電気学会産業システム情報化研究会
海洋GISと衛星測位

長基線RTK-GPS/GNSSの現状,課題と展望

Overview of Long-Baseline RTK-GPS/GNSS

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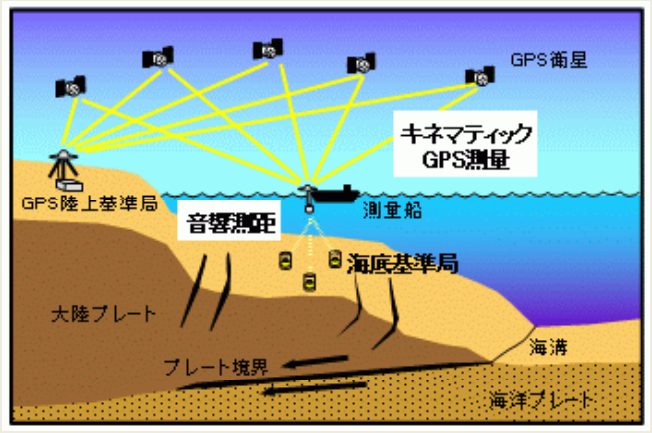
Long-Baseline RTK

Sea Applications of Precise GPS

GPS Tsunami Monitoring System



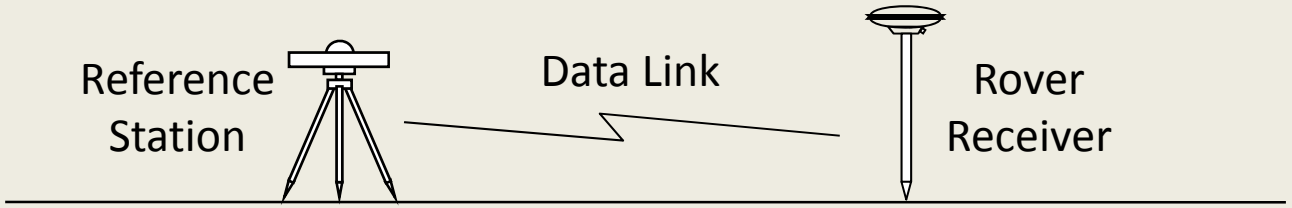
Ocean Bottom Crustal Movement Observation

Offshore/Marine Construction

http://www.tsunamigps.com, http://www1.kaiho.mlit.go.jp, http://www.dpoperators.org

RTK-GPS/GNSS

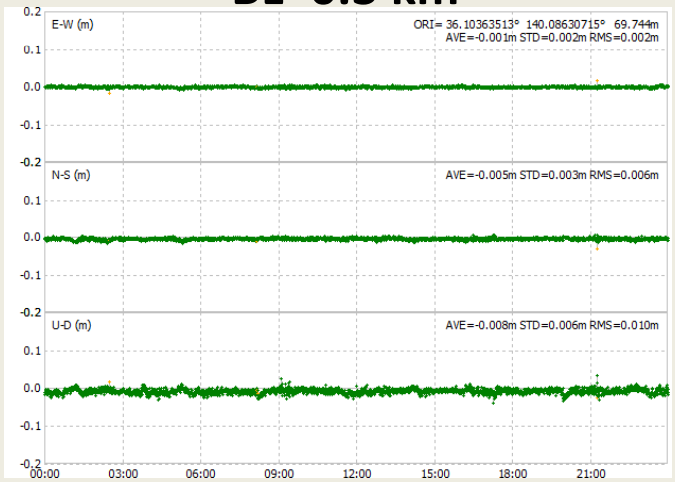
- Real-time Kinematic GPS/GNSS
  - cm-level Accuracy
  - Real-time Positions of Moving Receivers (Rovers)
- Relative Positioning with Carrier-phase
  - Transmit Reference Data to Rover via Wireless Link
  - OTF (On-the-fly) Integer Ambiguity Resolution



Effect of Baseline Length

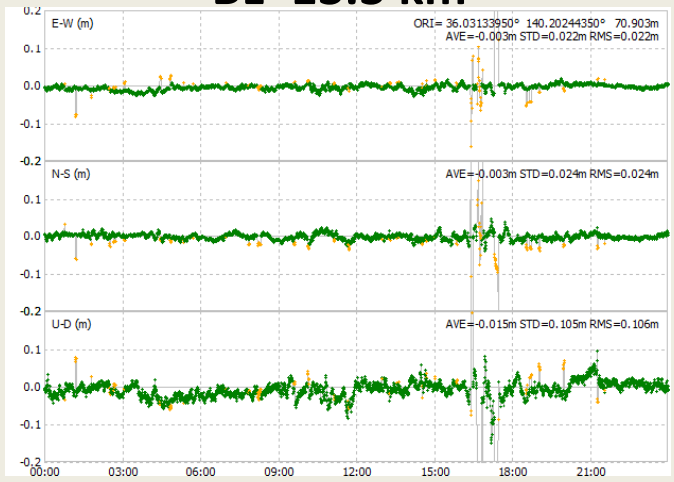
BL=0.3 km

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



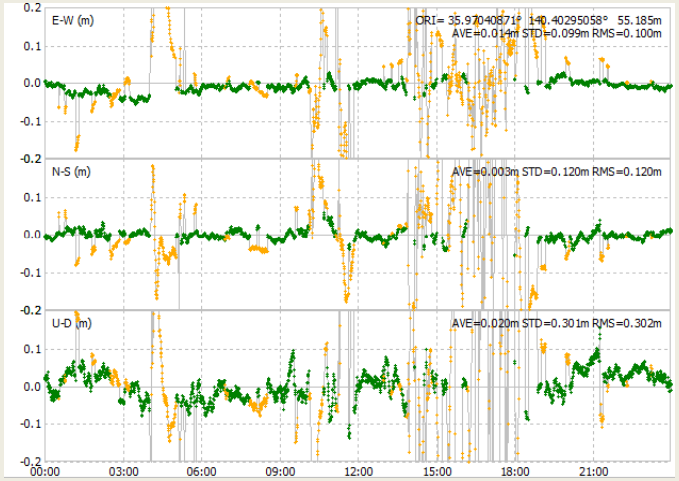
BL=13.3 km

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



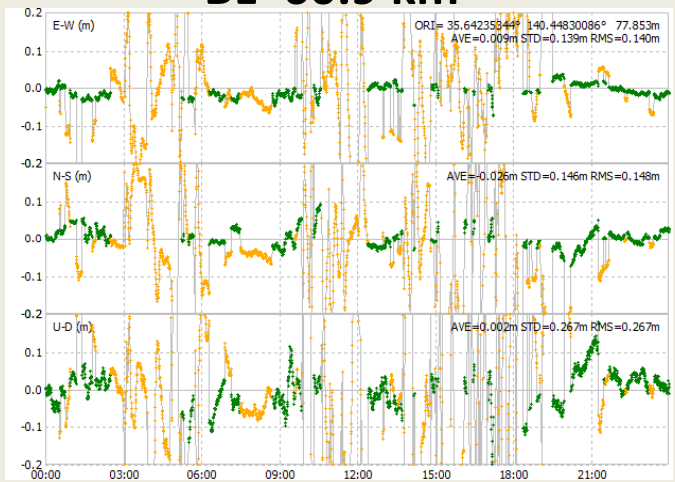
BL=32.2 km

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



BL=60.9 km

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



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

Long-BL RTK vs. Real-time PPP

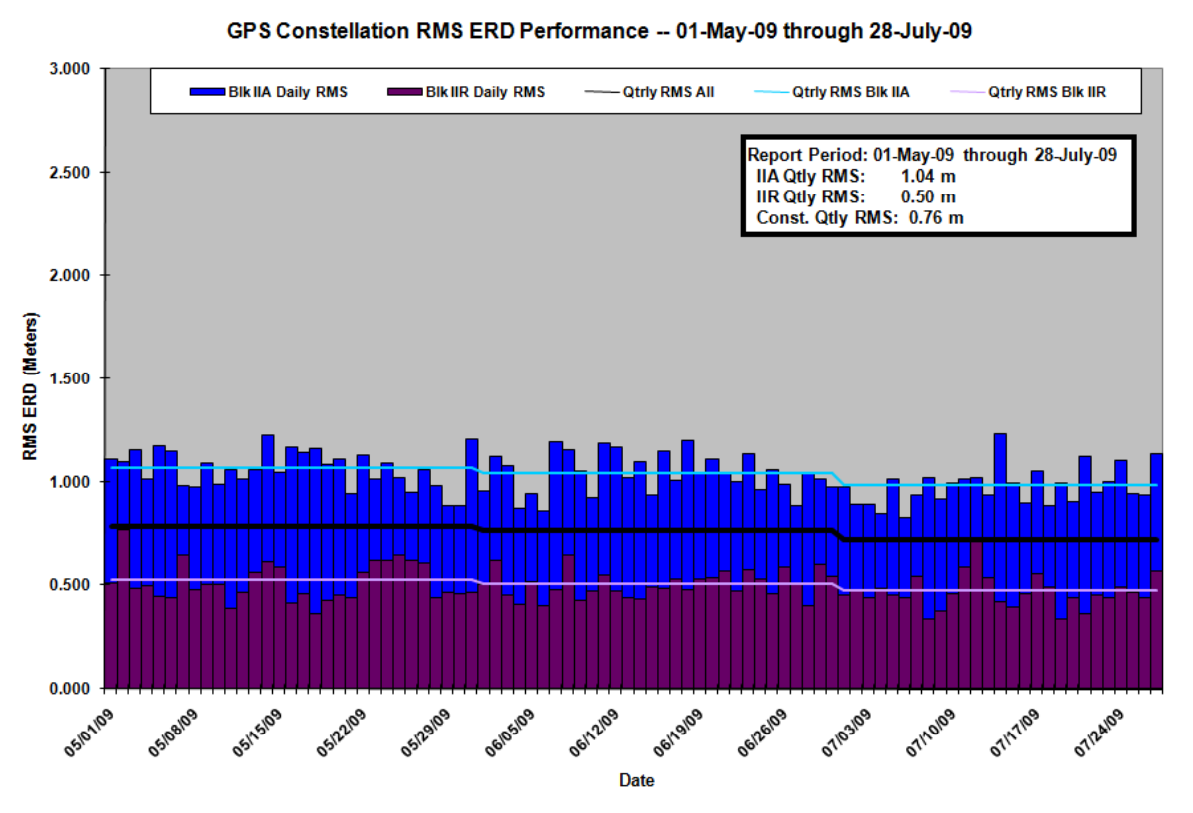
	Long-Baseline RTK	Real-time PPP
Location	100 - 3,000 km from Ref	Anywhere
Accuracy	2 - 10 cm RMS Horiz.	5 - 15 cm RMS Horiz.
Convergence Time	5 - 10 min	10 - 30 min
Reference Station	Needed	None
Ionosphere	Dual-Frequency	Dual-Frequency
Integer Ambiguity	Fixed	Float
Ephemeris/Clock	Broadcast (< 200 km) or Precise (IGU)	Precise (IGS-RT or Commercial)
Communication Link	Point-To-Point	Broadcast (Satellite)
Commercial Service	None	StarFire, SeaSTAR etc

Issues for Long-baseline RTK

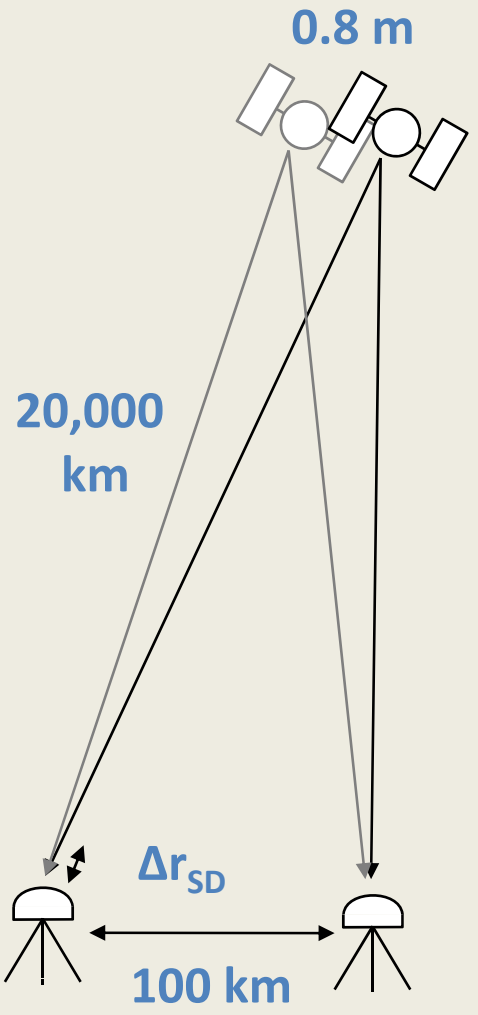
Issues for Long-baseline RTK

- 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

Broadcast Ephemeris



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



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

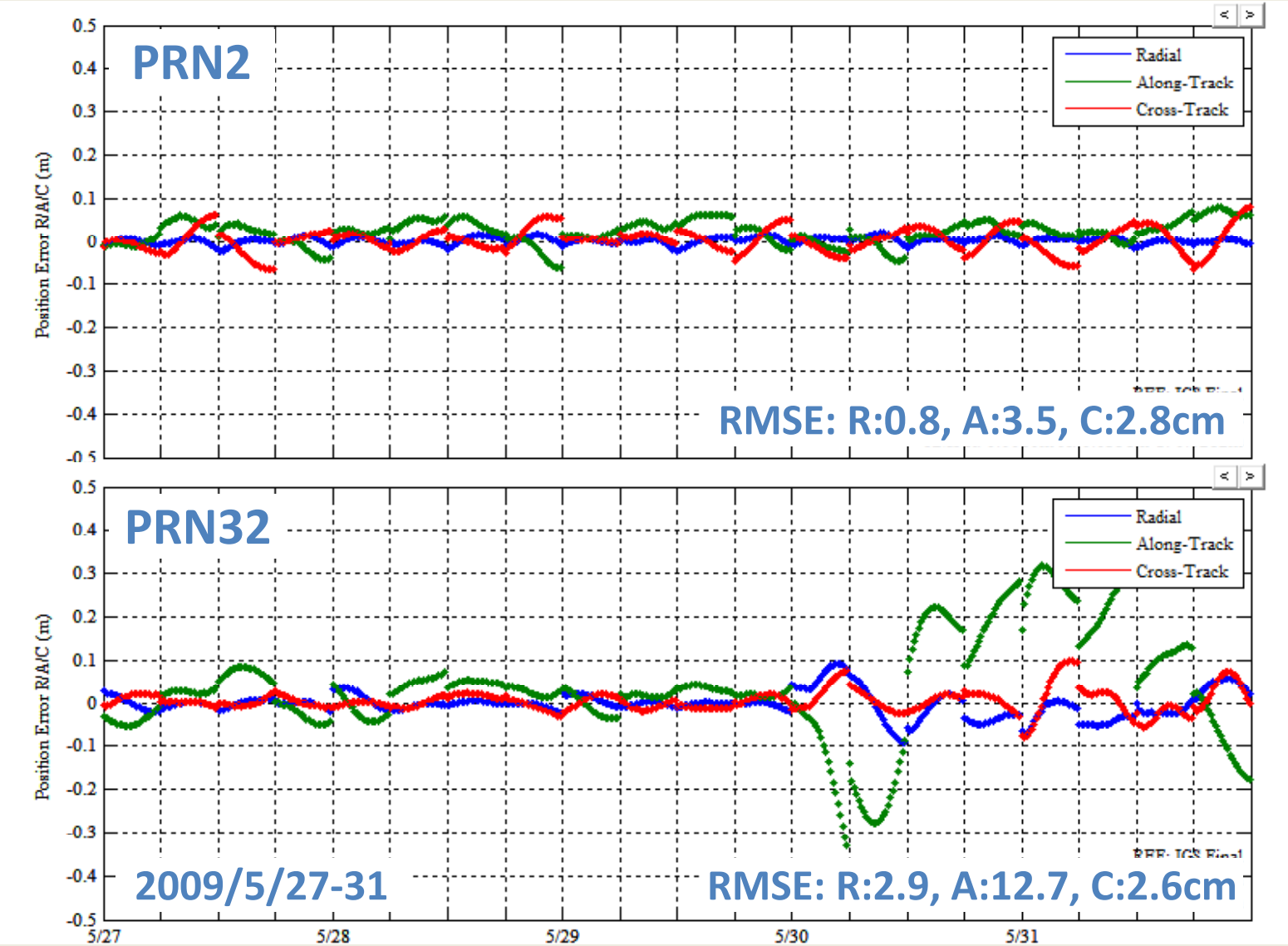
Precise Ephemeris

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

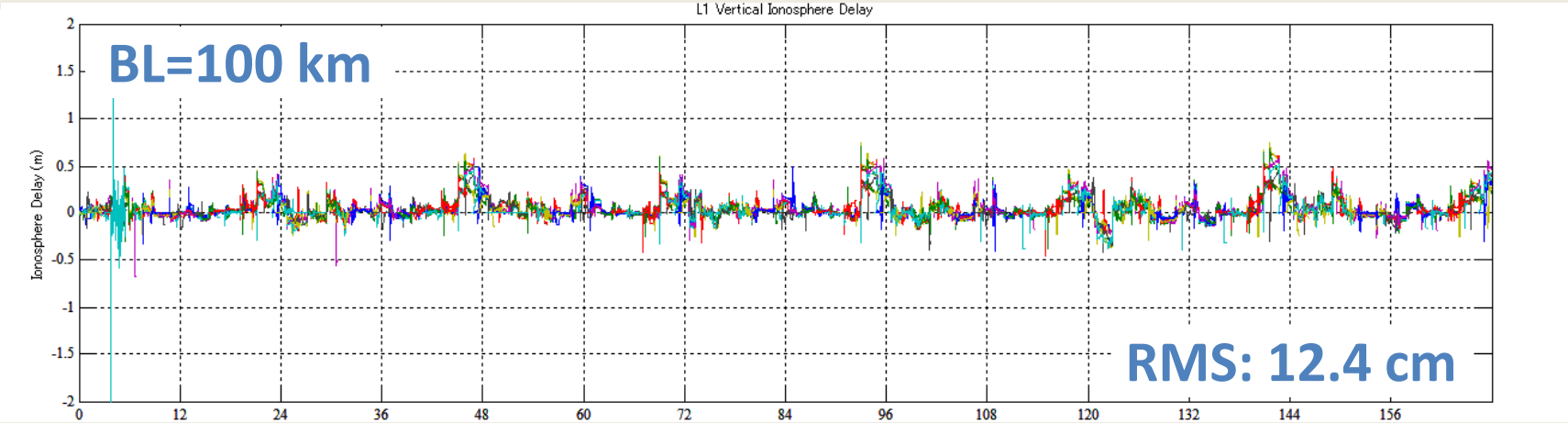
(2009/8, http://igscb.jpl.nasa.gov/)

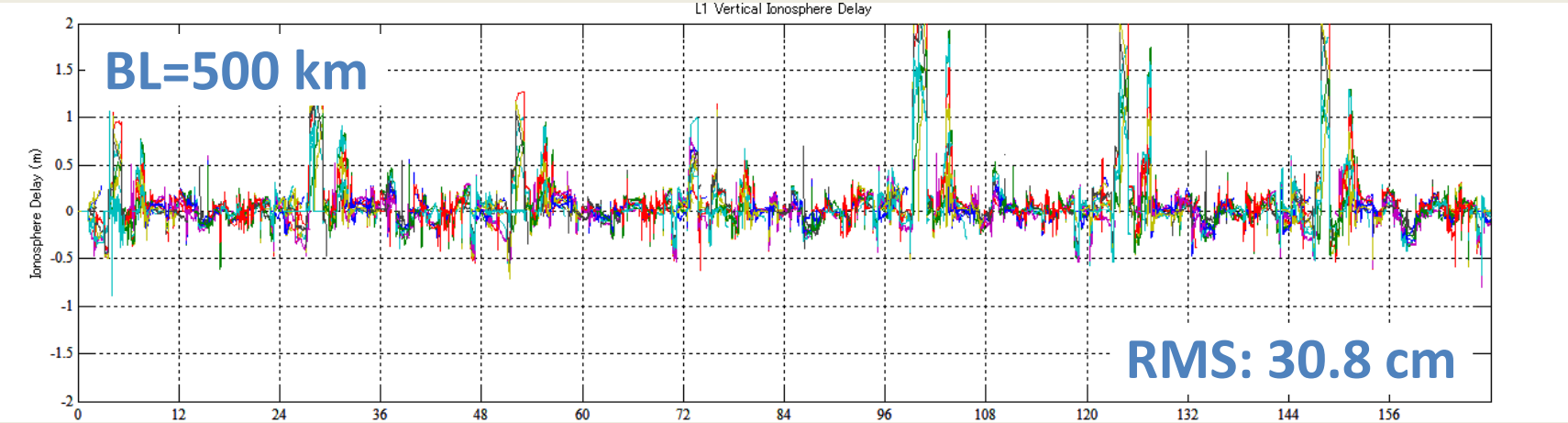
Accuracy of IGU-Predicted



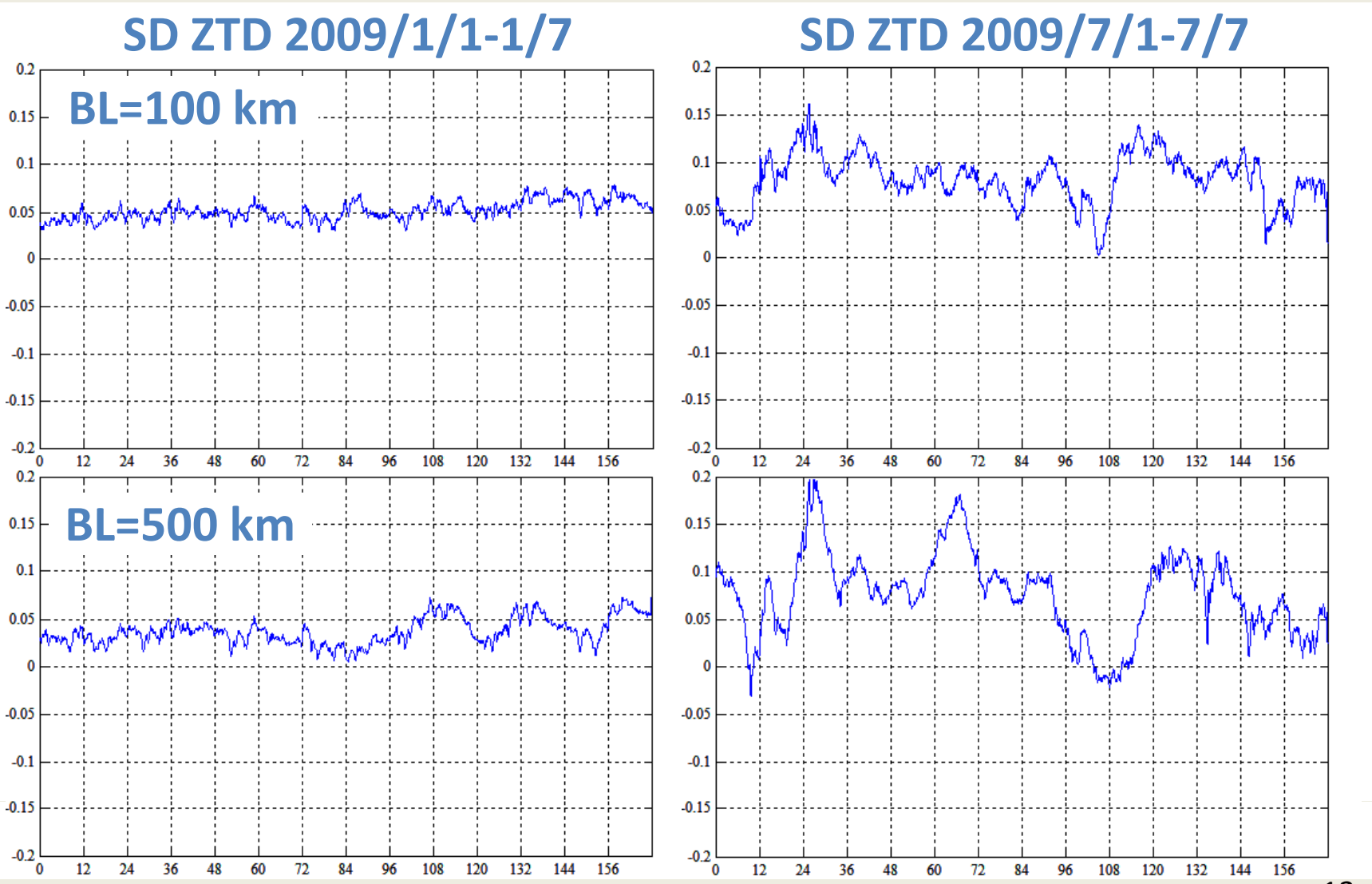
Ionosphere Delay

SD L1 Vertical Ionospheric Delay (1 Week)





Troposperic Delay



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

Integer Ambiguity Resolution (2)

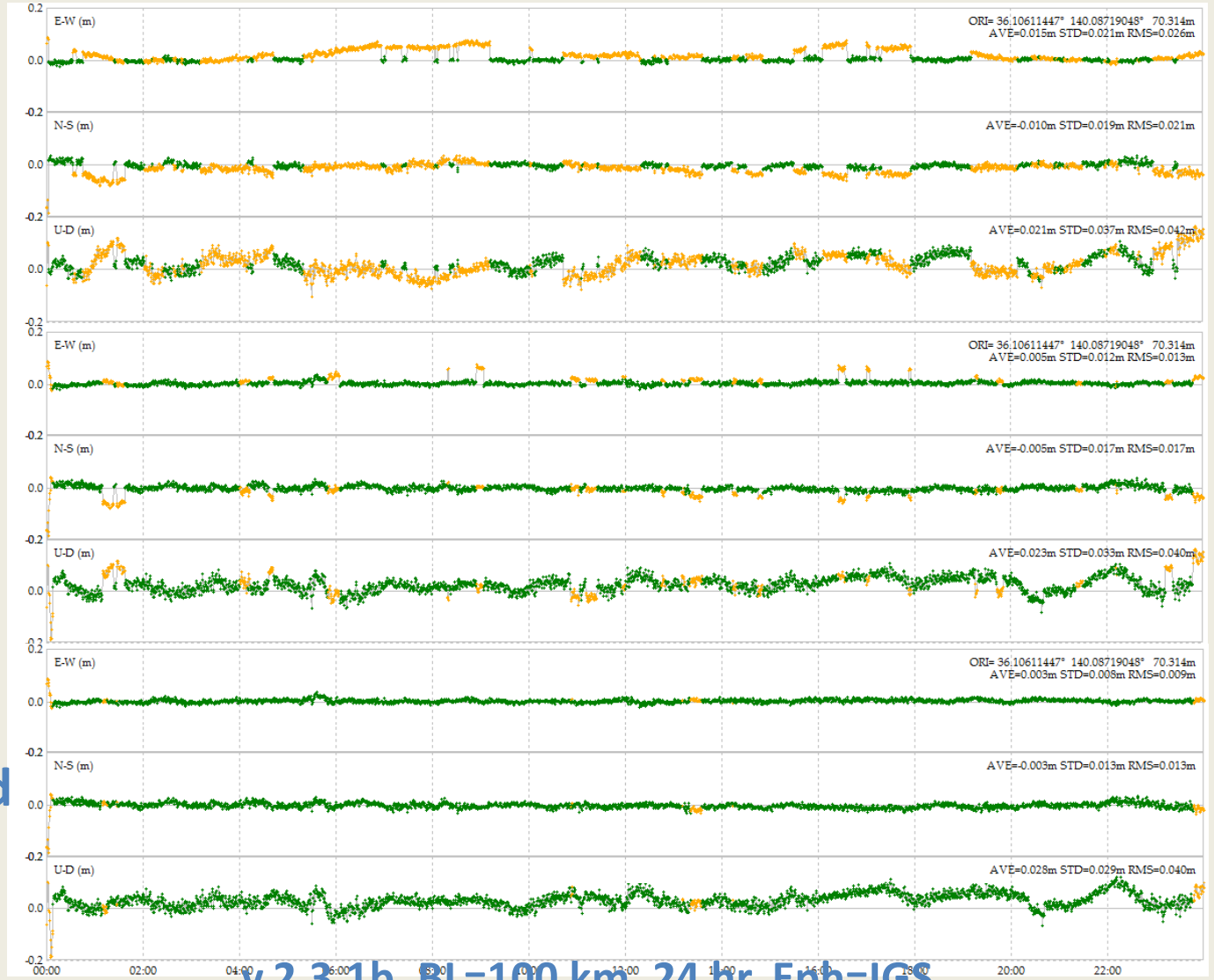
- RTKLIB v.2.3.0 (T. Takasu, 2009)
  - EKF-based States Estimation
    Rover Position, SD Vertical Ionos Delay, ZTD
    Residuals for Rover/Ref, SD Float Ambiguity L1/L2
  - Ionos: Random-Walk + Single Layer Model
  - Tropos: A Priori Model + Random-Walk + NMF
  - ILS Search by LAMBDA/MLAMBDA
  - Partial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

Integer Ambiguity Resolution (3)

Full Fix No Hold (43.1%)

Partial Fix No Hold (86.2%)

Partial Fix Fix and Hold (96.8%)



v.2.3.1b, BL=100 km, 24 hr, Eph=IGS

RTKLIB

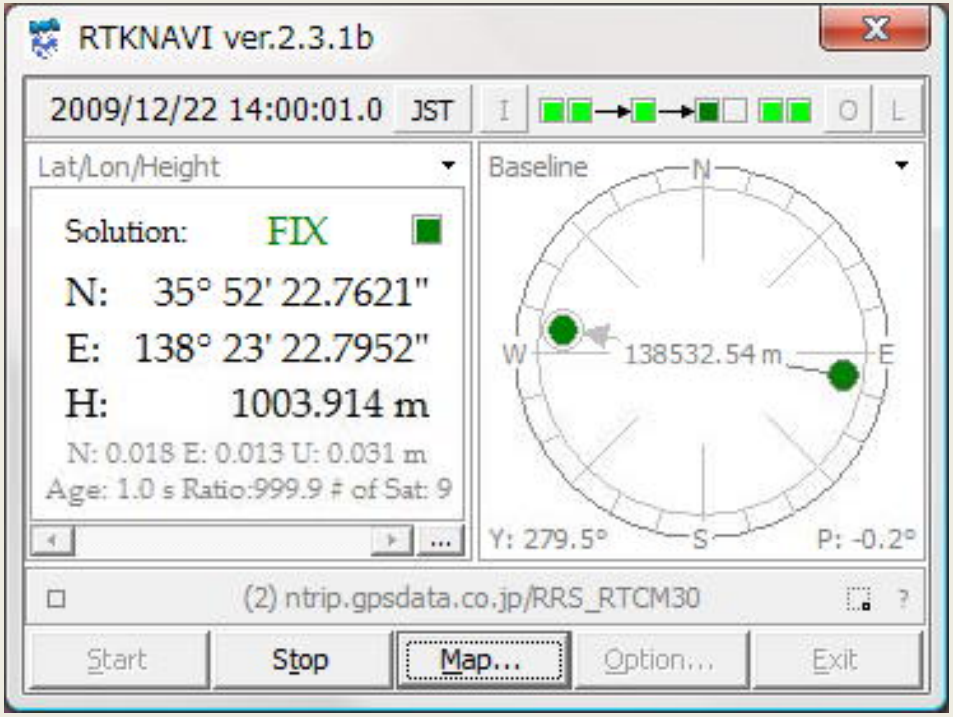
History

- 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

RTKLIB v.2.3.1

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

Long-baseline RTK with RTKLIB



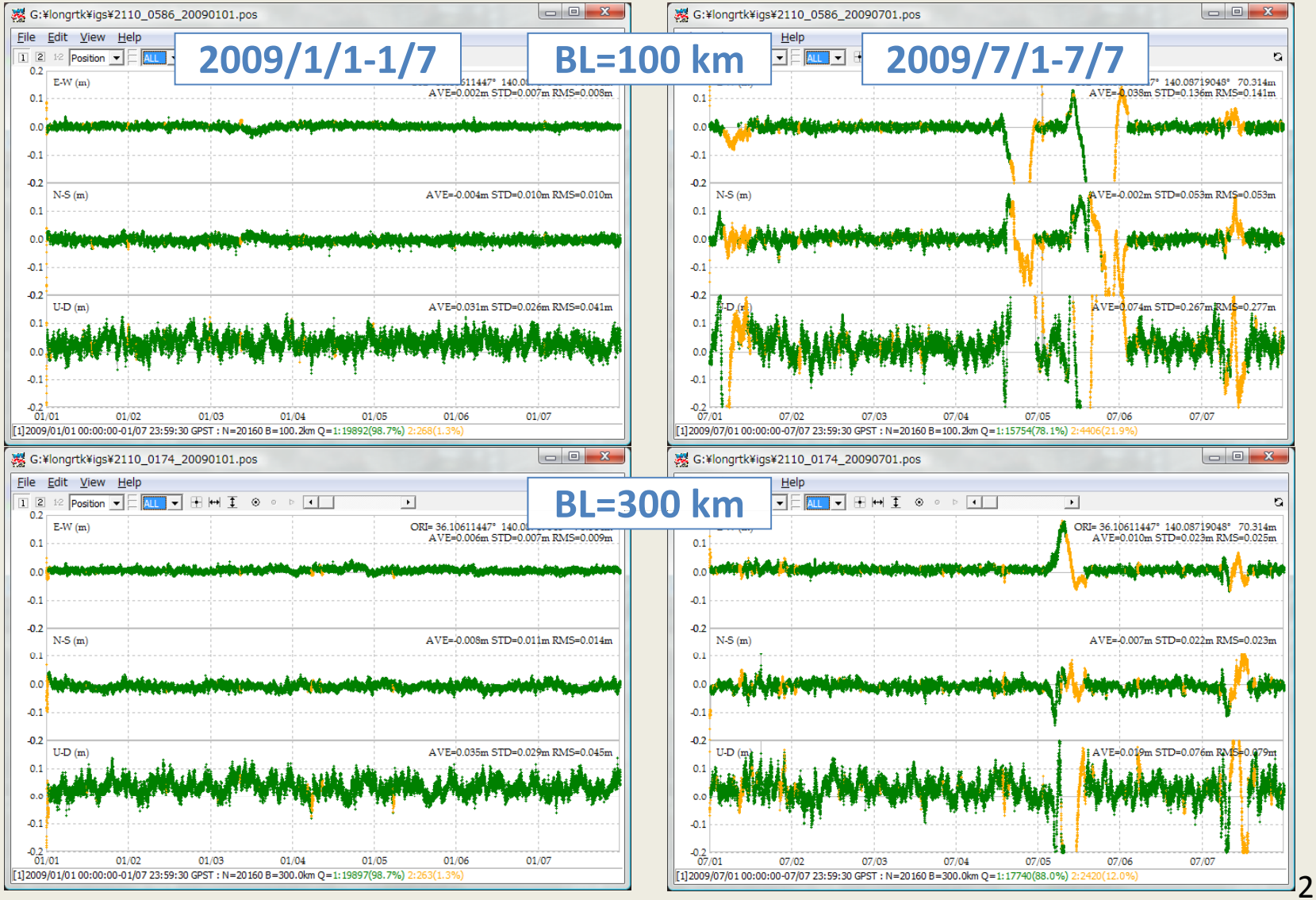
RTKNAVI: Real-time Positioning AP

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)



Future Plan

- Evaluation and Improvement
  - Evaluation with Real-time Data
  - Tuning of Parameters for Long-Baseline RTK
  - Improvement of Troposphere Estimation
  - More Effective Ambiguity Resolution Strategy
- Add Functionalities
  - Support GLONASS, QZSS, Galileo...
  - Support IGS RT-Orbit/Clock (NTRIP-RTCM)
  - Support Multi-baseline RTK