

ION GNSS 2010

**Kalman-Filter-Based Integer Ambiguity
Resolution Strategy for Long-Baseline RTK with
Ionosphere and Troposphere Estimation**



Tokyo University of Marine Science and Technology

Tomoji TAKASU and Akio YASUDA

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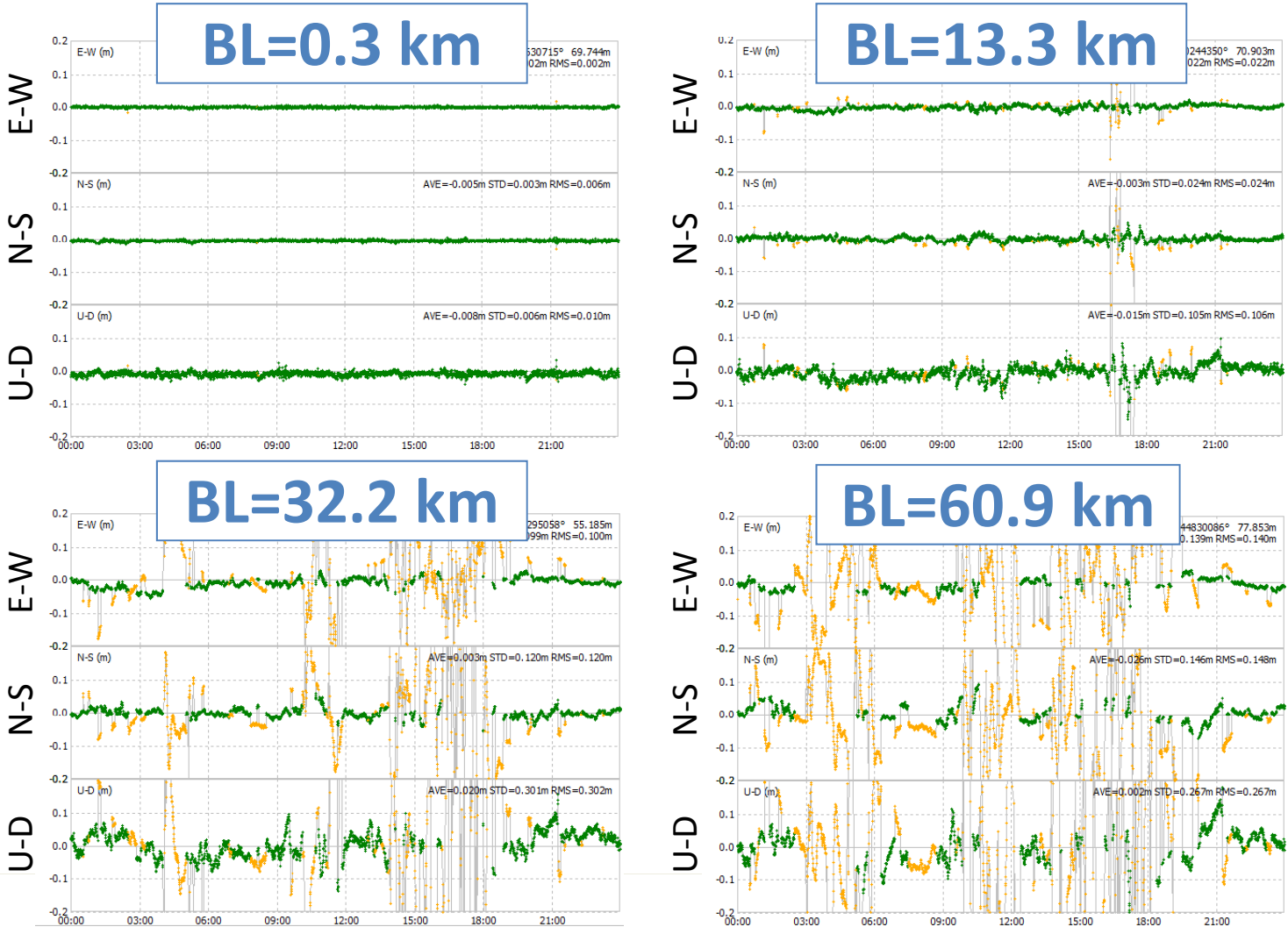
Background

RTK-GPS/GNSS

- Real-Time Kinematic GPS/GNSS
 - cm-level accuracy in real-time
 - Kinematic positions of moving receiver (rover)
- Carrier-Phase Based Relative Positioning
 - Transmit reference data to rover via wireless link
 - Must resolve integer ambiguity on-the-fly (OTF)
- Performance Depends on **Baseline Length**



Effect of Baseline Length

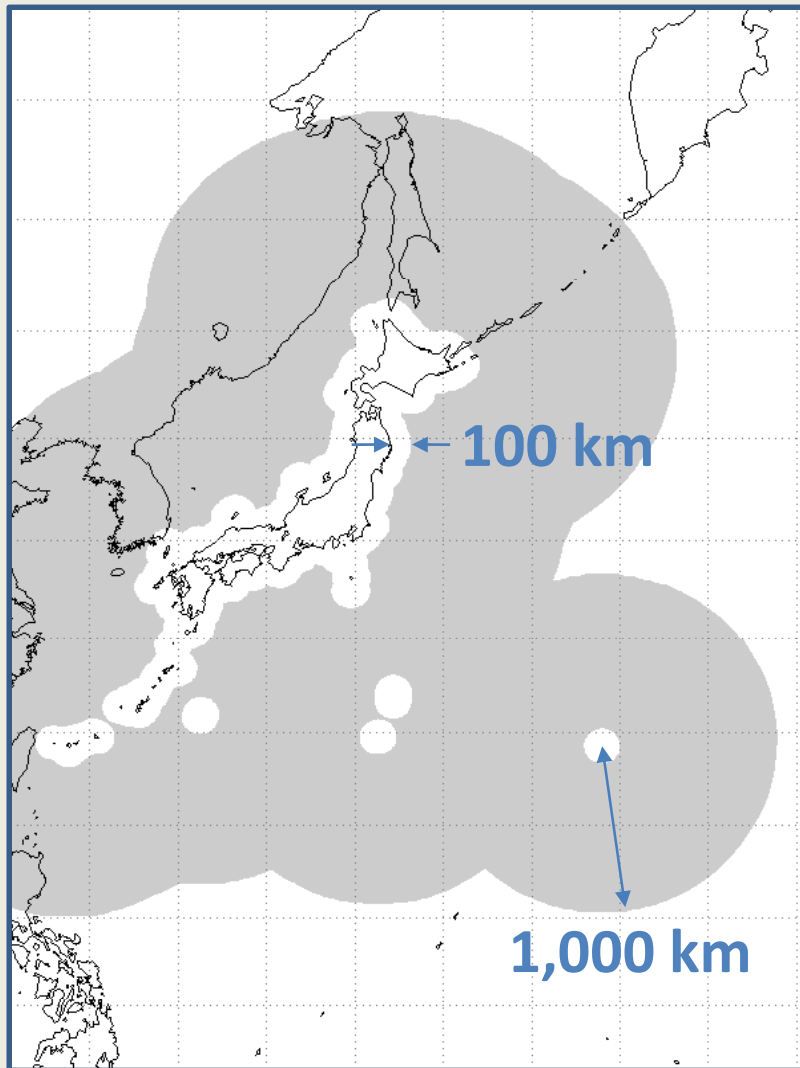


(24 hr Kinematic ●: Fixed Solution ●: Float Solution)

Baseline Length and RTK Strategy

	BL (km)	Error Elimination				Strategy
		Ephem	Ionos	Tropos	Others	
S	0 – 10	Broadcast	-	-	-	Conventional RTK
M	10 – 100	Broadcast	Dual-Freq	-	-	
			Interpolation		-	Network RTK
L	100 – 1,000	Real-time Precise (IGU)	Dual-Freq	Estimate ZTD + MF	Earth Tides	Long- Baseline RTK
VL	>1,000	Non-RT Precise (IGR, IGS)	Dual-Freq	Estimate ZTD + MF	Earth Tides, Ph-WU	Post- Processing or PPP

Application of Long-Baseline RTK



**GPS Tsunami
Monitoring System
(Currently ~15 km off-shore)**

<http://www.tsunamigps.com>

Strategy for Long-Baseline RTK

Conventional AR Strategies

- Short-Baseline RTK
 - Rapid initialization/re-initialization (OTF-AR)
 - Efficient integer vector search algorithm
 - Ionosphere negligible in DD equations
- Medium/Long-Baseline Post-Processing
 - Estimate WL/NL amb. by forming iono-free LC
 - Sequential rounding of WL/NL ambiguities
 - Slow convergence
 - Larger noise due to LC in kinematic mode

Linear Combinations

LC	Coefficients				Terms in DD Equation				DD Noise (cm)	Notes
	Φ_1	Φ_2	P_1	P_2	R+T	I_1	N_1	N_2		
L1	λ_1				1	1	λ_1		0.6	
L2		λ_2			1	γ		λ_2	0.6	
P1			1		1	-1			60	
P2				1	1	$-\gamma$			60	
L3	$C_1\lambda_1$	$C_2\lambda_2$			1	0	$C_1\lambda_1$	$C_2\lambda_2$	1.8	Iono-Free LC
MW	λ_{WL}	$-\lambda_{WL}$	$-\lambda_{NL}/\lambda_1$	$-\lambda_{NL}/\lambda_2$	0	0	λ_{WL}	$-\lambda_{WL}$	42	
(L1+P1)/2	$\lambda_1/2$		1/2		1	0	$\lambda_1/2$		30	Alt. Iono-Free
(L2+P2)/2		$\lambda_2/2$		1/2	1	0		$\lambda_2/2$	30	

$$\lambda_1=19\text{cm}, \lambda_2=24\text{cm}, \lambda_{WL}=86\text{cm}, \lambda_{NL}=11\text{cm}, \gamma=f_1^2/f_2^2, C_1=\gamma/(\gamma-1), C_2=-1/(\gamma-1)$$

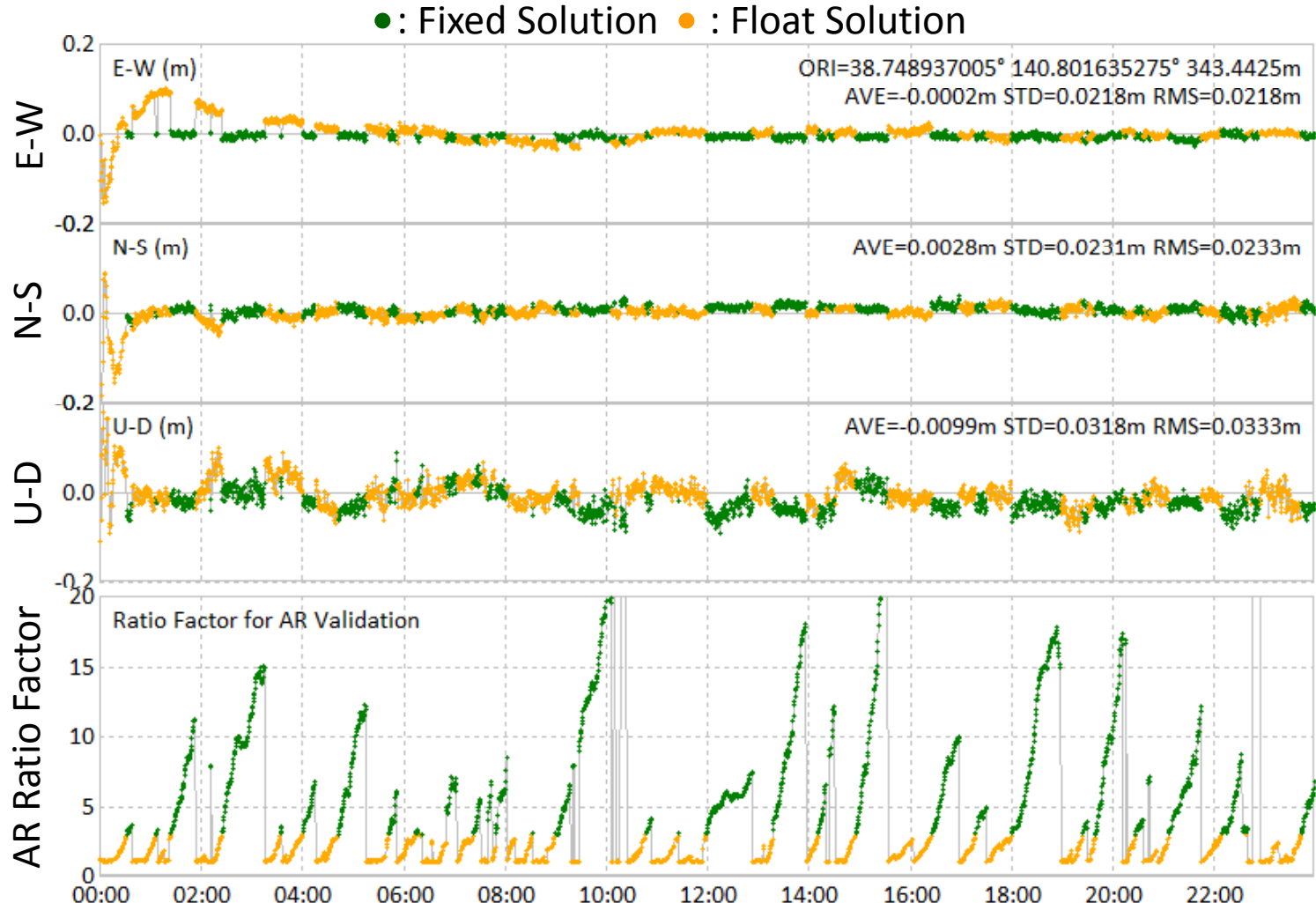
AR Strategy for Long-Baseline RTK

- No Linear Combination (LC)
 - Use all original phase and code observables
 - Not generate WL or NL LC
 - Estimate ionosphere terms explicitly
 - Suppress carrier-phase noises
- Directly Resolve L1 and L2 Ambiguities (N_1, N_2)
 - Search integer vector under ILS condition
 - Efficient process by LAMBDA/MLAMBDA with shrinking space by linear transformation

Other Strategies

- Extended Kalman-Filter for Real-Time Est.
- Ephemeris
 - IGU Predicted Orbit (Accuracy ~ 5 cm)
- Troposphere
 - Estimate ZWD and gradient at ref and rover sites with mapping function (NMF)
- Other Corrections
 - Receiver/satellite antenna PCV: IGS05.ATX
 - Earth tides: solid earth tide model by IERS

Results by Simple Implementation



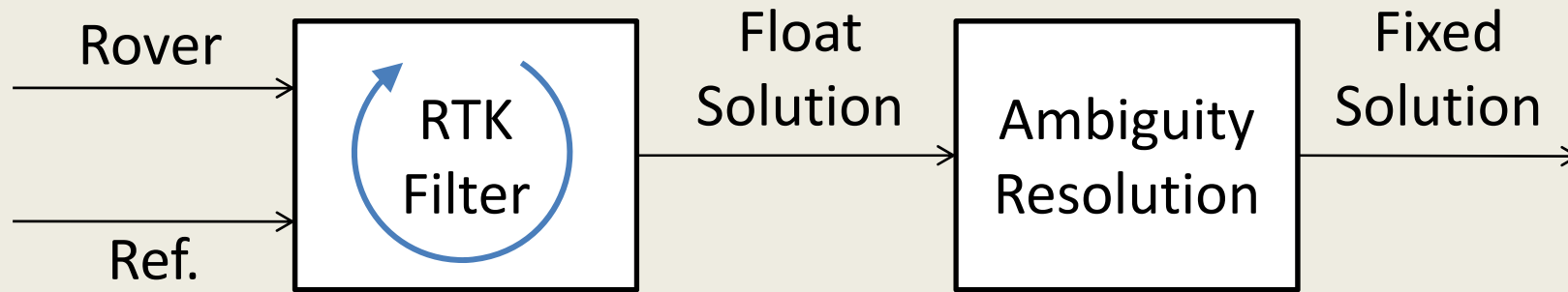
BL=300.0 km STD=2.2,2.3,3.2cm, Fix Ratio=46.4%

Partial Fixing of Ambiguities

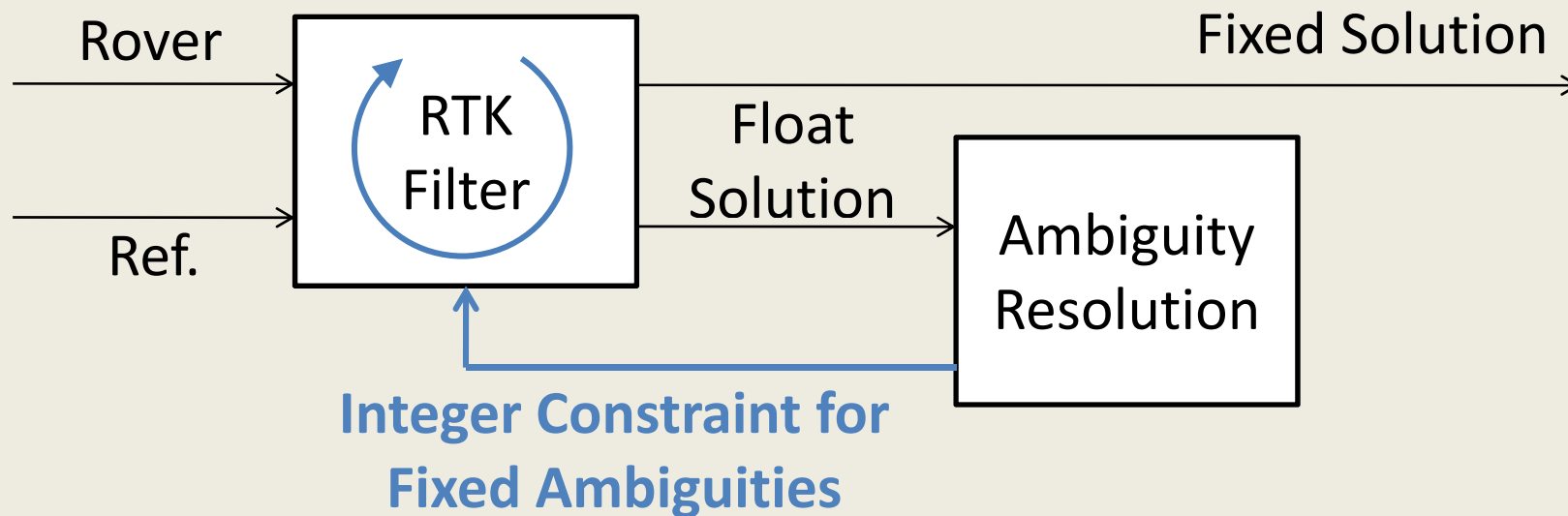
- Search Type AR Strategy under ILS Condition
 - All of ambiguities should be fixed at the same time
 - Rising satellites often disturb ambiguity fixing
- Not All Ambiguities must be Fixed
 - Trade-off between accuracy vs. fixing ratio
- Some Criteria to Determine Fixed or Float
 - Variance of estimated ambiguity
 - Duration of continuous valid data
 - Satellite elevation angle

Feedback Fixed Ambiguity to Filter

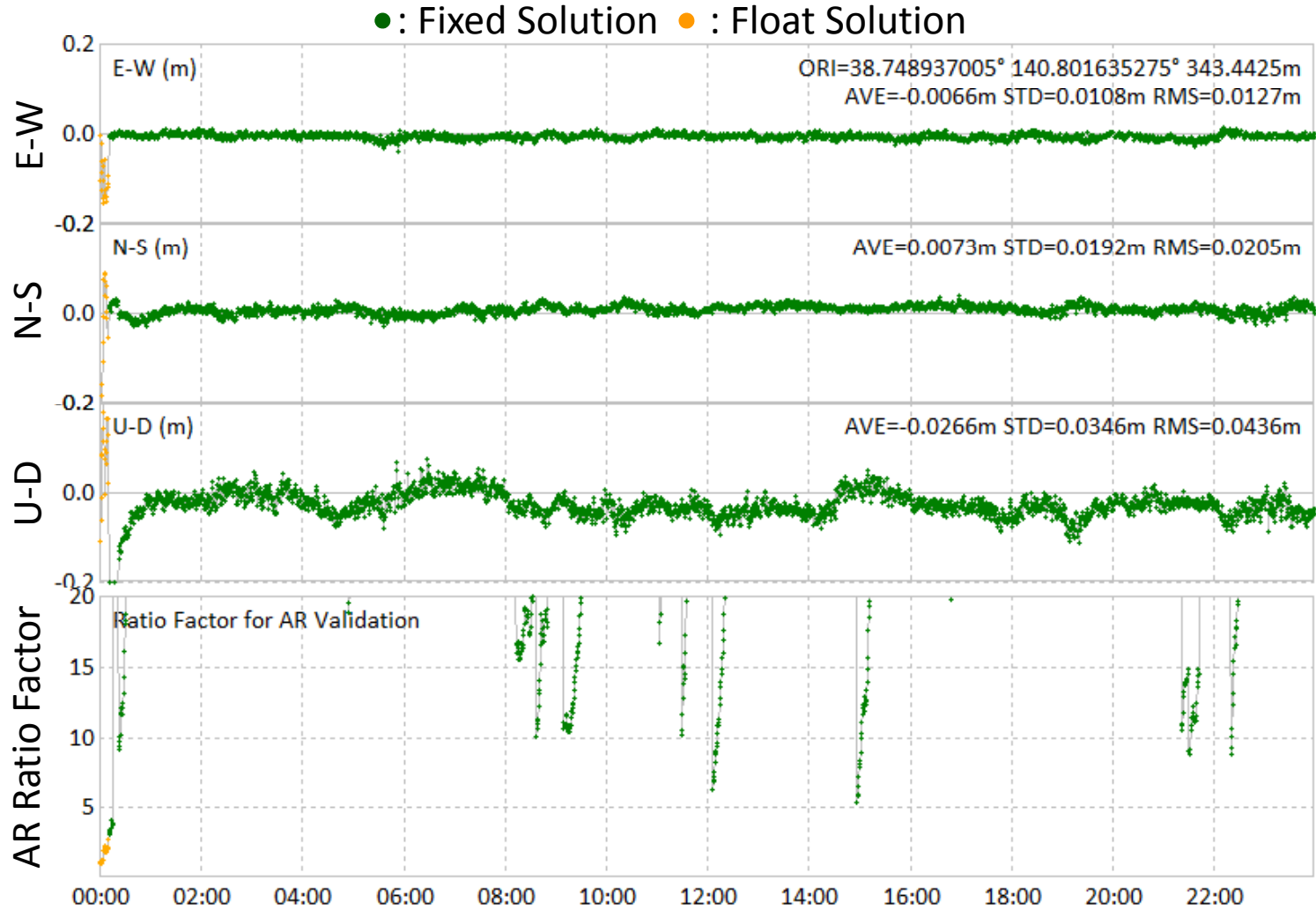
Open Loop AR



Fix and Hold Mode



Performance Improvement

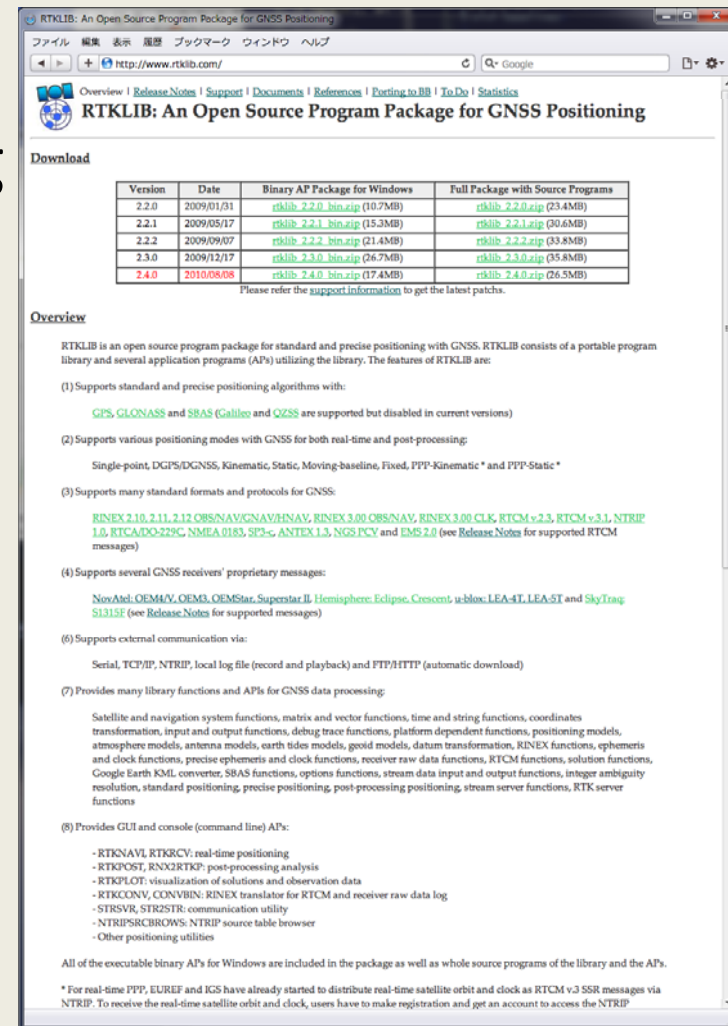


BL=300.0 km STD=1.1,1.9,3.5cm, Fix Ratio=99.3%

Implementation

RTKLIB v.2.4.1b

- Open source program package for GNSS positioning
 - Whole source codes are freely available
 - License: GPLv3
 - 5000+ downloads (2.3.0)
- Portable library + several APs
 - ANSI C + socket/pthread ...
 - Portable command-line APs
 - GUI APs for Windows



The screenshot shows the RTKLIB website interface. At the top, there are navigation links: Overview, Release Notes, Support, Documents, References, Porting to BB, To Do, and Statistics. Below this is the title "RTKLIB: An Open Source Program Package for GNSS Positioning".

The "Download" section features a table with the following data:

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)

Below the table, it says "Please refer the support information to get the latest patches."

The "Overview" section describes RTKLIB as an open source program package for standard and precise positioning with GNSS. It lists several features:

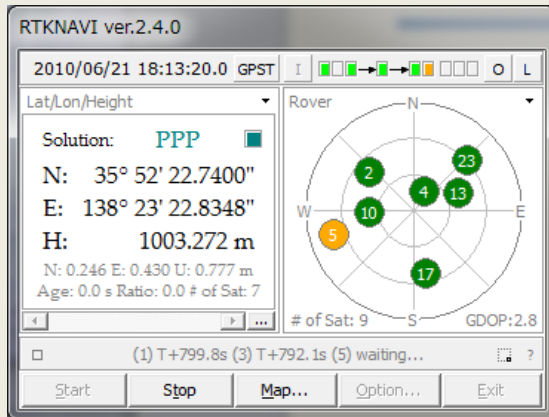
- (1) Supports standard and precise positioning algorithms with:
 - GPS, GLONASS and SBAS (Galileo and QZSS) are supported but disabled in current versions
- (2) Supports various positioning modes with GNSS for both real-time and post-processing:
 - Single-point, DGPS/DGNSS, Kinematic, Static, Moving-baseline, Fixed, PPP-Kinematic* and PPP-Static*
- (3) Supports many standard formats and protocols for GNSS:
 - RINEX 2.10, 2.11, 2.12 OBS/NAV/GNAV/HNAV, RINEX 3.00 OBS/NAV, RINEX 3.00 CLK, RTCM v.2.3, RTCM v.3.1, NTRIP 1.0, RTCA/DO-229C, NMEA 0183, SPS-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 S1315F (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:
 - Satellite 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, Google Earth KML converter, SBAS functions, options functions, stream data input and output functions, integer ambiguity resolution, standard positioning, precise positioning, post-processing positioning, stream server functions, RTK server functions
- (8) Provides GUI and console (command line) APIs:
 - RTKNAV, RTKRCV: real-time positioning
 - RTKPOST, RNXRTP: post-processing analysis
 - RTKPLT: visualization of solutions and observation data
 - RTKCONV, CONVBIN: RINEX translator for RTCM and receiver raw data log
 - STRSVR, STR2STR: communication utility
 - NTRIPSRCBROWS: NTRIP source table browser
 - Other positioning utilities

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

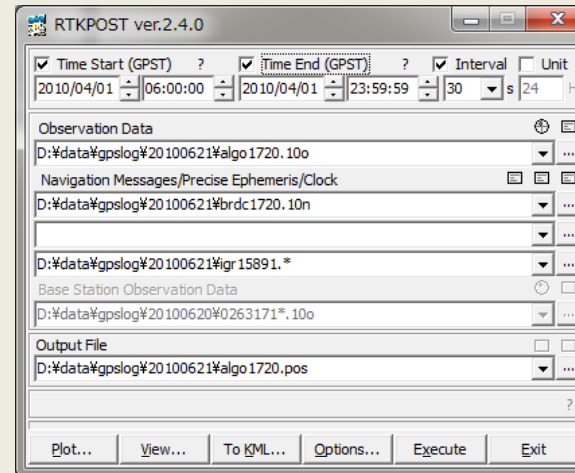
* For real-time PPP, EUREF and IGS have already started to distribute real-time satellite orbit and clock as RTCM v.3 SSR messages via NTRIP. To receive the real-time satellite orbit and clock, users have to make registration and get an account to access the NTRIP.

<http://www.rtklib.com>

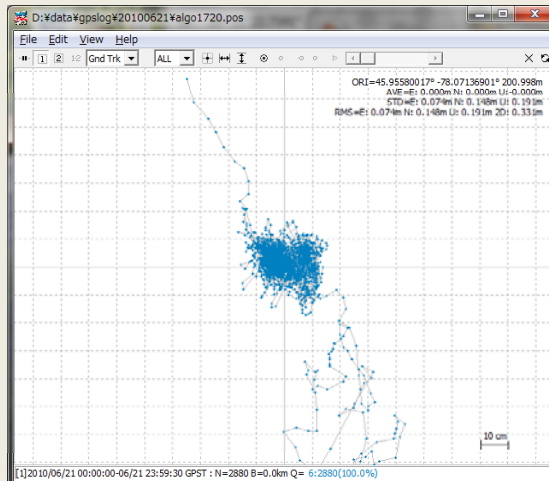
RTKLIB APs on Windows



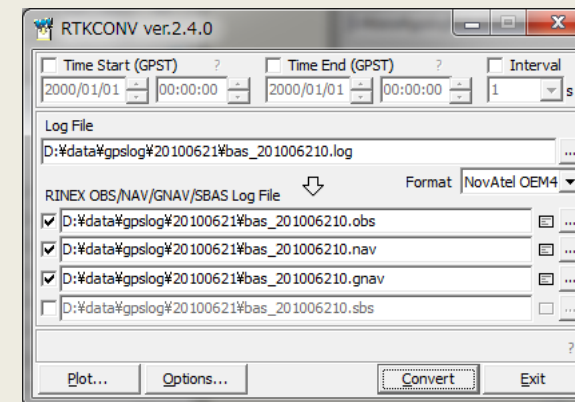
RTKNAVI: Real-time AP



RTKPOST: Post-Processing



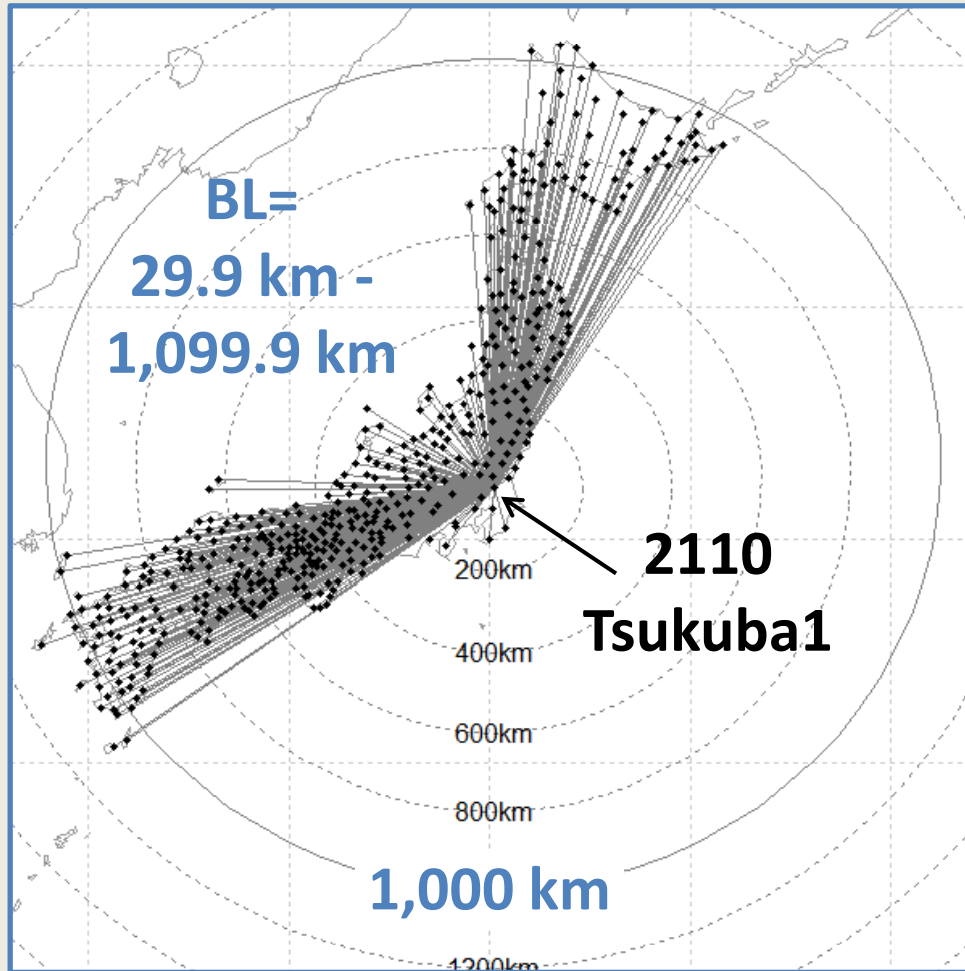
RTKPLOT: Plotting solutions



RTKCONV: RINEX converter

Tests for Performance Evaluation

Offline Test



January 1-7, 2009 (Winter)

July 1-7, 2009 (Summer)

30 s x 1 week RINEX

Rover:

477 GEONET Stations

Reference:

GEONET 2110 Tsukuba1

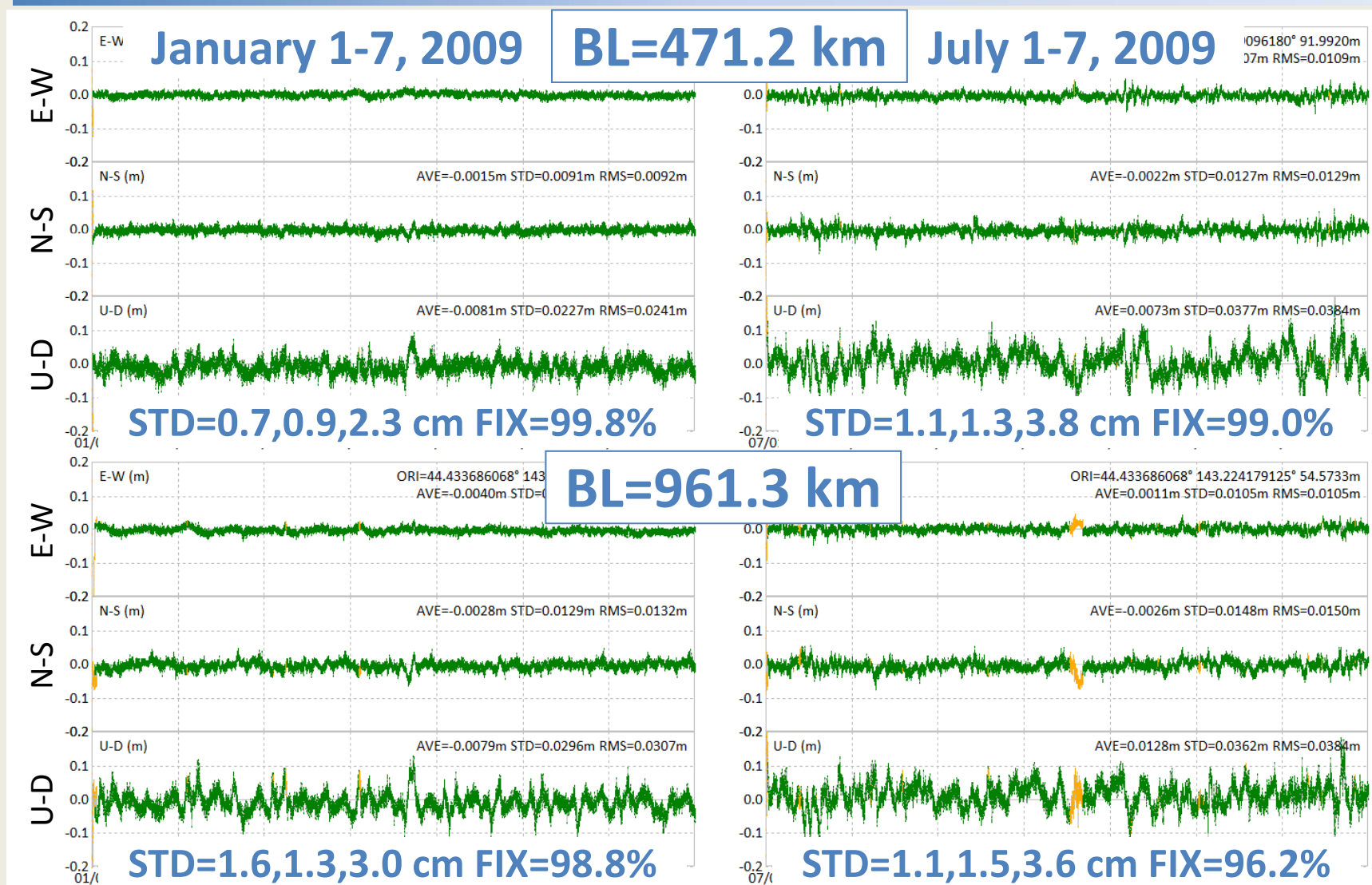
Ephemeris:

IGU (predicted)

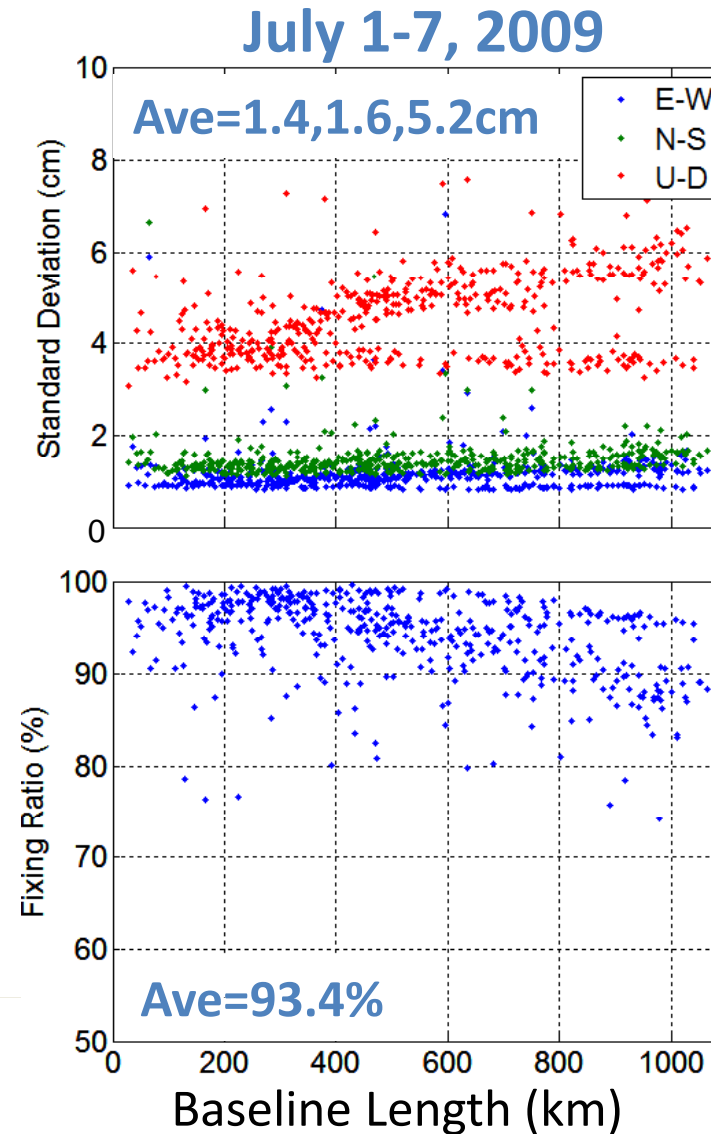
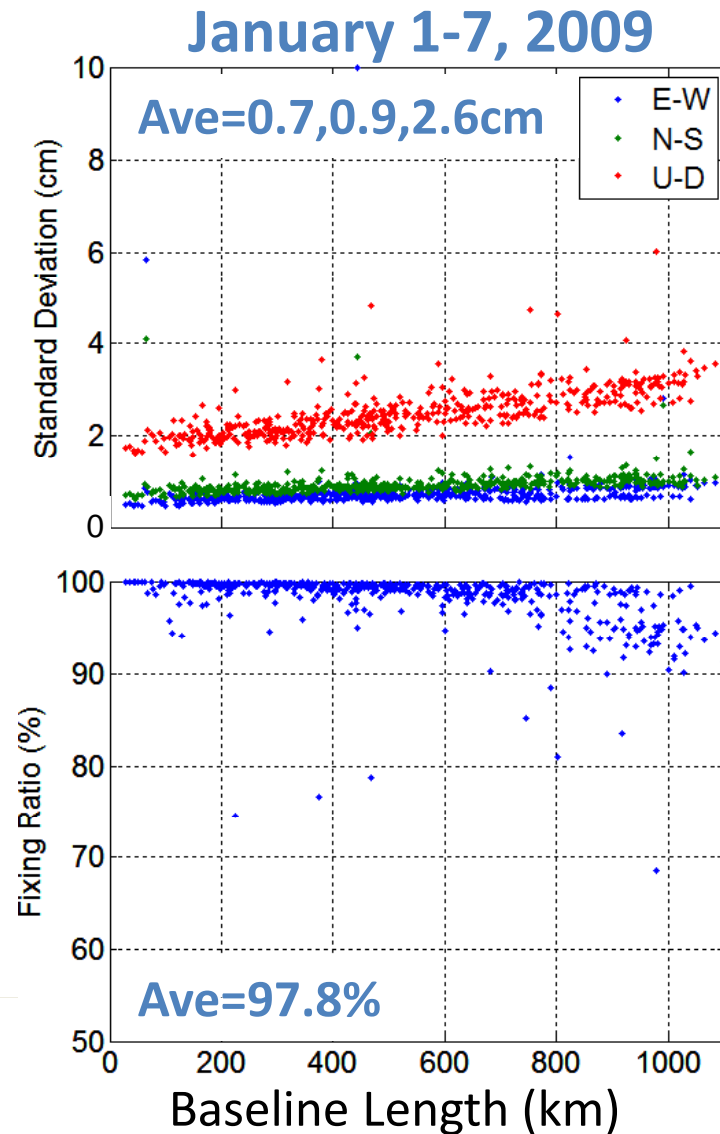
Analysis S/W:

RTKPOST v2.4.1b

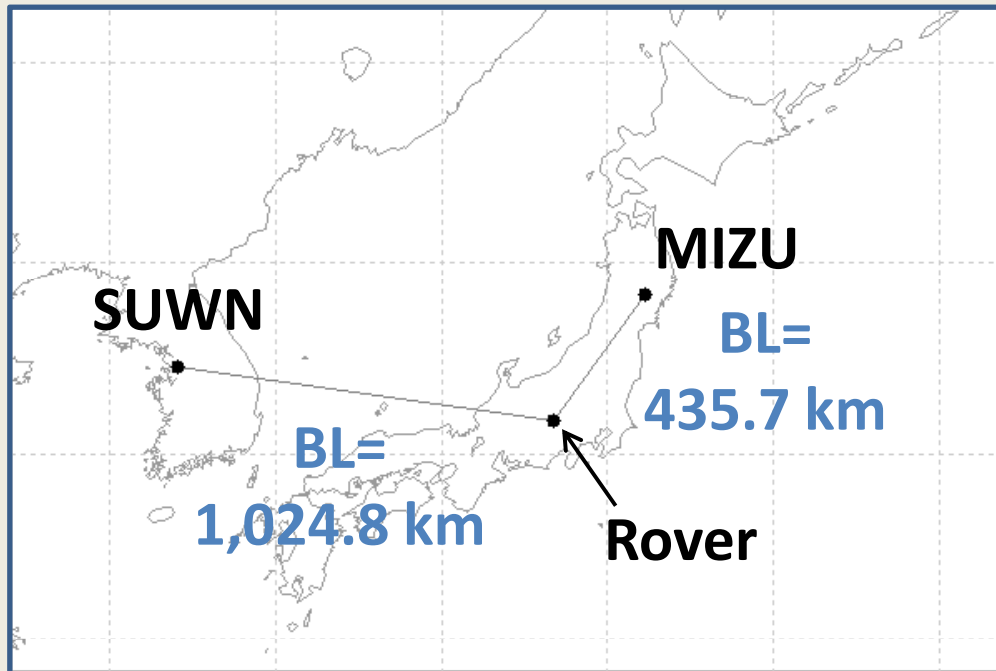
Offline Test Results



Summary of Offline Test Results



Real-Time Test



September 17-20, 2009

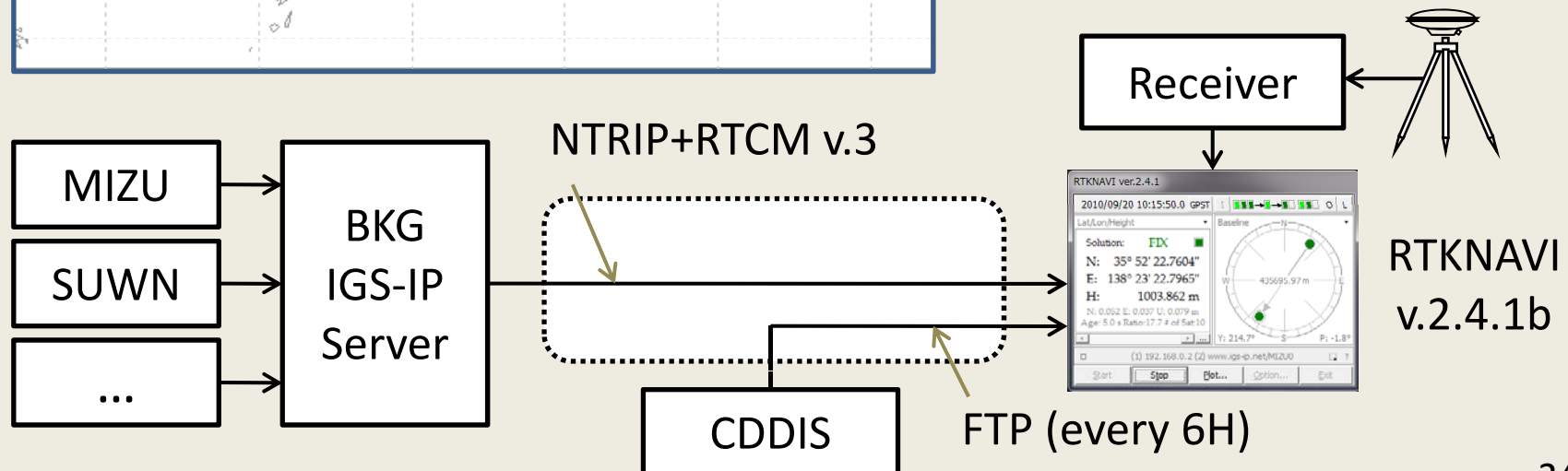
1 Hz x 72 H

Rover: NovAtel

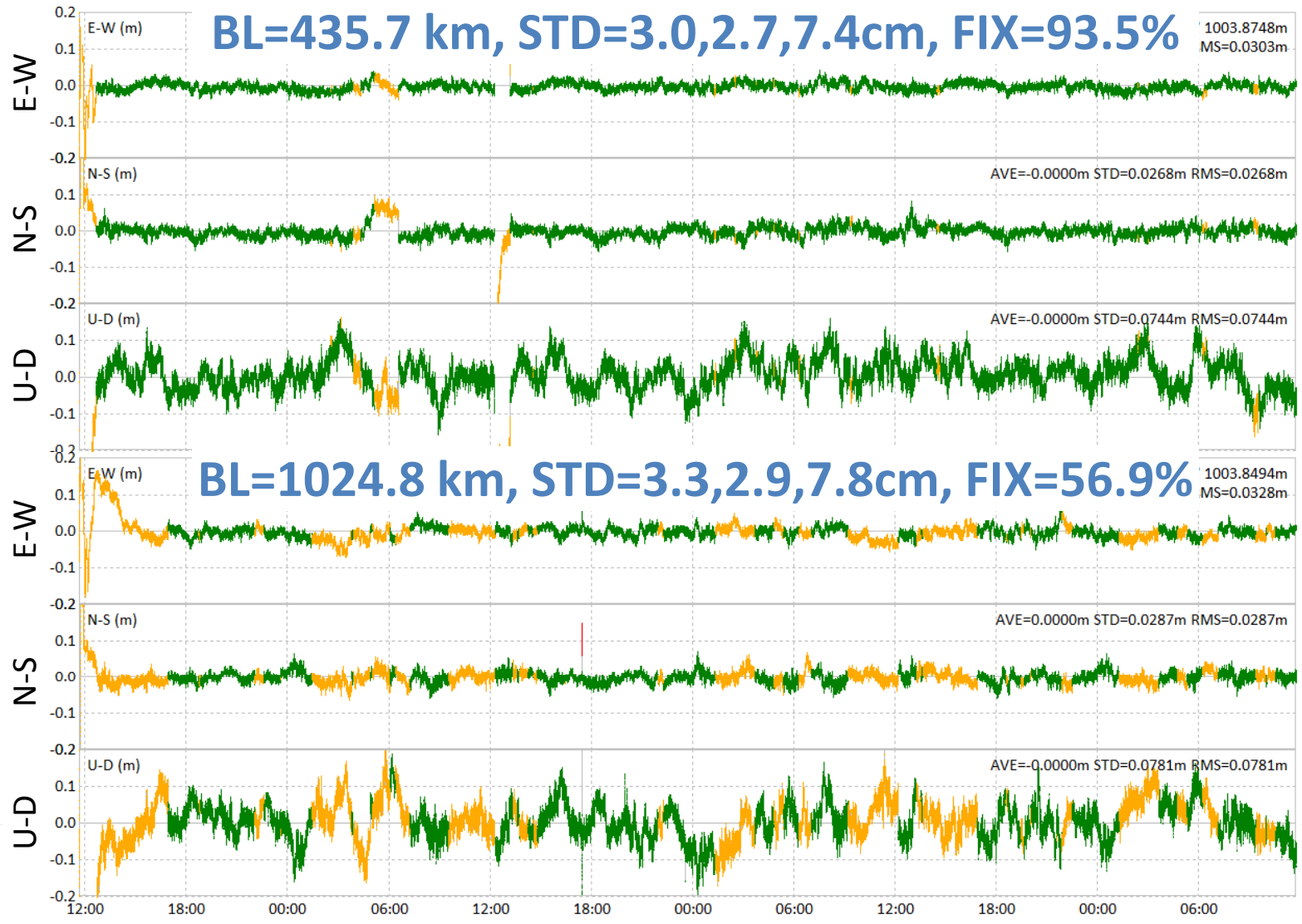
OEMV-3 + GPS-702-GG

Reference:

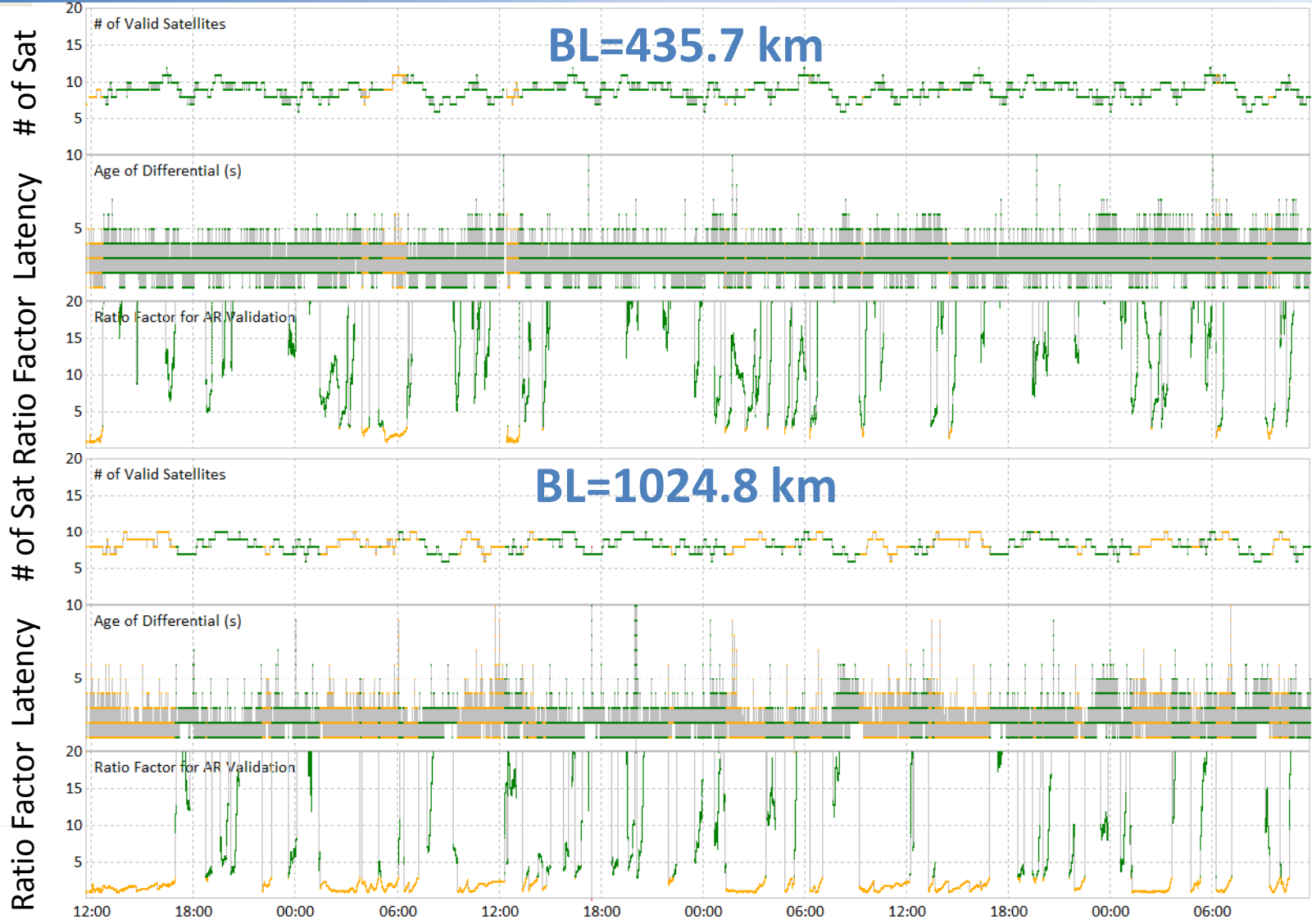
IGS MIZU and SUWN



Real-Time Test Results (1)



Real-Time Test Results (2)



Conclusion and Future Work

Conclusion and Future Work

- A strategy for long-baseline RTK proposed
- Offline test in 30 - 1,100 km baselines
- Real-time test in 436 and 1,025 km baselines
- Proposed strategy works well up to 1,000 km baseline
- Performance degraded in summer time
- Need integration of meteorological info to improve troposphere correction