ION GNSS 2010

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

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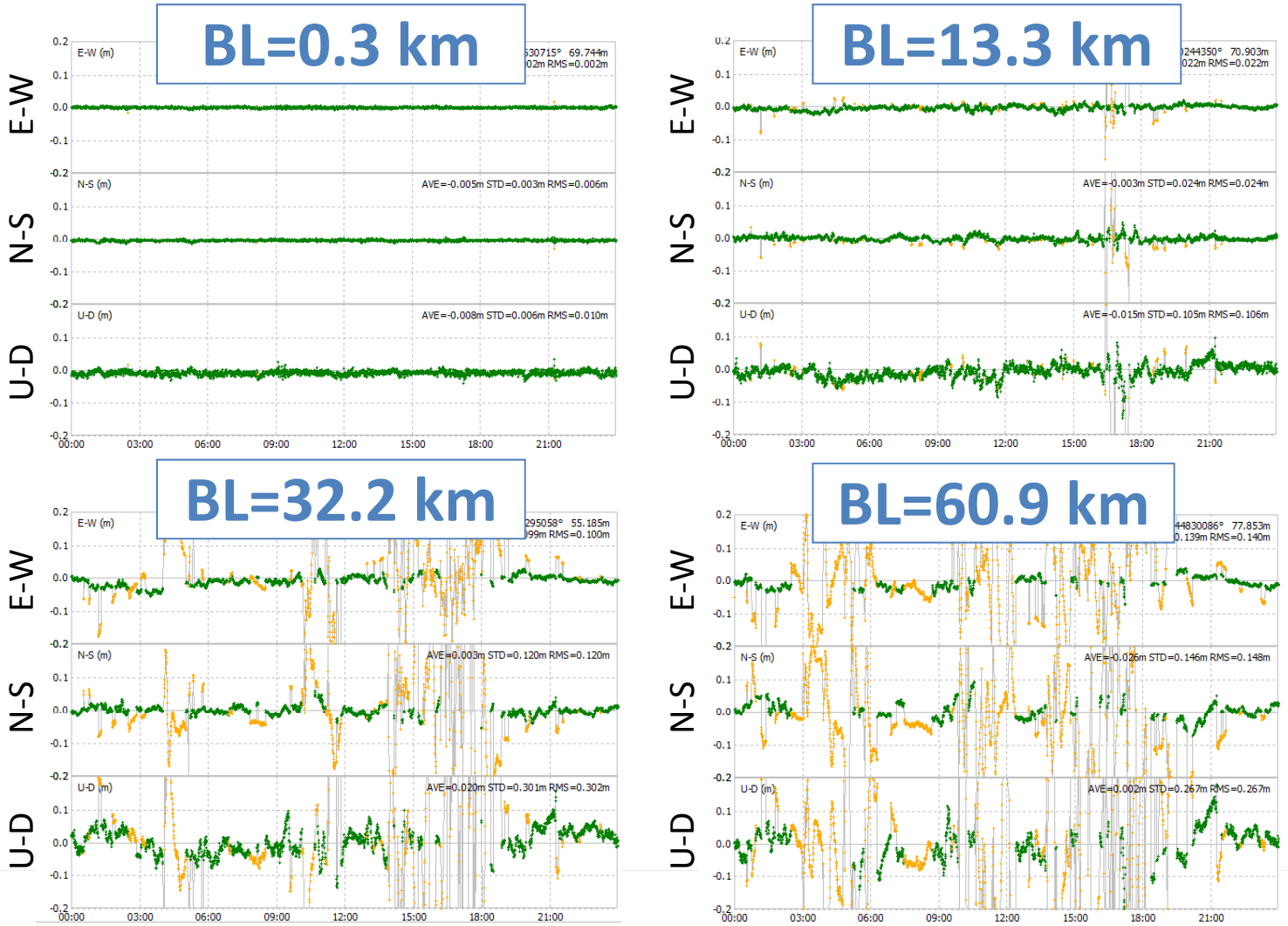
- Performance Evaluation
- Conclusion and Future Work

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

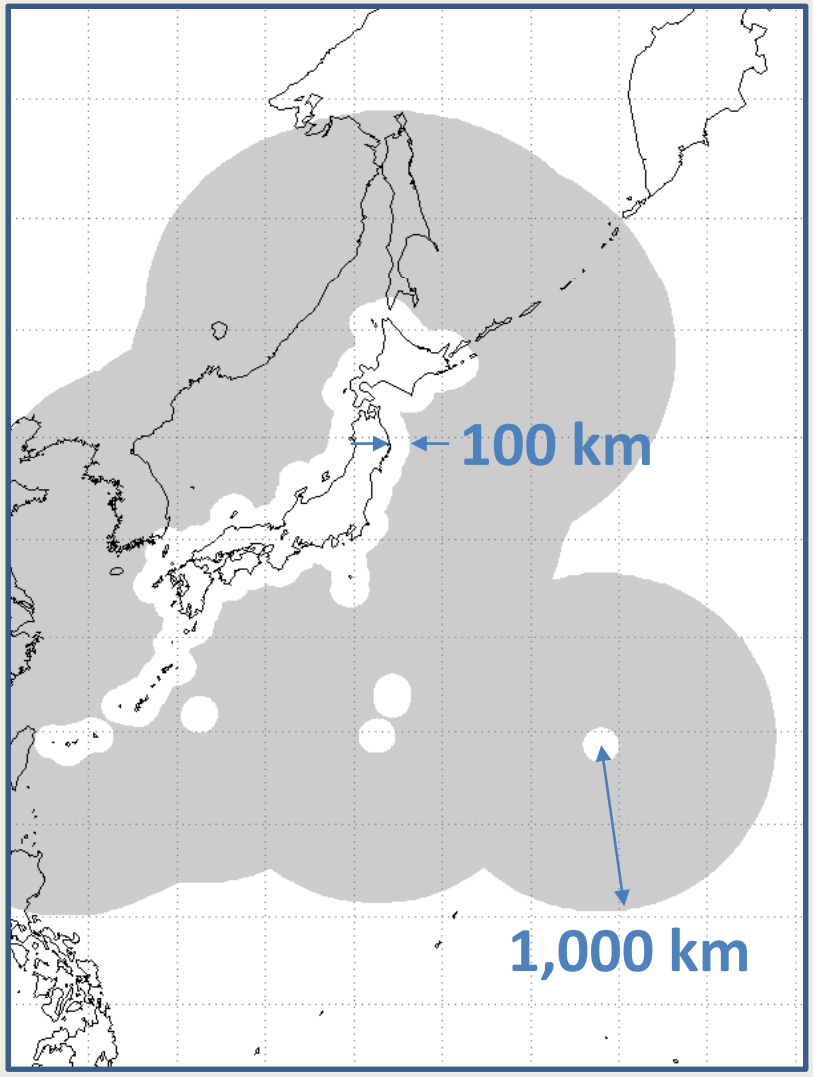


(24 hr Kinematic ●: Fixed Solution ●: Float Solution)

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	

λ_1=19cm, λ_2=24cm, λ_{WL}=86cm, λ_{NL}=11cm, $\gamma=f_1^2/f_2^2$, $C_1=\gamma/(\gamma-1)$, $C_2=-1/(\gamma-1)$

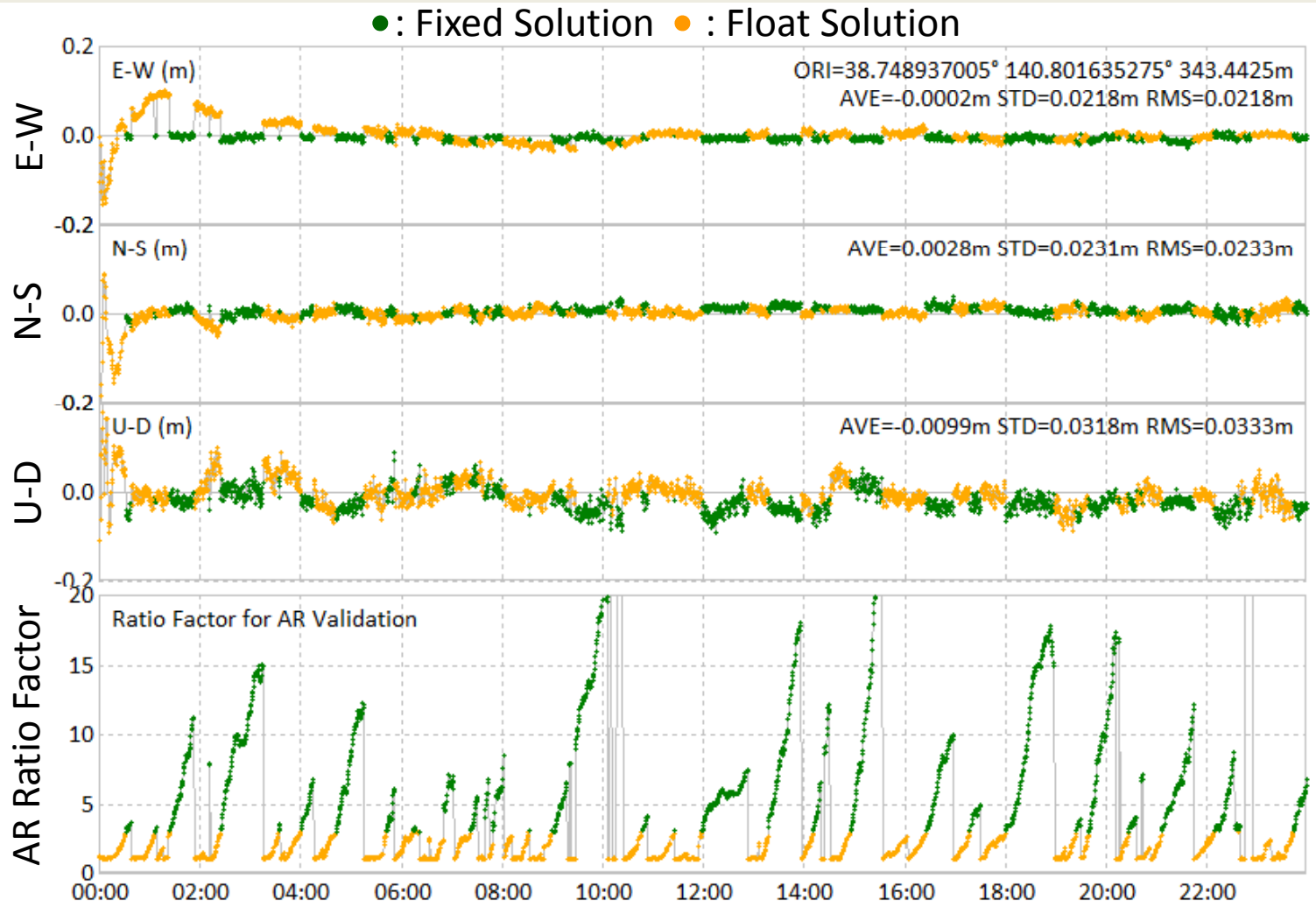
AR Strategy for Long-Baseline RTK

- 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



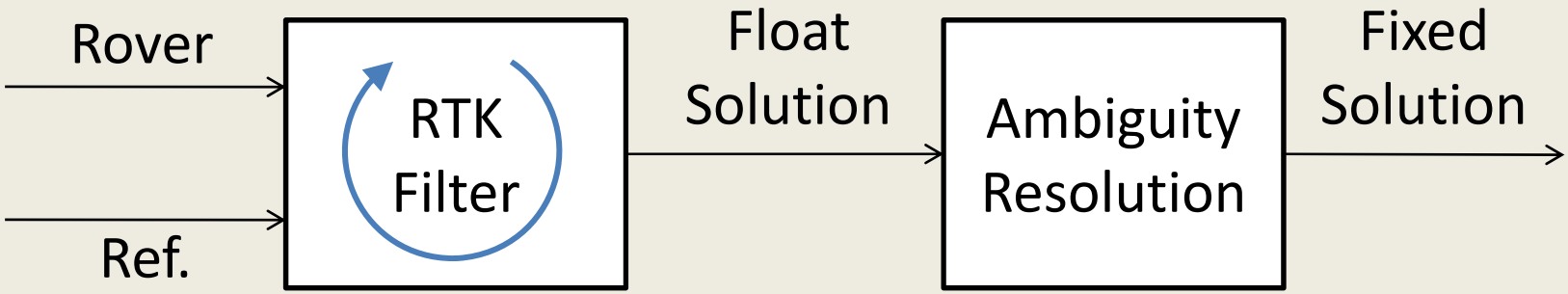
BL=300.0 km STD=2.2,2.3,3.2cm, Fix Ratio=46.4%

Partial Fixing of Ambiguities

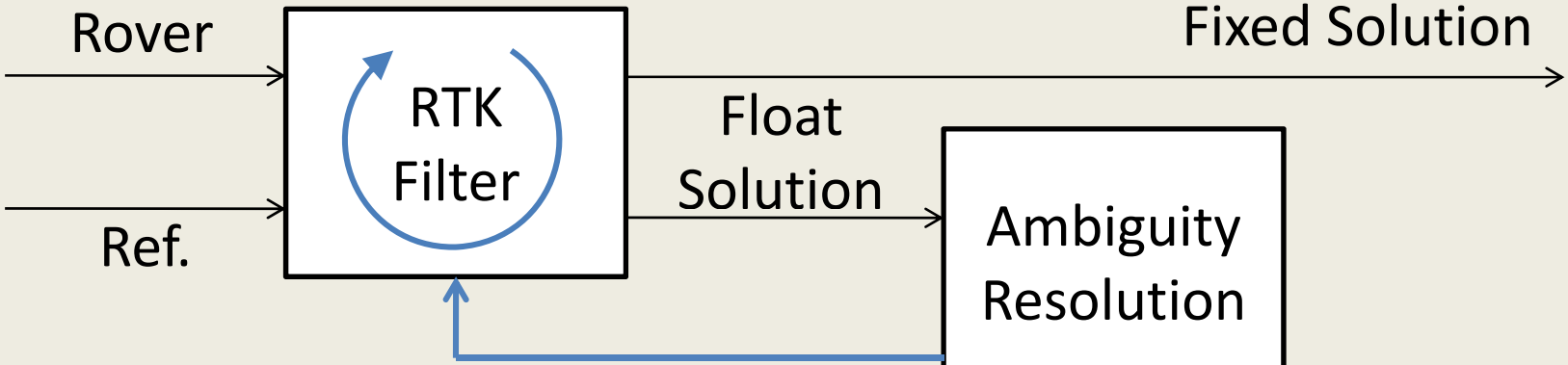
- Search Type AR Strategy under ILS Condition
  - All of ambiguities should be fixed at the same time
  - Rising satellites often disturb ambiguity fixing
- Not All Ambiguities must be Fixed
  - Trade-off between accuracy vs. fixing ratio
- Some Criteria to Determine Fixed or Float
  - Variance of estimated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

Feedback Fixed Ambiguity to Filter

Open Loop AR

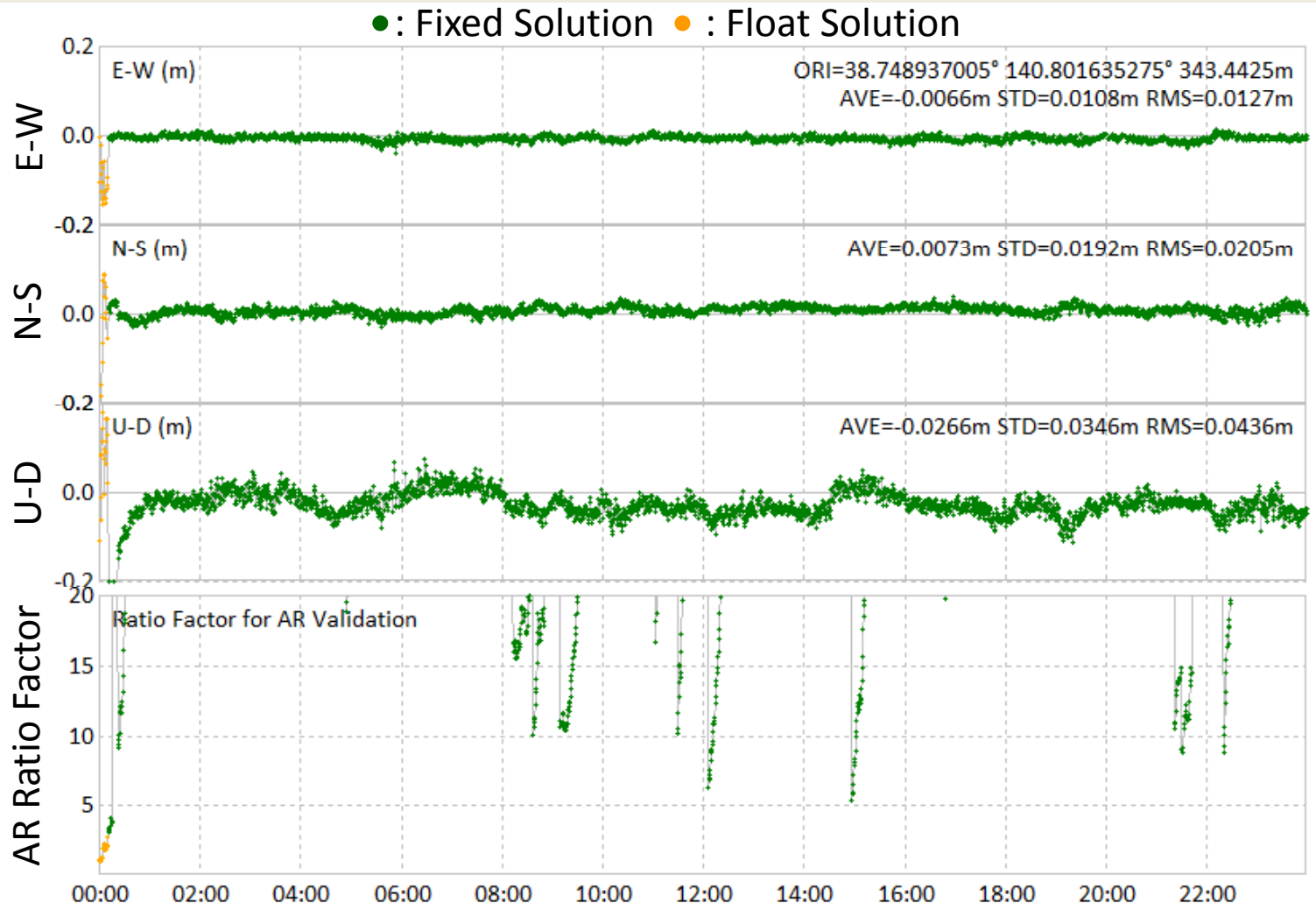


Fix and Hold Mode



Integer Constraint for Fixed Ambiguities

Performance Improvement

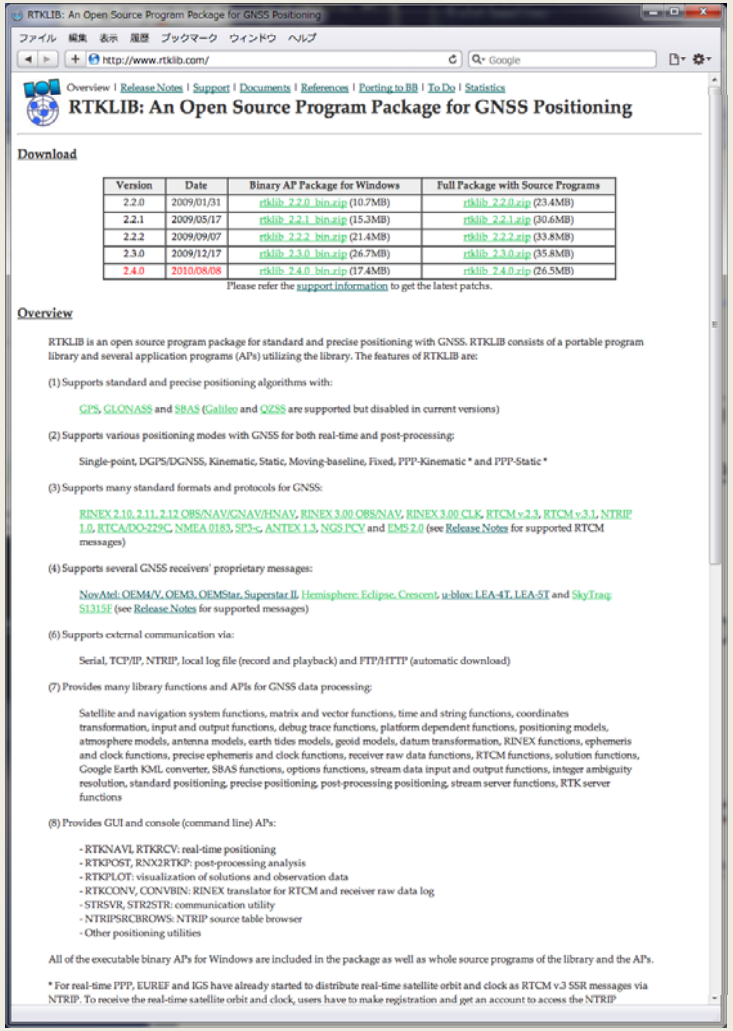


BL=300.0 km STD=1.1,1.9,3.5cm, Fix Ratio=99.3%

Implementation

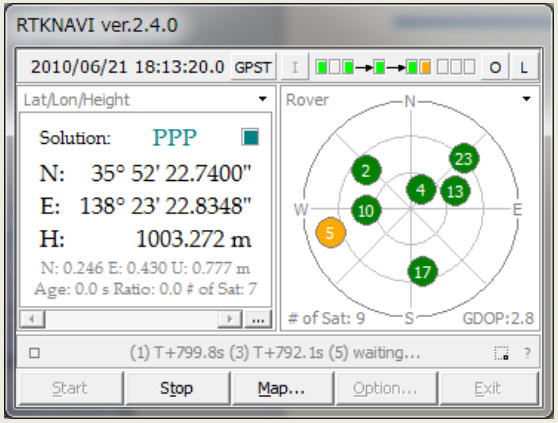
RTKLIB v.2.4.1b

- 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

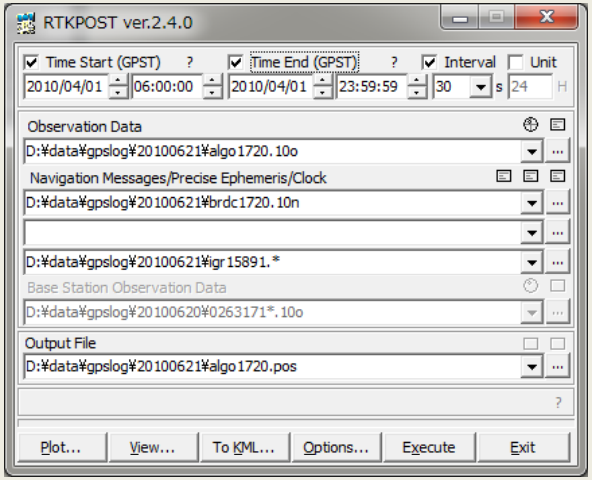


http://www.rtklib.com

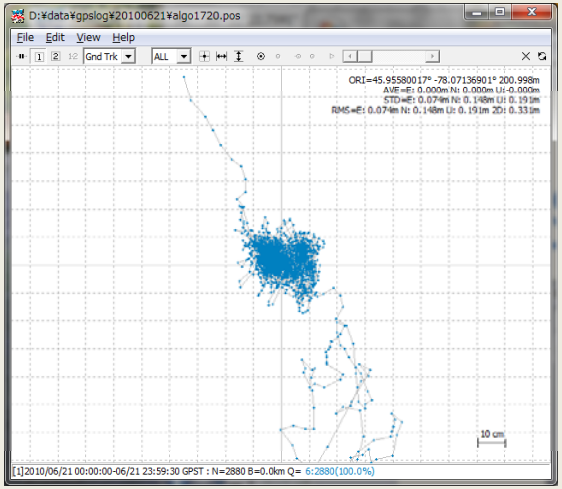
RTKLIB APs on Windows



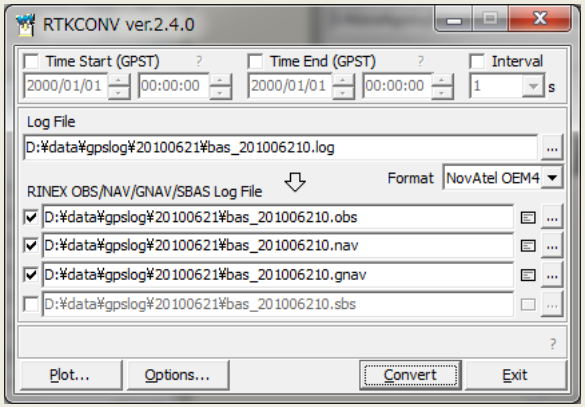
RTKNAVI: Real-time AP



RTKPOST: Post-Processing



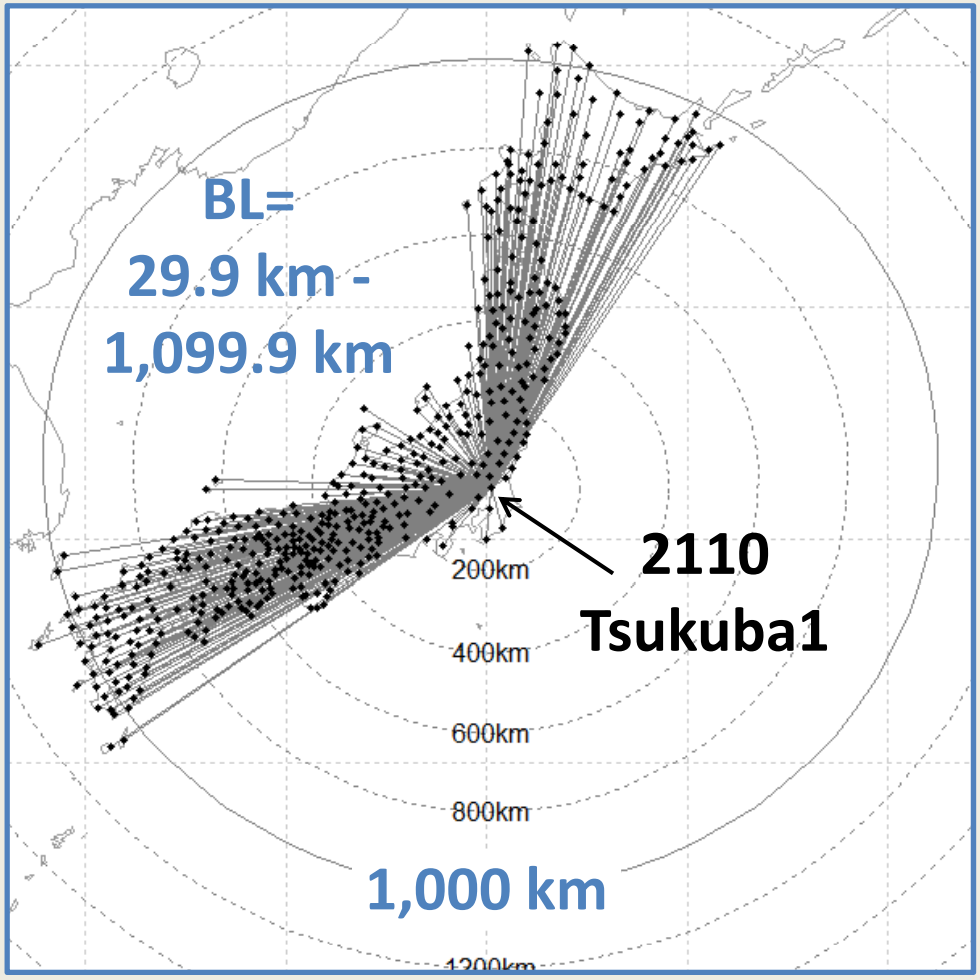
RTKPLOT: Plotting solutions



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

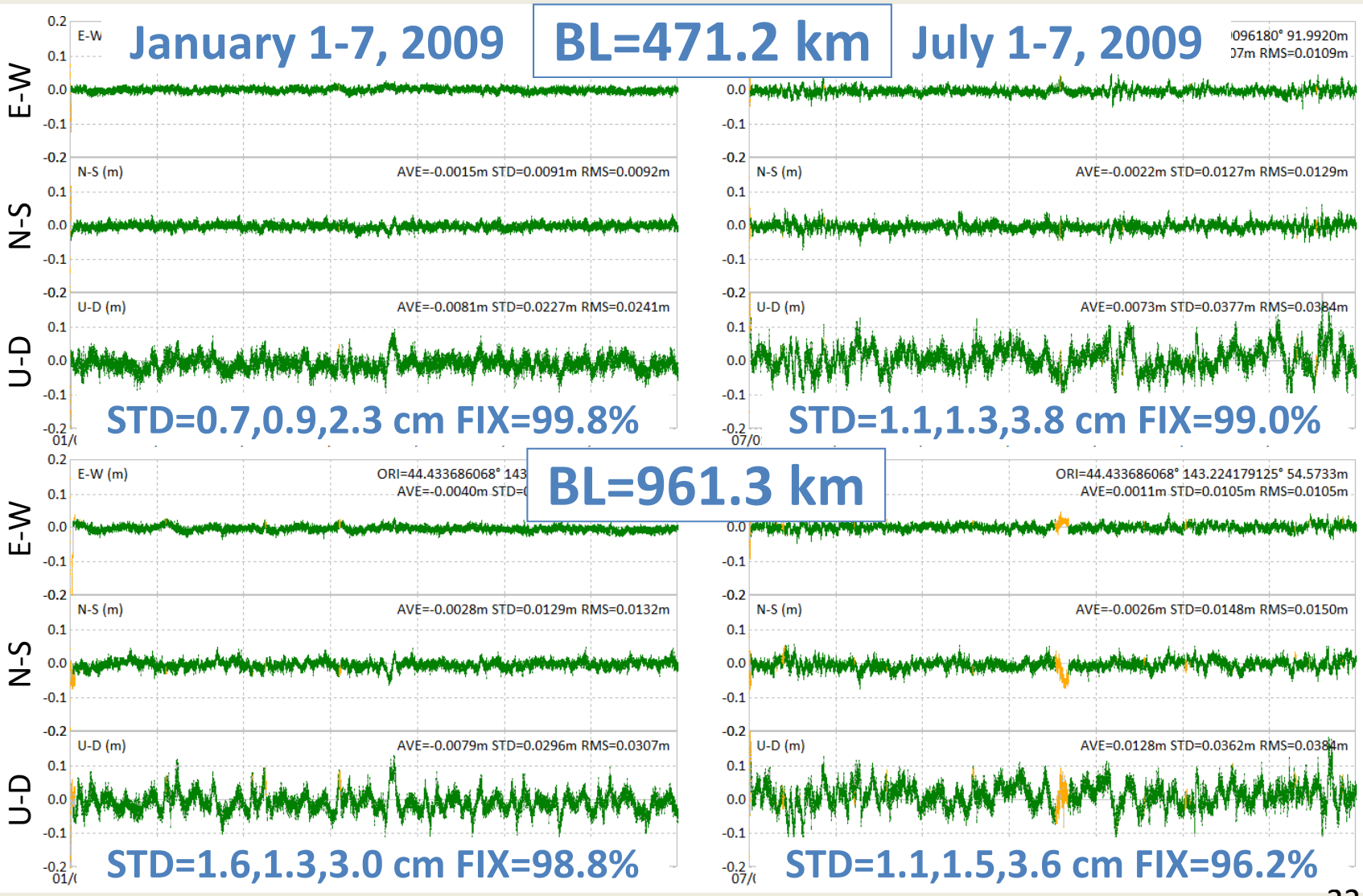
Ephemeris:

IGU (predicted)

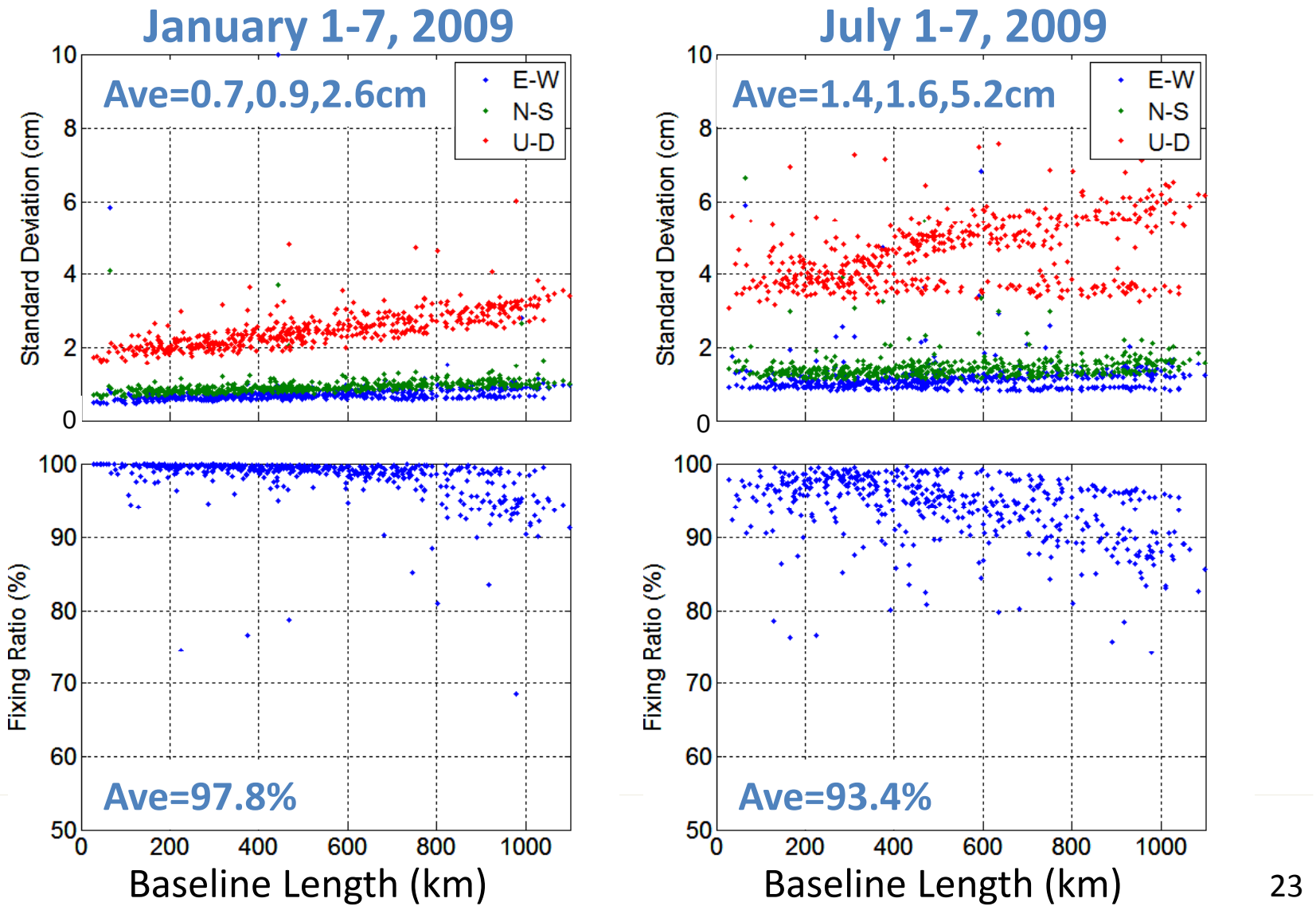
Analysis S/W:

RTKPOST v2.4.1b

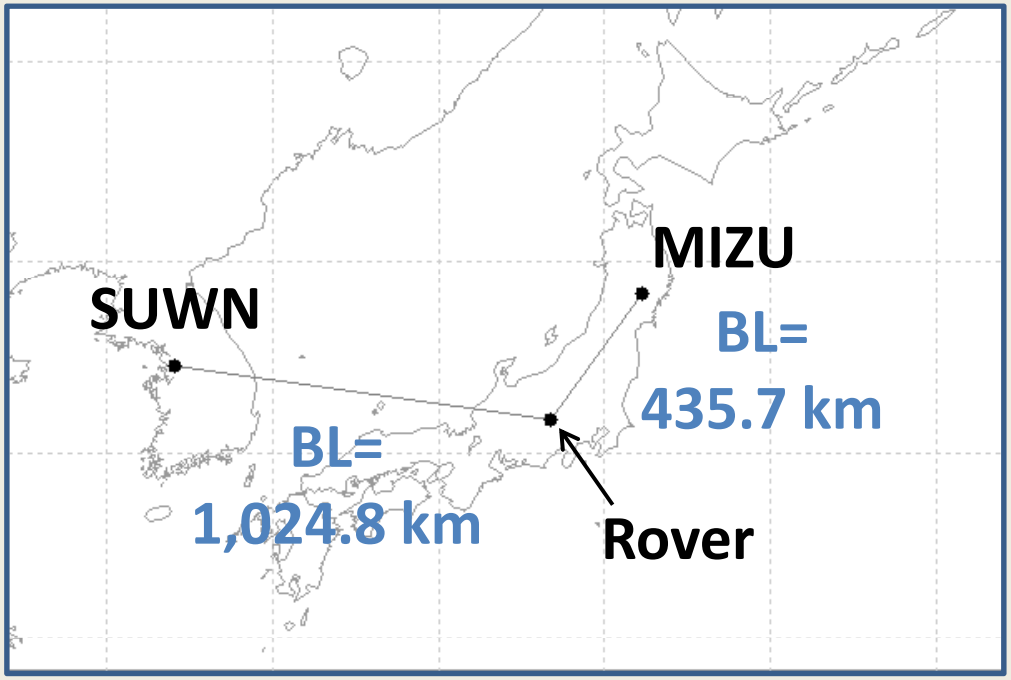
Offline Test Results



Summary of Offline Test Results



Real-Time Test



September 17-20, 2009

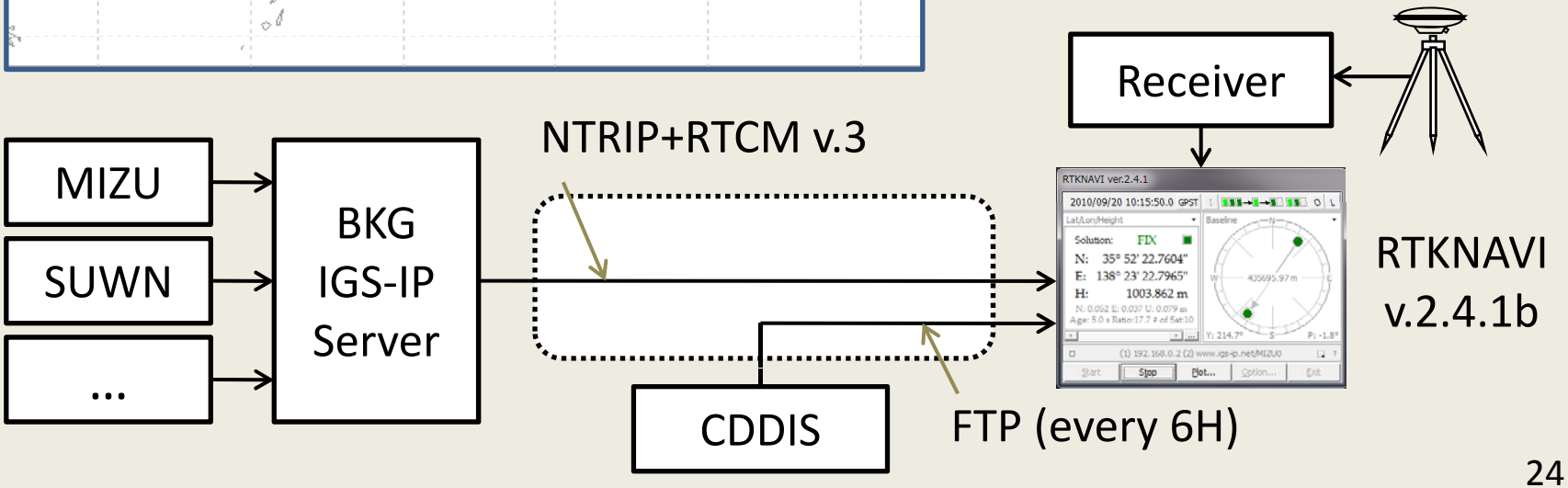
1 Hz x 72 H

Rover: NovAtel

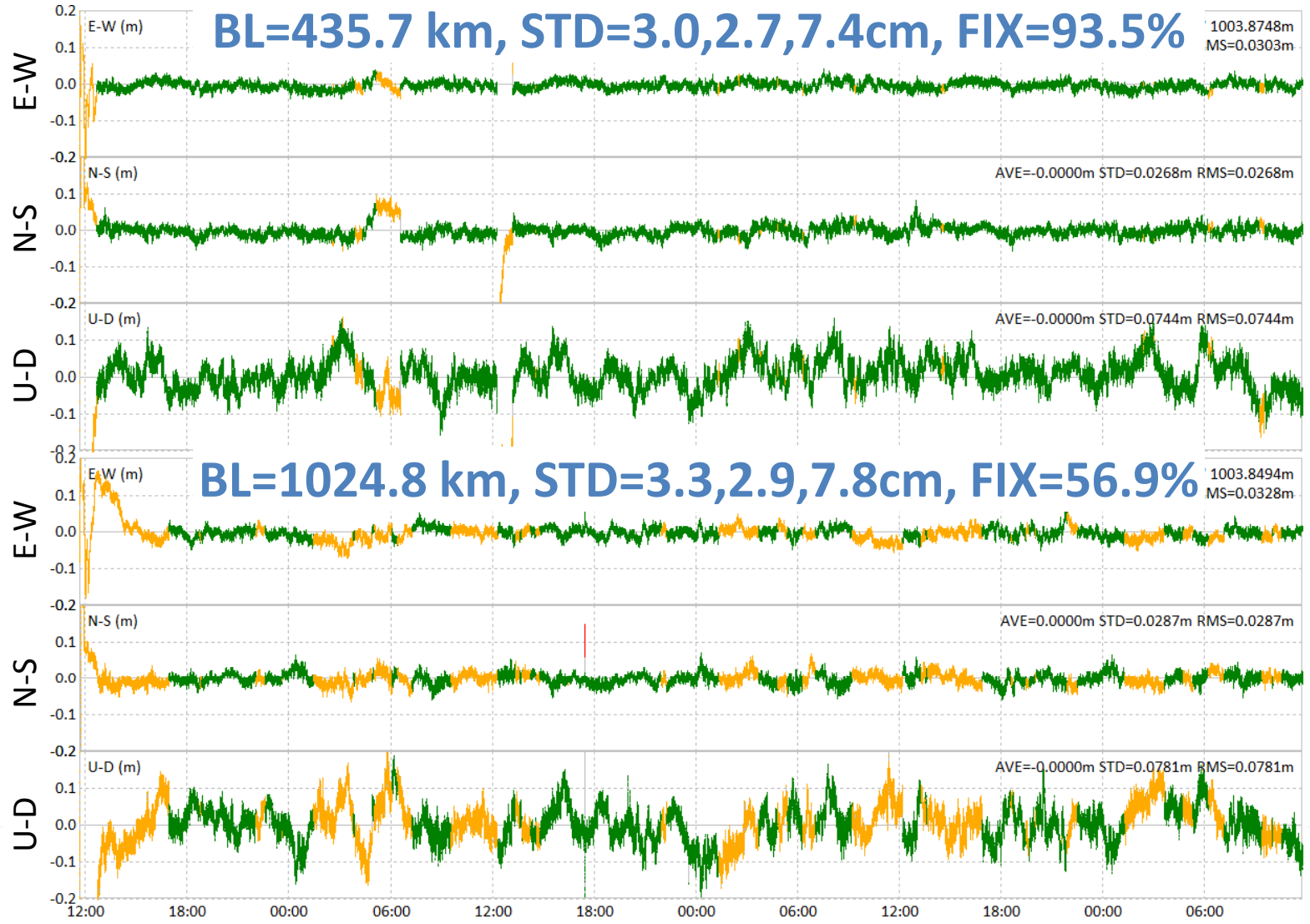
OEMV-3 + GPS-702-GG

Reference:

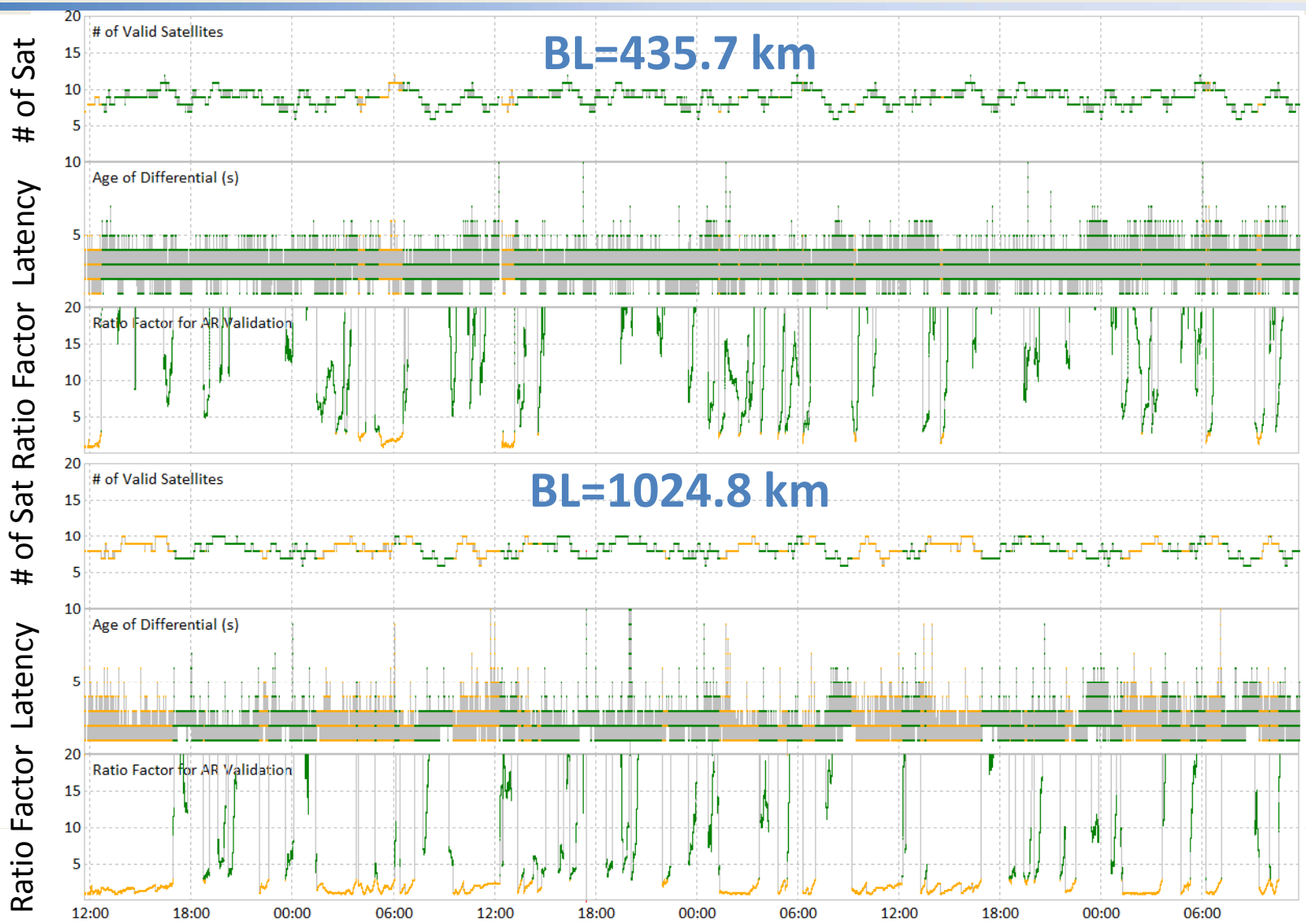
IGS MIZU and SUWN



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