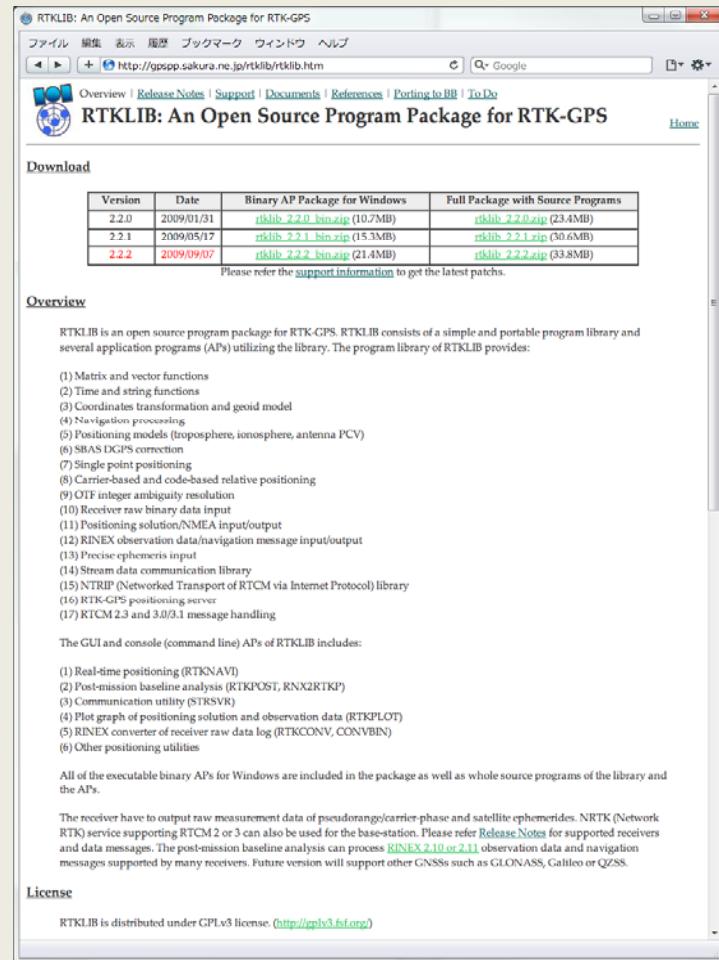
\*1: products.igs-ip.net, \*2: gnss.gsoc.dlr.de, \*3: igs-ip.gmv.com, \*4: wox.geopp.de

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# 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 APIs
  - ANSI C + socket/pthread ...
  - Portable command-line APIs
  - GUI APIs for Windows



<http://www.rtklib.com>

# RTKLIB Features

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- 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

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- 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

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- 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

# Example of RT Orbit/Clock

The screenshot shows a software interface titled "RTCM Monitor" with the tab "RTCM SSR" selected. The main window displays a large table of data for multiple satellites (SAT) over time (Intv(s)). A blue line highlights a specific row of data for Satellite 1 (row 1). The table includes columns for SAT, Status, Intv(s), IOD, URA, Da, T0, D0-A(m), D0-C(m), D0-R(m), D1-A(mm), D1-C(mm), D1-R(mm), C0(m), C1(mm/s), C2(mm/s), C3(mm/s), C4(mm/s), C5(mm/s), C6(mm/s), C7(mm/s), C8(mm/s), C9(mm/s), C10(mm/s), C11(mm/s), C12(mm/s), C13(mm/s), C14(mm/s), and C15(mm/s).

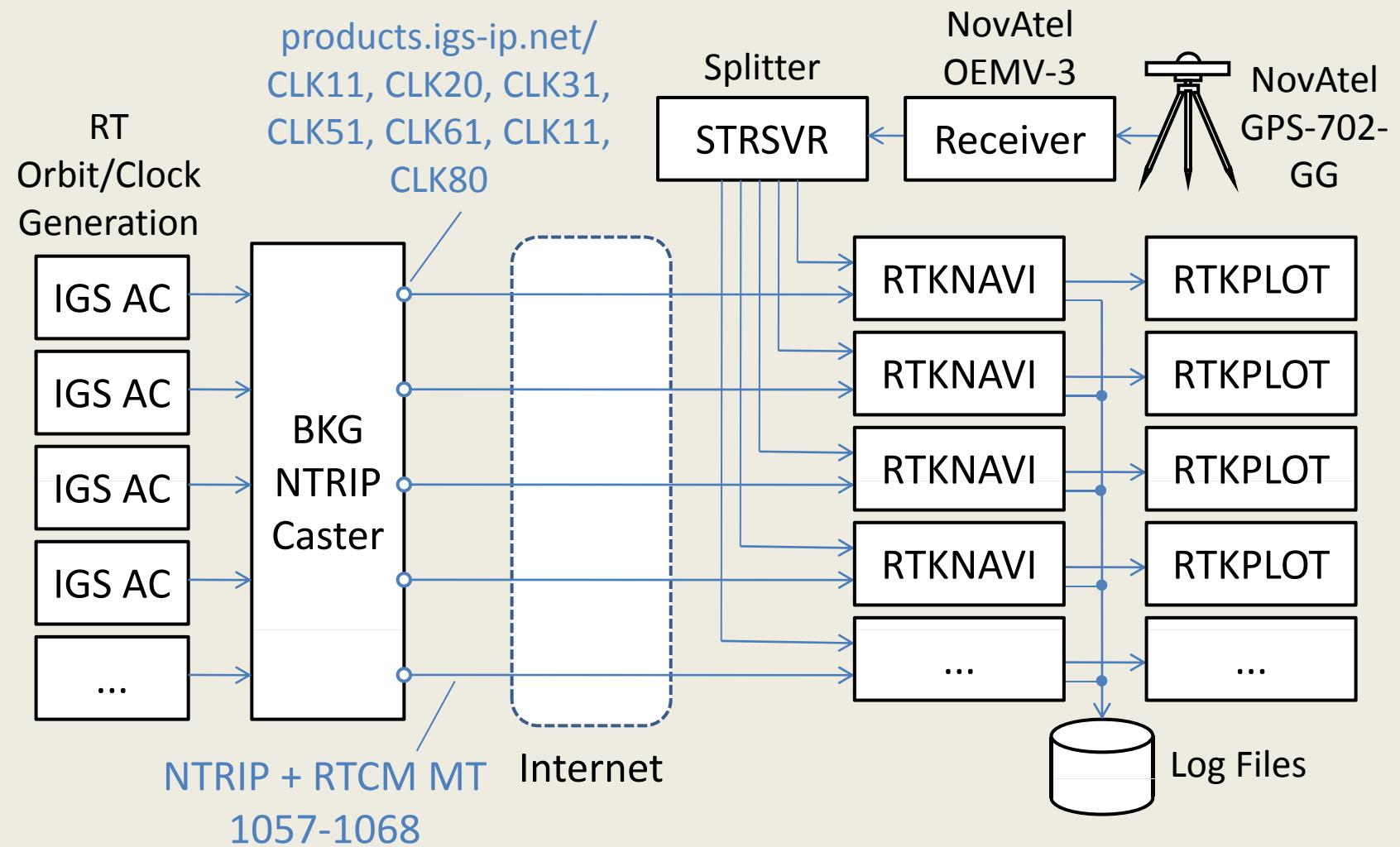
The detailed view below the main table shows the first four rows of data again, with the first row highlighted in blue. This view includes columns for SAT, Status, Intv(s), IOD, URA, Da, T0, D0-A(m), D0-C(m), D0-R(m), D1-A(mm), D1-C(mm), D1-R(mm), C0(m), C1(mm/s), C2(mm/s), C3(mm/s), C4(mm/s), C5(mm/s), C6(mm/s), C7(mm/s), C8(mm/s), C9(mm/s), C10(mm/s), C11(mm/s), C12(mm/s), C13(mm/s), C14(mm/s), and C15(mm/s).

SAT	Status	Intv(s)	IOD	URA	Da	T0	D0-A(m)	D0-C(m)	D0-R(m)	D1-A(mm)	D1-C(mm)	D1-R(mm)	C0(m)	C1(mm/s)	C2(mm/s)	C3(mm/s)	C4(mm/s)	C5(mm/s)	C6(mm/s)	C7(mm/s)	C8(mm/s)	C9(mm/s)	C10(mm/s)	C11(mm/s)	C12(mm/s)	C13(mm/s)	C14(mm/s)	C15(mm/s)	
1	-	1	77	0	0	2010/06/21 03:34:55	0.492	1.364	-1.107	-0.003	0.112	-0.324	0.389	0.000	0.000	0.000	1.50	0.97	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	OK	1	3	0	0	2010/06/21 05:58:25	0.572	0.011	0.691	0.224	-0.060	-0.020	-0.345	0.000	0.000	0.000	2.38	2.48	0.00	0.00	4.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	OK	1	62	0	0	2010/06/21 05:58:25	1.101	1.546	-0.369	0.108	-0.136	-0.232	-0.2172	0.000	0.000	0.000	-1.65	-1.38	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	OK	1	7	0	0	2010/06/21 05:58:25	1.217	-0.717	-0.125	-0.057	-0.236	-0.048	-0.312	0.000	0.000	0.000	-0.53	-0.78	0.00	0.00	-1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

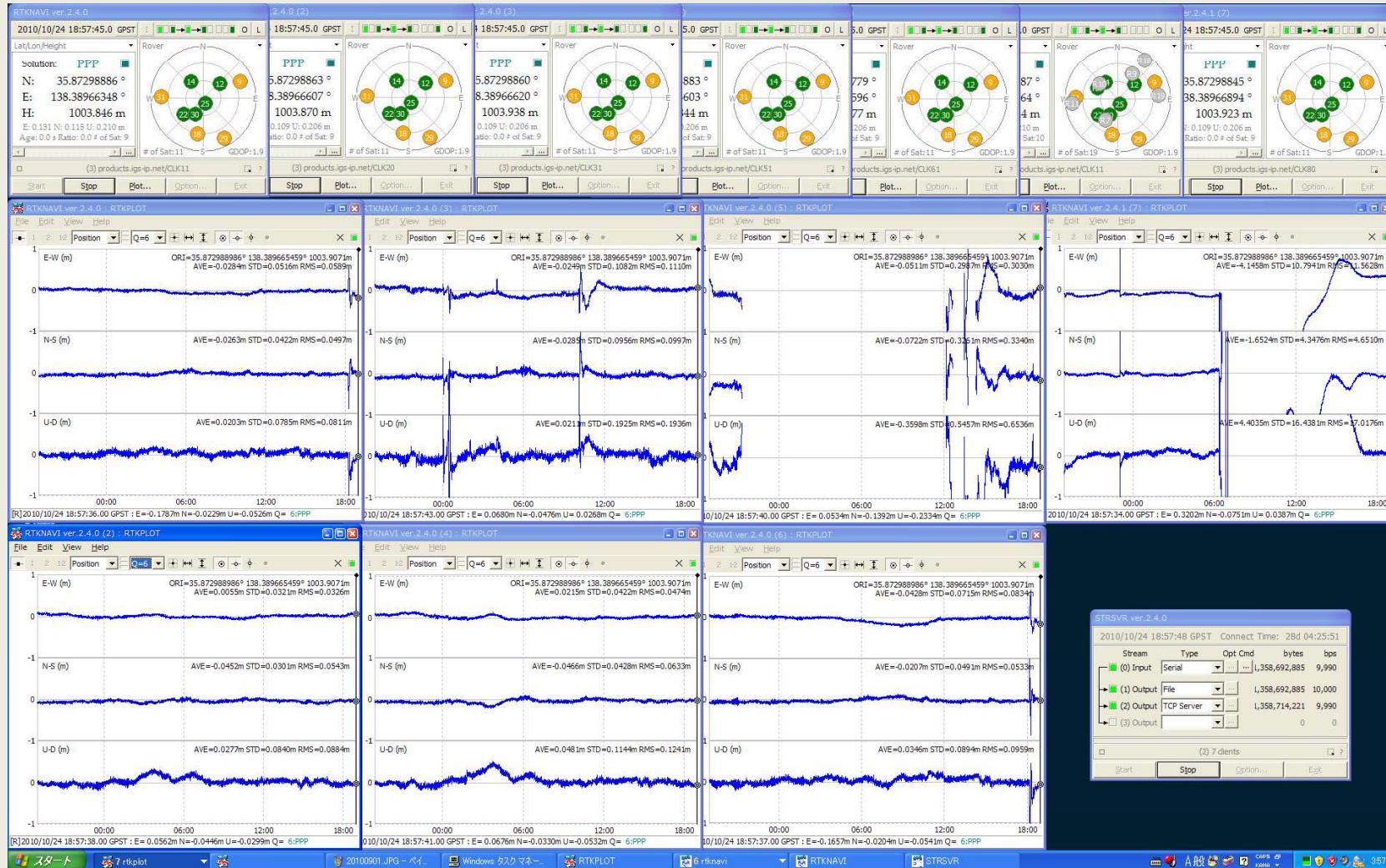
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# Performance Evaluation

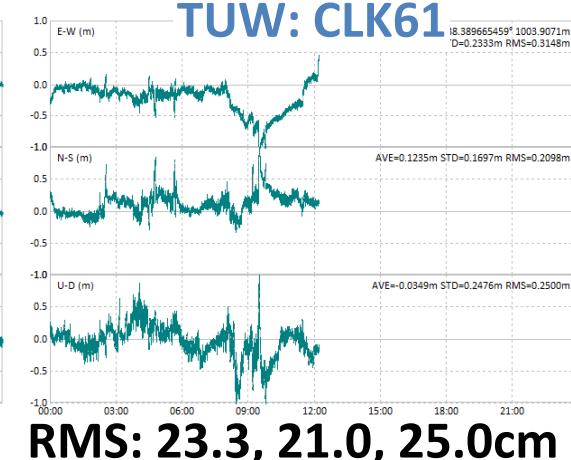
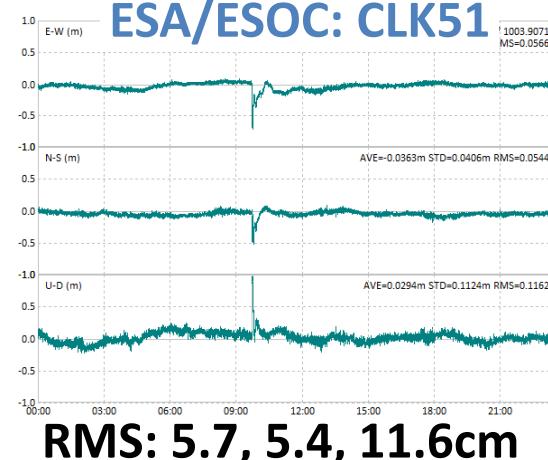
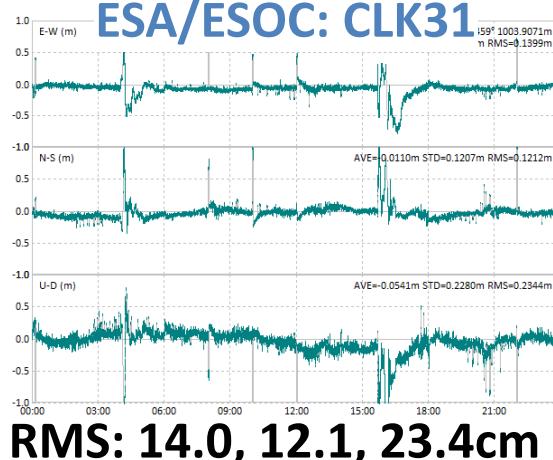
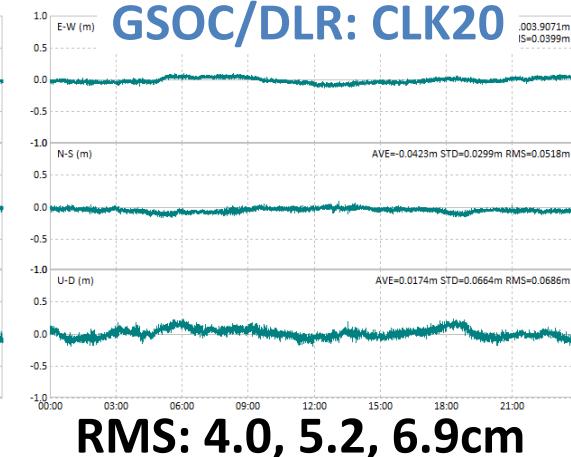
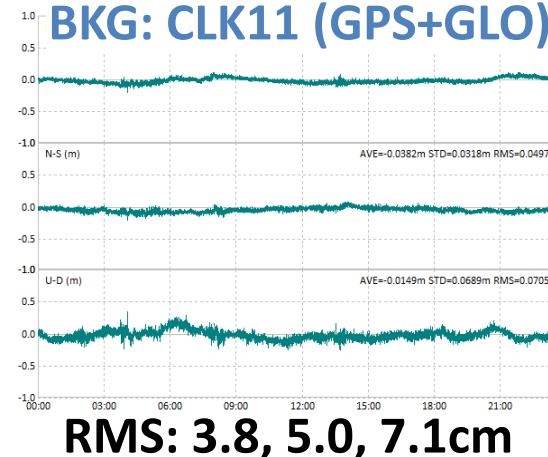
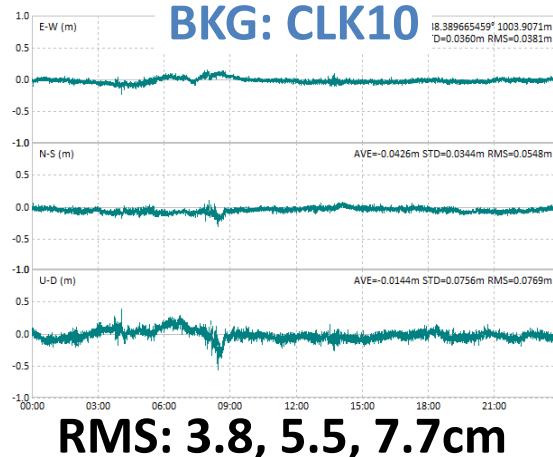
# Setup of Experiment



# Snapshot of Experiment

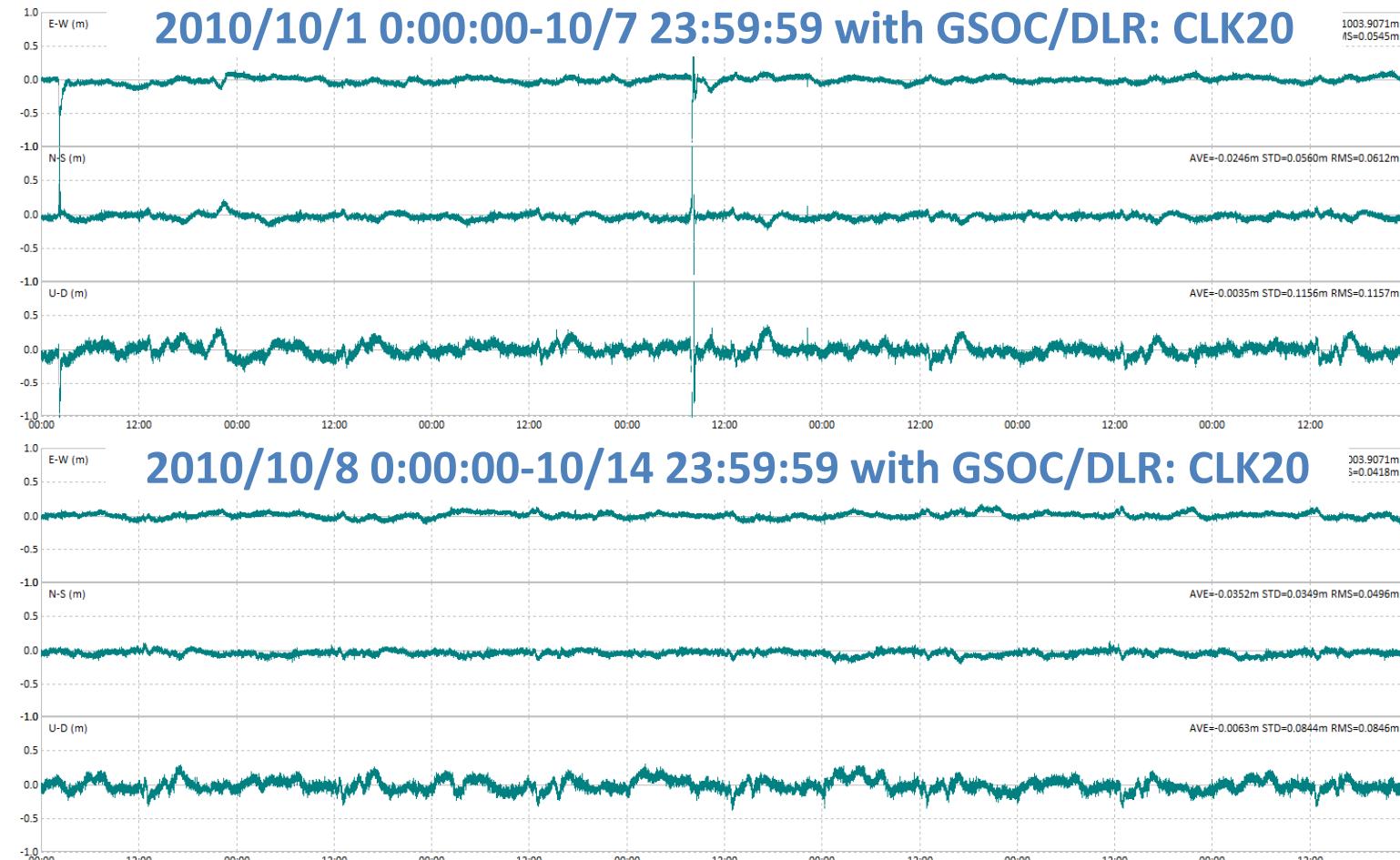


# PPP-Kinematic Result (24H)



2010/9/18 0:00-23:59, 1Hz, NovAtel OEMV-3+GPS-702, RTKLIB 2.4.0

# PPP-Kinematic Results (2 weeks)



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

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## Future Plan

# Future Enhancement

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- Single Frequency RT-PPP
  - With IGS predicted IONEX with automatic download
  - Ionosphere eliminated by using  $(L1+P1)/2$  LC
  - Future support of ionosphere SSR for by IGS-RTPP
- PPP-AR (ambiguity resolution)
  - Need server-side support by network analysis
  - Future support of PPP-AR by IGS-RTPP
- Multi-GNSS RT-PPP
  - Also need server-side support for RT orbits/clocks of Galileo, QZSS, Compass, ...

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# Conclusion

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- Real-Time PPP Issues
  - Lack of precise RT Orbit and Clock
  - Lack of receiver or S/W supporting RT PPP
- Real-Time Orbit and Clock provided by IGS-RTPP
- Real-Time PPP Implementation in RTKLIB v.2.4.0
- dm-level accuracy by PPP-Kinematic Mode
- Future Enhancement

IGS RT-Orbit/Clock: <http://igs.bkg.bund.de>  
RTKLIB 2.4.0: <http://www.rtklib.com>