


2009年度AOBセミナー

長基線RTK-GPS/GNSSの課題と展望
Overview of Long-Baseline RTK-GPS/GNSS

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Long-Baseline RTK

RTK-GPS/GNSS

- Relative Positioning based on Carrier-Phase
 - Real-time Position of A Moving Receiver
 - Typical Accuracy: 1 cm + 1ppm x BL RMS (Horizontal)
 - Transmit Reference Station Data to Rover via Wireless Link
 - OTF (On-the-Fly) Integer Ambiguity Resolution
- Network-based RTK
 - Single Receiver with Mobile Communication
 - Commercial Services with Many Reference Stations



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Applications of RTK-GPS/GNSS



Geodetic Survey



Construction
Machine Control



Precision Agriculture



ITS (Intelligent
Transport System)



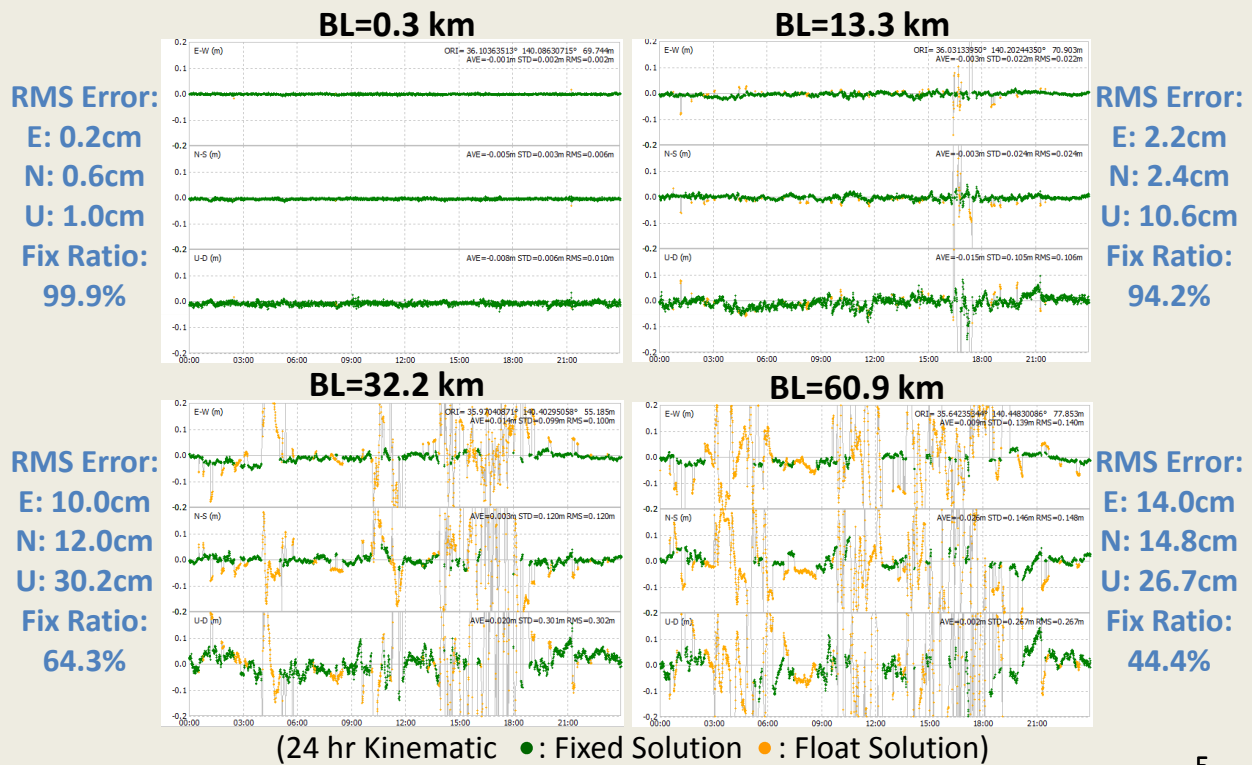
Mobile Mapping
System



Sports

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Effect of Baseline Length



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Demands of Long-baseline RTK

- No Reference Station in the vicinity of user
 - Land of Vast Country (Russia, Canada, ...)
 - Sea (Ships, Buoys, Plants, Construction, ...)
 - Air (Flight), Space (Satellites)
- Need Separation of Movements between user and reference
 - Nation/World-wide Crustal Deformation Monitor
 - Observation of Seismic Event by Large Earthquake

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Long-BL RTK vs. Real-time PPP

	Long-Baseline RTK	Real-time PPP
Receiver	Need Ref Station	Single Receiver
Result	Baseline Vector	Position in Ref Frame
Baseline Length	100 km - 3,000 km	Anywhere
Ephemeris	Broadcast/Precise (IGU)	Precise (IGU)
SV Clock	Broadcast	Precise (?)
Ionosphere	Elimination/Estimation	Iono-Free LC
Troposphere	Model/Estimation	Estimation
Antenna PCV	Model	Model
Earth Tides	Ignored/Model	Model/Estimated
Integer Ambiguity	Fixed	Float

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Issues of Long-baseline RTK

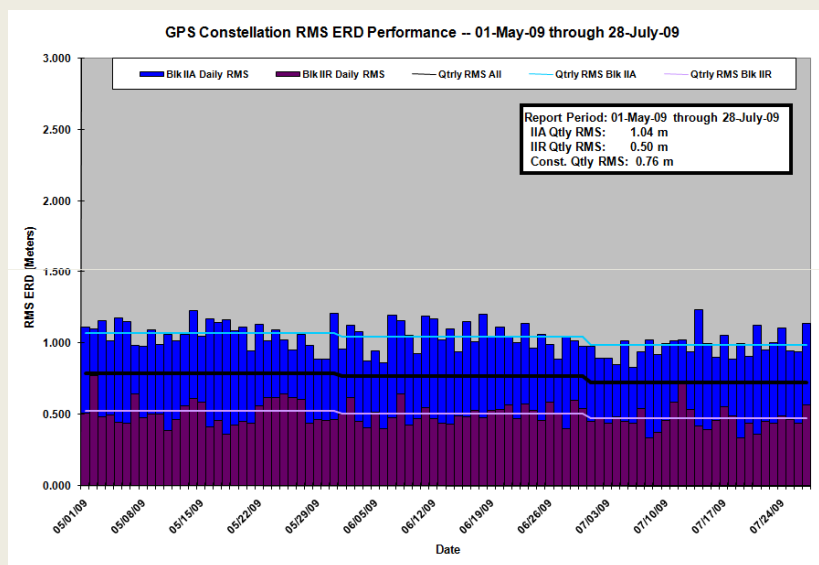
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Issues for Long-BL RTK

- Error Sources = Residuals of DD
 - Satellite Ephemeris (BL=100 km-)
 - Ionosphere (BL=10 km-)
 - Troposphere (BL=50 km-)
 - Antenna PCV, Earth Tides, Phase Windup ...
 - Multipath + Receiver Noise (= Short BL)
- Strategy of Ambiguity Resolution
 - Slow Convergence of Float Ambiguity Estimation
 - Must Keep Integer Nature of Ambiguities

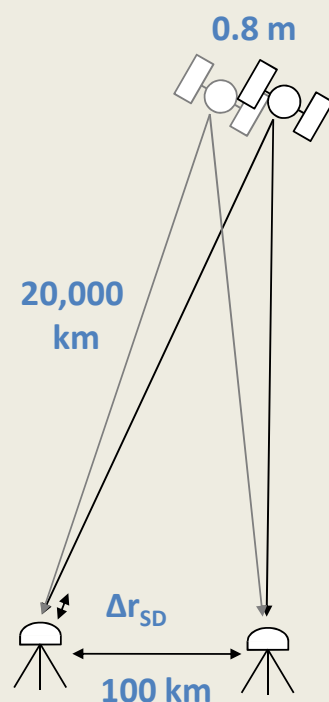
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Broadcast Ephemeris



D.Boyd, GPS Constellation Status and Performance, CGSIC 49th, 2009

$$\Delta r_{SD} = 0.8 \text{ m} \times 100 \text{ km} / 20,000 \text{ km} = 4 \text{ mm}$$



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Precise Ephemeris

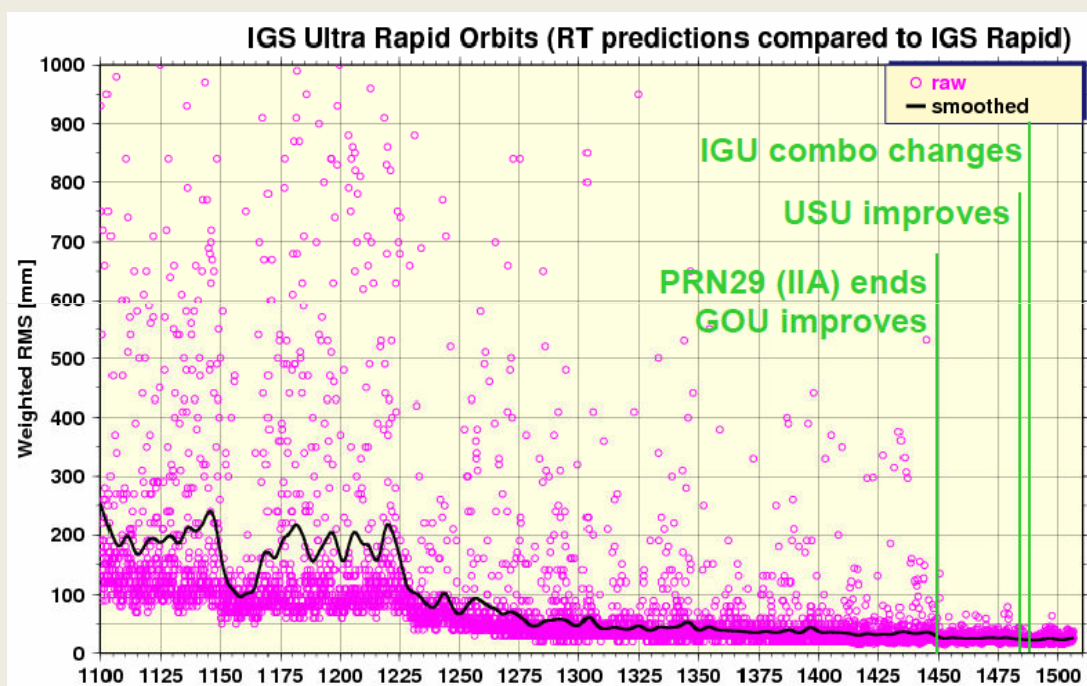
IGS Product Table

		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

(2009/8, <http://igs.cb.jpl.nasa.gov/>)

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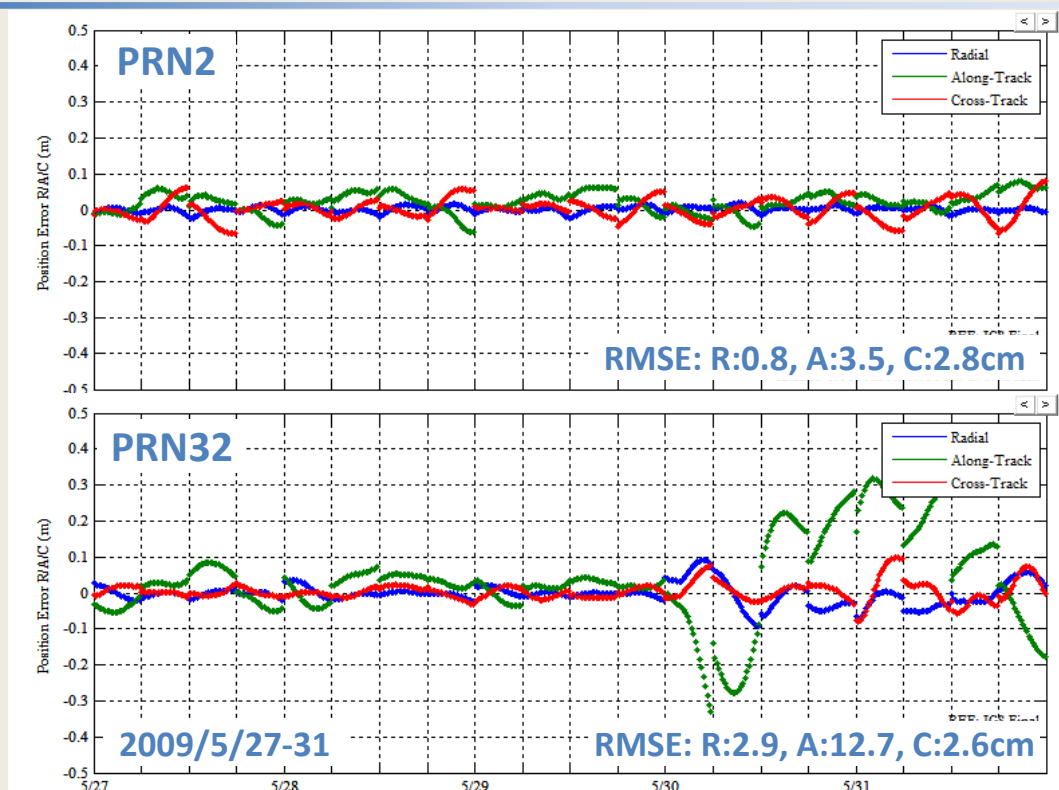
Improvement of IGU Orbit



(J. Ray et. al., Status of IGS Ultra-Rapid Products for Real-Time Applications, 2008 AGU Fall Meeting)

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Accuracy of IGU-Predicted



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Real-time Precise Ephemeris

- IGS RTWG+EUREF
- Orbit/Clock
 - Orbit - IGU-Predicted
 - Clock - Estimated
- Protocol/Format
 - NTRIP v.1.0
 - RTCM3 MT1057-1068 (Draft Proposal)

GNSS Data Center
Real-time Satellite Orbit and Clock Corrections to Broadcast Ephemeris from IGS and EUREF GNSS Resources

EUREF's Real-time Analysis project and the IGS Real-time Pilot Project provide access to precise GNSS satellite orbits and clocks via NTRIP for test and evaluation.

1. Ephemeris Correctors in RTCM Version 3 Format

Precise orbits and clocks can be derived from corrections to Broadcast Ephemeris. RTCM's 'State Space Representation' (SSR) Working Group is in the process of developing appropriate v3 messages to disseminate such corrections in real-time. The following messages are proposed:

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

Omit 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.

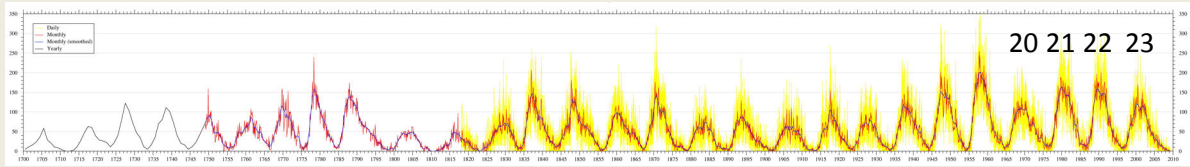
2. Broadcast Ephemeris Corrections Streams

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

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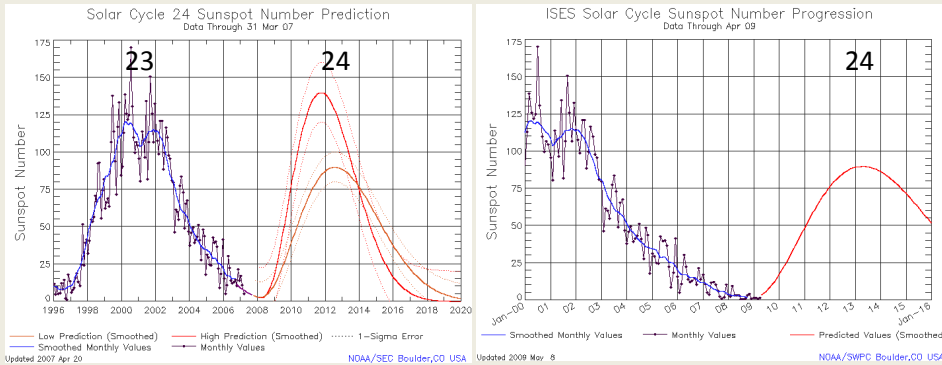
Solar Cycle

International Sunspot Number (ISN): 1700-2009



by SIDC (Solar Influences Data Analysis Center) in Belgium (<http://sidc.oma.be>)

Solar Cycle Prediction: Cycle 24

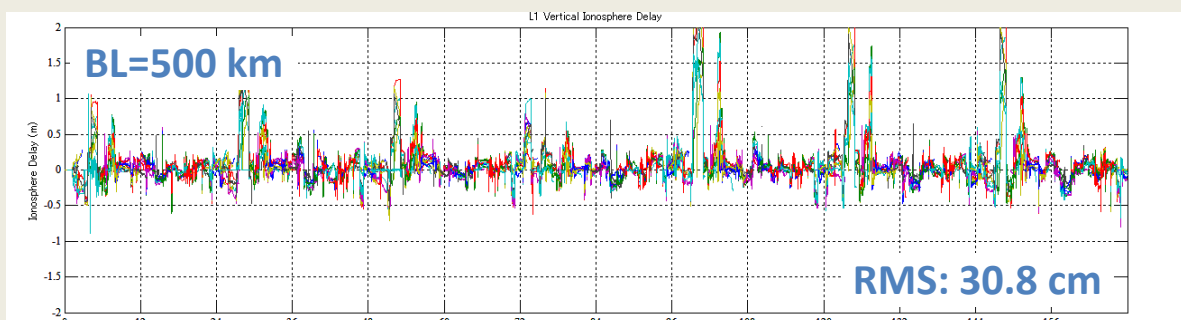
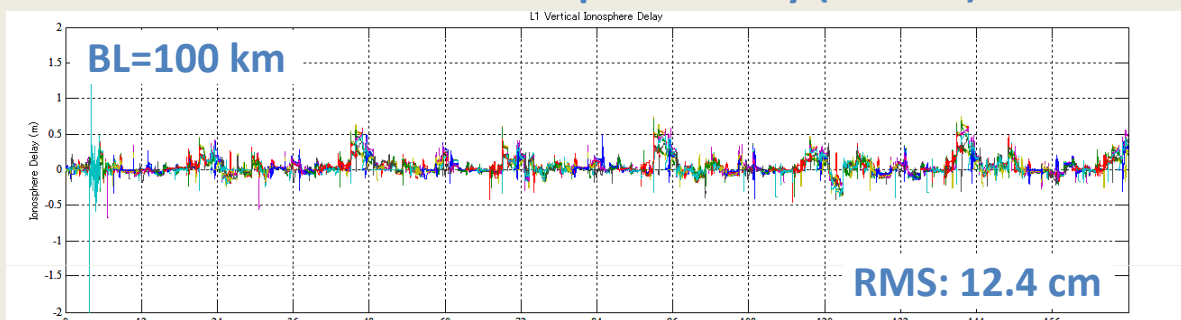


by NOAA SWPC (Space Weather Prediction Center) (<http://www.swpc.noaa.gov/SolarCycle>)

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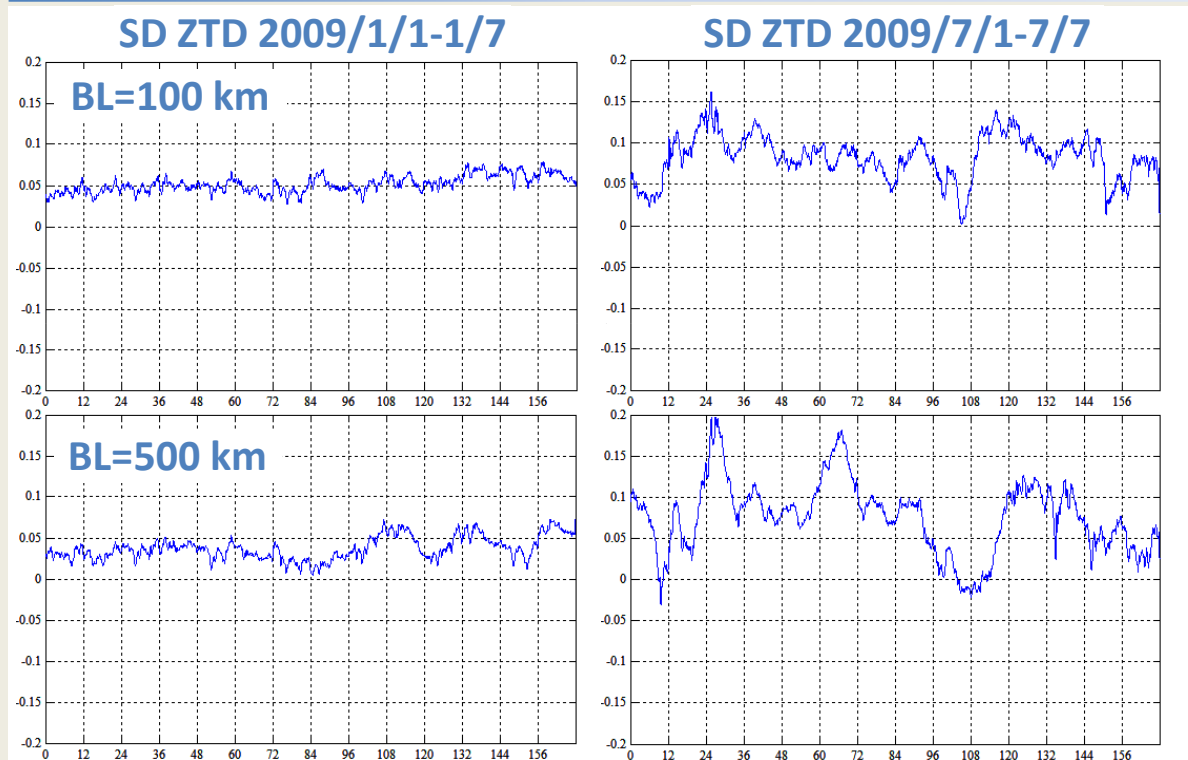
Ionosphere Delay

SD L1 Vertical Ionospheric Delay (1 Week)



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Tropospheric Delay



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Integer Ambiguity Resolution (1)

- Ambiguity Resolution for Long Baseline RTK
 - Eliminate Ionos with Integer Nature of Ambiguity
- Search Strategy for Short Baseline RTK
 - Solve Statistically Optimal ILS Problem
 - Efficient Strategy like LAMBDA
 - Issue: No Ionos Elimination
- WL/NL Strategy for Static Post Processing
 - Fix WL by Rounding of MW LC Average
 - Fix NL by Rounding Iono-Free LC + WL
 - Issue: Long Convergence, Reliability with Dual-Freq

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Integer Ambiguity Resolution (2)

- RTKLIB v.2.3.0 (T. Takasu, 2009)
 - EKF-based States Estimation
Rover Position, SD Vertical Ionos Delay, ZTD
Residuals for Rover/Ref, SD Float Ambiguity L1/L2
 - Ionos: Random-Walk + Single Layer Model
 - Tropos: A Priori Model + Random-Walk + NMF
 - ILS Search by LAMBDA/MLAMBDA
 - Partial Fixing with AR Elevation Mask
 - Tight Constraint to Fixed Ambiguity (Fix and Hold)

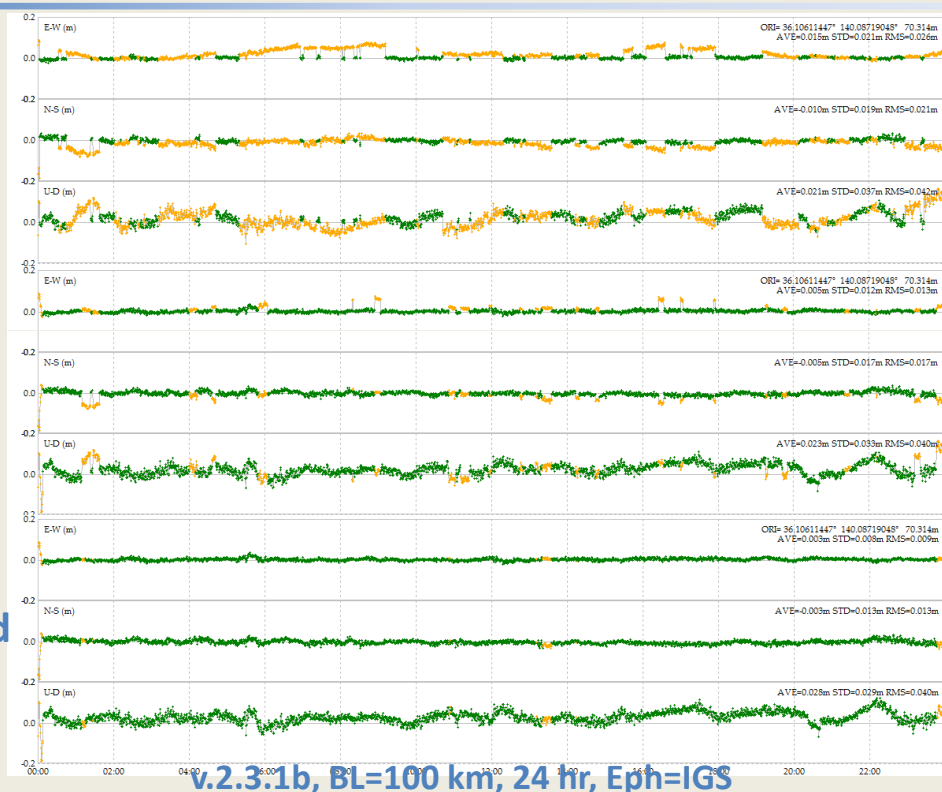
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Integer Ambiguity Resolution (3)

Full Fix
No Hold
(43.1%)

Partial Fix
No Hold
(86.2%)

Partial Fix
Fix and Hold
(96.8%)



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RTKLIB

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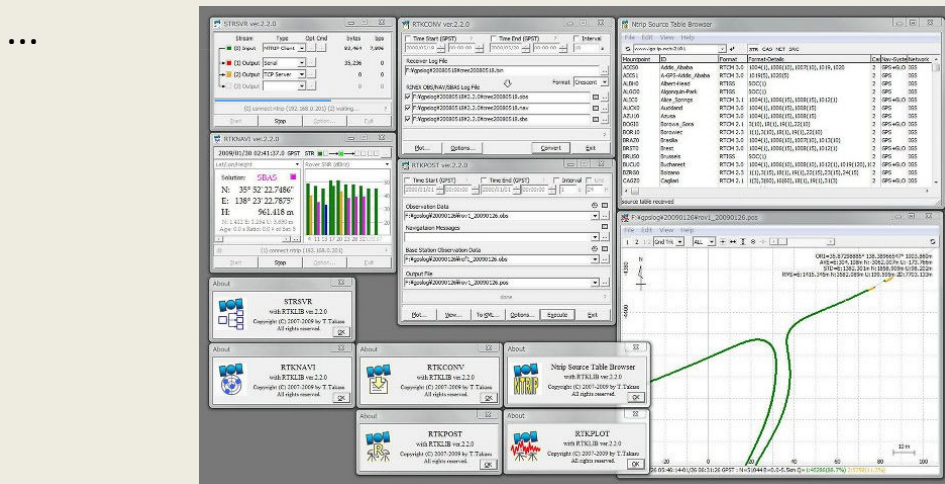
History

- 2006/4 v.0.0.0 First version for RTK+C prog. lecture
- 2007/1 v.1.0.0 Simple post processing AP
- 2008/7 v.2.1.0 Add APs, support medium-range
- 2009/1 v.2.2.0 Add real-time AP, support NTRIP, start to distribute it as Open Source
- 2009/5 v.2.2.1 Support RTCM, NRTK, many receivers
- 2009/12 v.2.3.0 Support GLONASS, INS/GPS, ...
- 2010/3? v.2.3.1 ...
- 2010/5? V.2.4.0 Support Real-time PPP with IGS

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RTKLIB APs

- RTKNAVI, RTKRCV** : Real-time positioning
- RTKPOST, RNX2RTKP** : Post-processing baseline analysis
- RTKPLOT** : Plot raw observation data and solutions
- RTKCONV** : RINEX converter for raw receiver log



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RTKLIB v.2.3.1

- New Features
 - Support Precise Ephemeris for Real-time AP
 - Support Stream Type of FTP Download
 - Tuning for Long-Baseline RTK
 - Support Output Swap at day/hour boundary
 - Improvement of Troposphere Model
 - Full Positioning Options for RNX2RTKP
- Tuning for Long-Baseline RTK

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Preliminary Evaluation (1)

Rov	Ref	BL (km)	2009/1/1 - 1/7				2009/7/1 - 7/7			
			SDE	SDN	SDU	Fixing	SDE	SDN	SDU	Fixing
2110	3023	50.6	0.5	0.6	1.6	99.8%	1.6	1.9	5.7	90.2%
	0586	100.2	0.7	0.9	2.5	98.7%	4.0	2.7	9.3	78.1%
	0562	150.8	0.6	0.8	2.4	99.0%	3.7	2.2	6.6	83.6%
	0241	200.4	0.7	0.9	2.2	99.5%	3.4	3.4	15.0	85.2%
	0601	250.3	0.7	1.0	2.7	96.8%	3.2	2.1	6.5	79.1%
	0174	300.0	0.7	1.0	2.8	98.7%	2.0	1.8	5.2	88.0%
	0579	351.9	0.9	0.9	2.8	99.3%	3.4	3.9	11.2	81.3%
	0324	400.6	1.0	0.9	2.9	96.7%	2.6	2.0	6.5	74.3%
	0905	450.6	3.2	5.4	21.2	64.8%	7.2	5.7	19.7	63.2%
	0369	500.4	1.0	0.9	3.3	98.7%	2.4	1.8	6.0	85.6%
0837	995.6	3.1	1.9	8.5	91.4%	7.0	7.3	19.4	66.0%	

SDE/SDN/SDU: Standard Dev E/N/U (cm), v.2.3.1b, Eph=IGS

Preliminary Evaluation (2)

