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The Current Status of MADOCA-PPP Development



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- **Improvement of Orbits and Clocks**
- **FCB Products for PPP-AR**
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Status of MADOCA Development

MADOCA

Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

- **For PPP service via QZSS LEX and L6b***
 - Many PPP applications over global area
 - Providing sub-dm to cm-class accuracy
- **Precise orbit/clock for multiple constellation GNSS**
 - Key-technology for future precise positioning
 - Over-100 satellites expected in near future
 - GPS, GLONASS, QZSS and Galileo already supported, BeiDou planned

* under study

PPP Applications



Automated Farming



Natural Hazard Mitigation



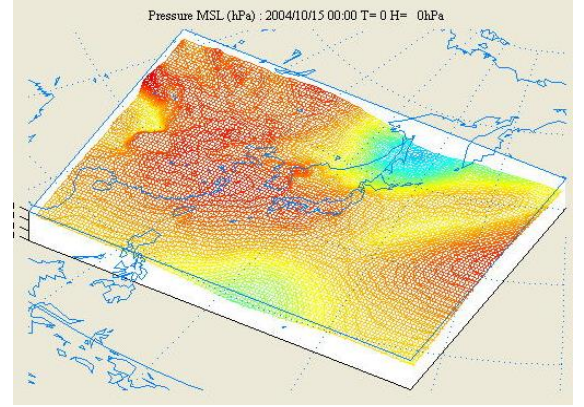
Mining Machine Control



Offshore Construction

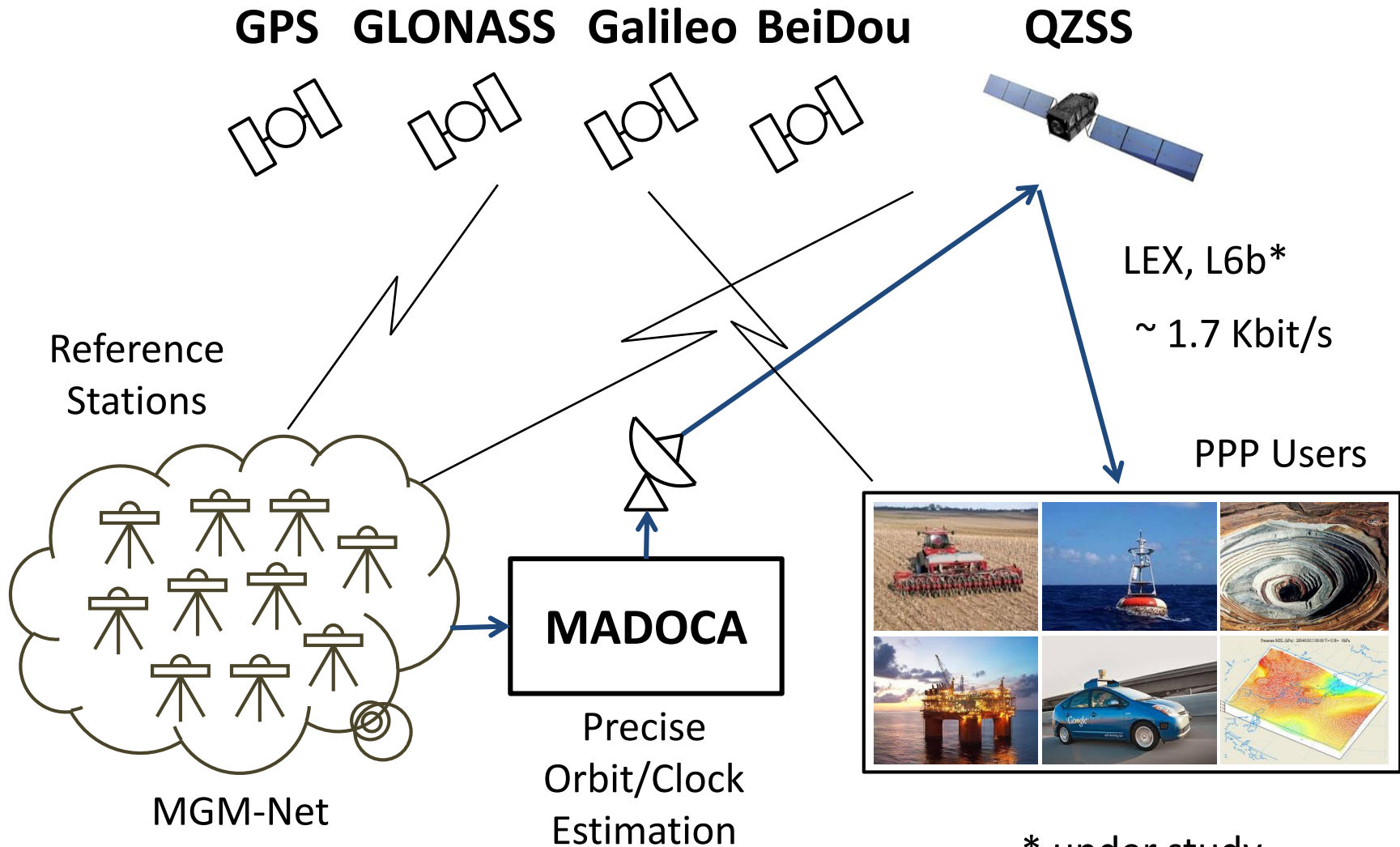


Autonomous Driving



Weather Forecast

MADOCA-PPP via QZSS

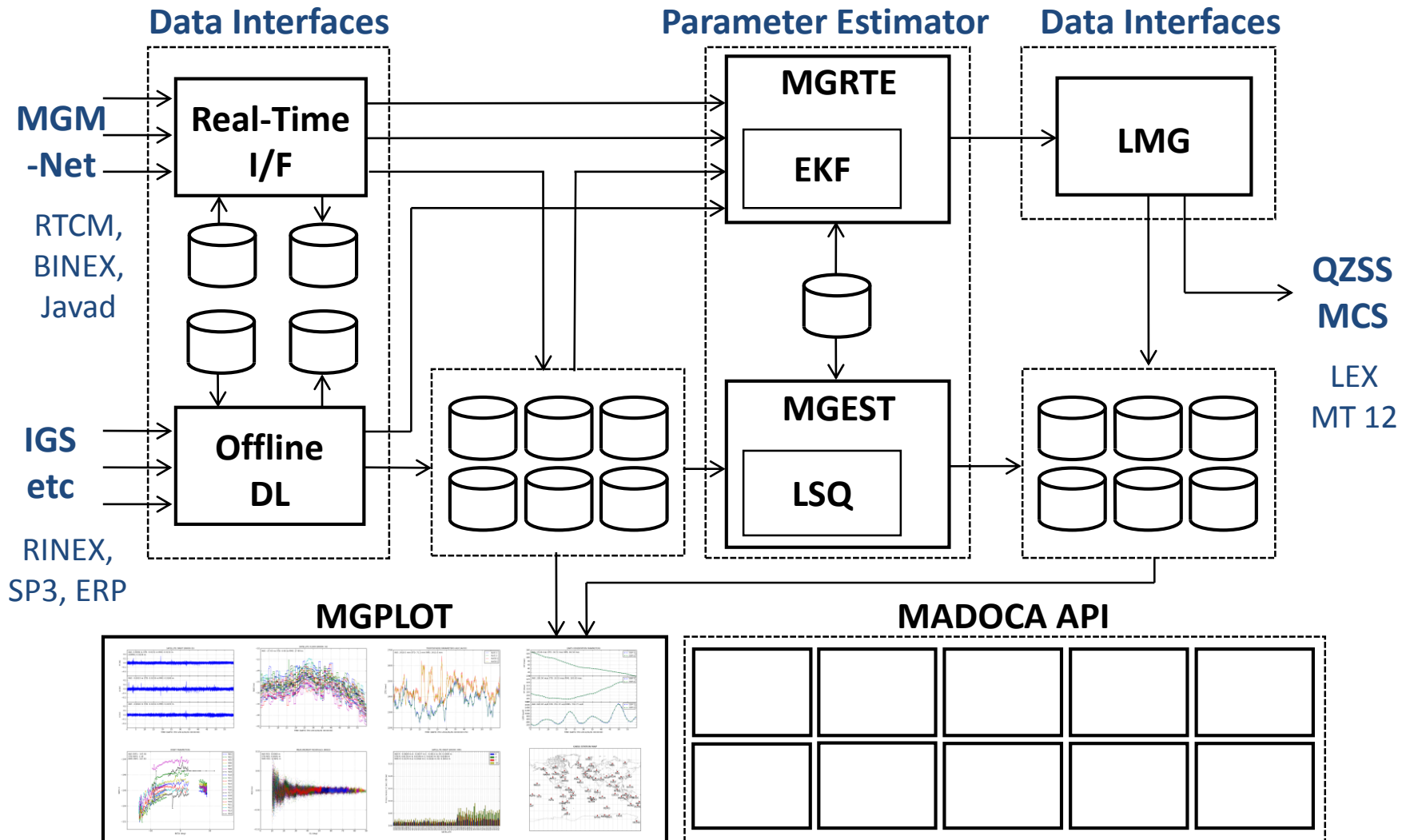


* under study

R&D Activities for MADOCA

- **June 2011 - March 2013 (1st phase)**
 - Design and implementation of S/W from scratch
 - Verification by post-processing and simulation
- **April 2013 -**
 - Broadcasting MT12 via QZSS-1 "Michibiki" LEX channel
 - Support GPS, QZSS and GLONASS (Nov 2013 -)
- **Feb 2014 - March 2016 (2nd phase)**
 - Continuous improvement of accuracy, stability and reliability on orbits and clocks
 - Support BeiDou
 - New features added: FCB and local-iono/trop products
 - Multiple-sensor integration to PPP for severe environment

Architecture (1st Phase)



MADOCA LEX Format

- Definition has been added in recent IS-QZSS as LEX MT12 (IS-QZSS 1.6 draft, 5.7.2.2.5)
- Formats based on RTCM 3 SSR orbit, high-rate clock, DCB and URA with minor modification

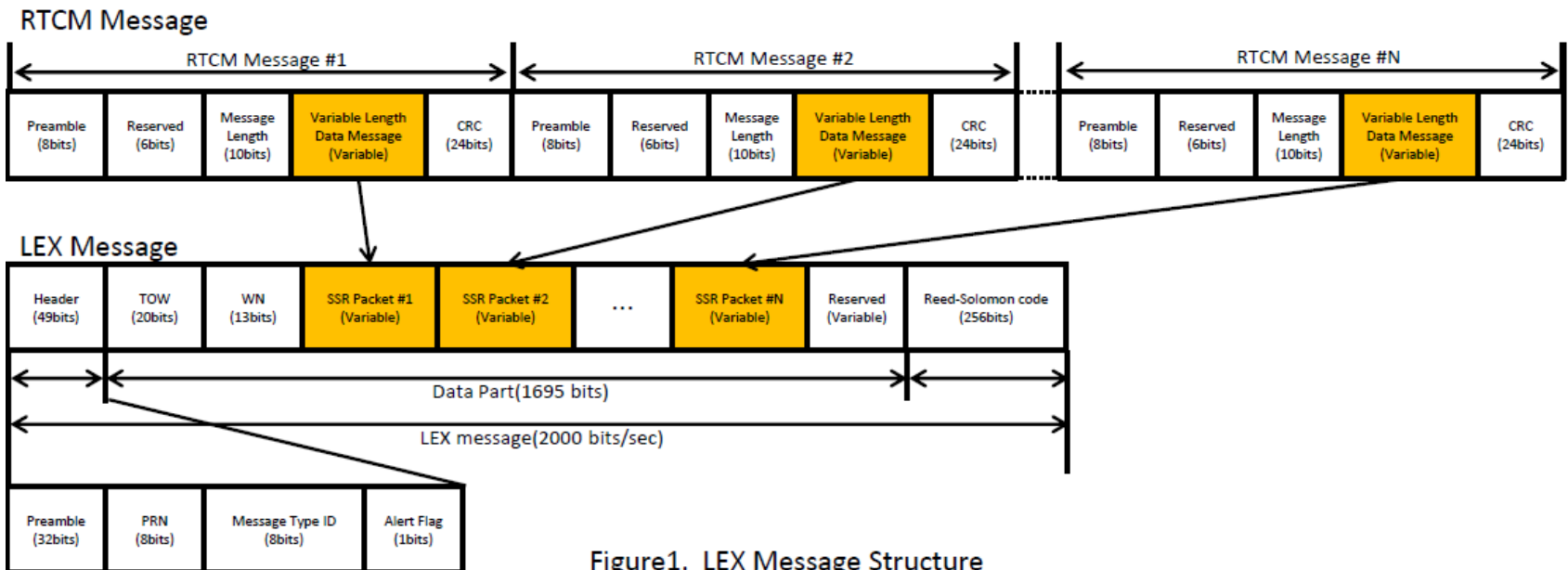


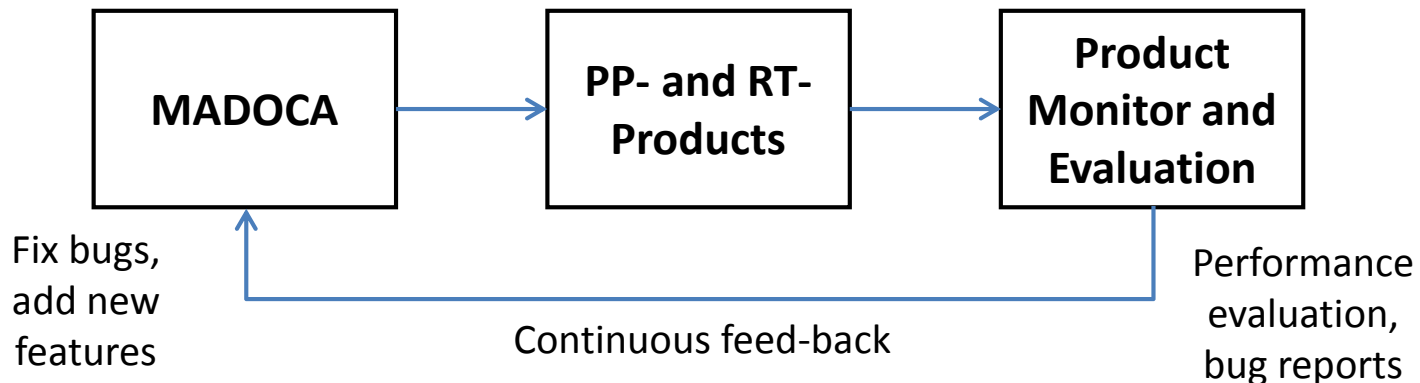
Figure1. LEX Message Structure

Improvement of Orbit and Clock

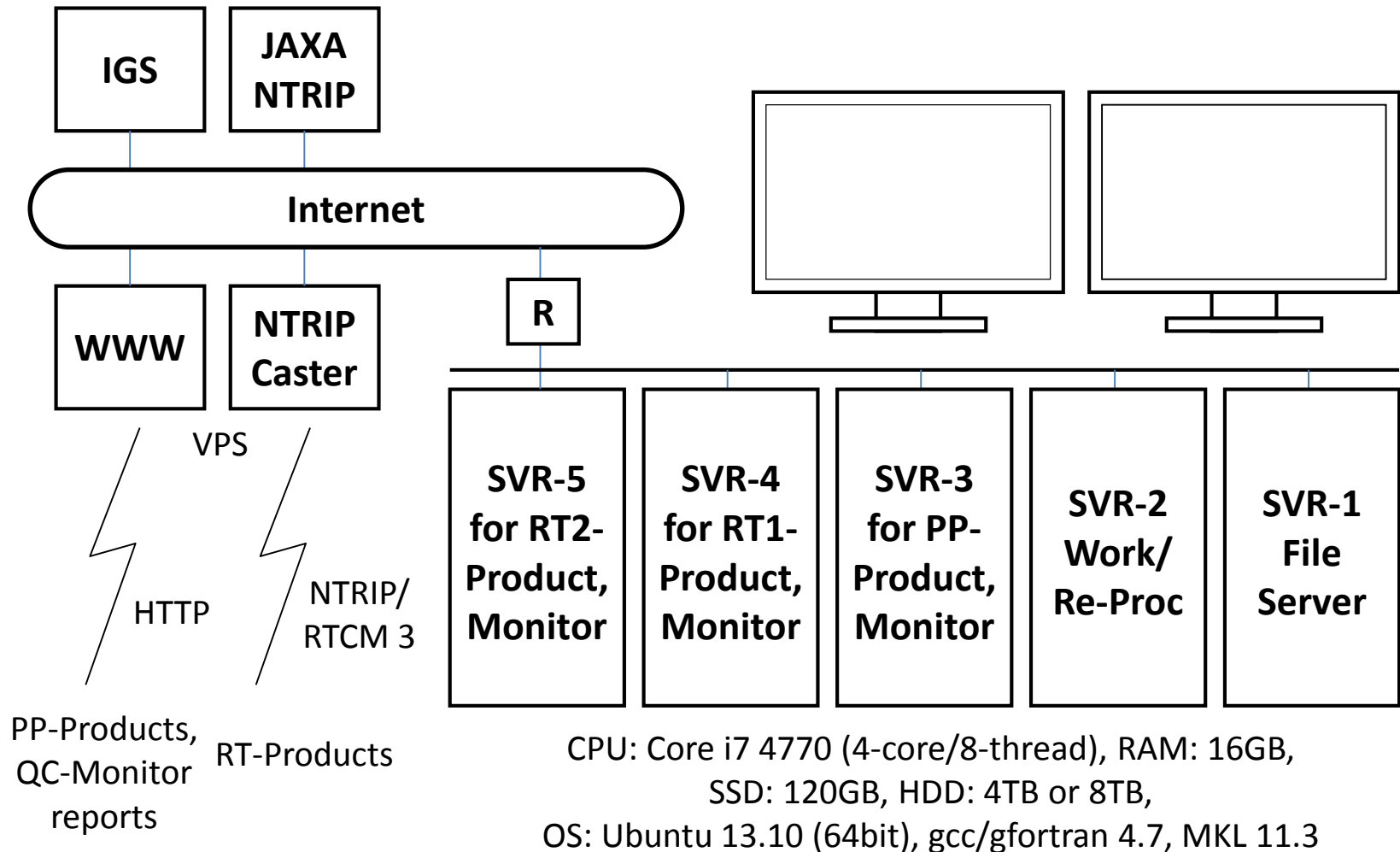
MADOCA Evaluation System (1)

- **Objectives**

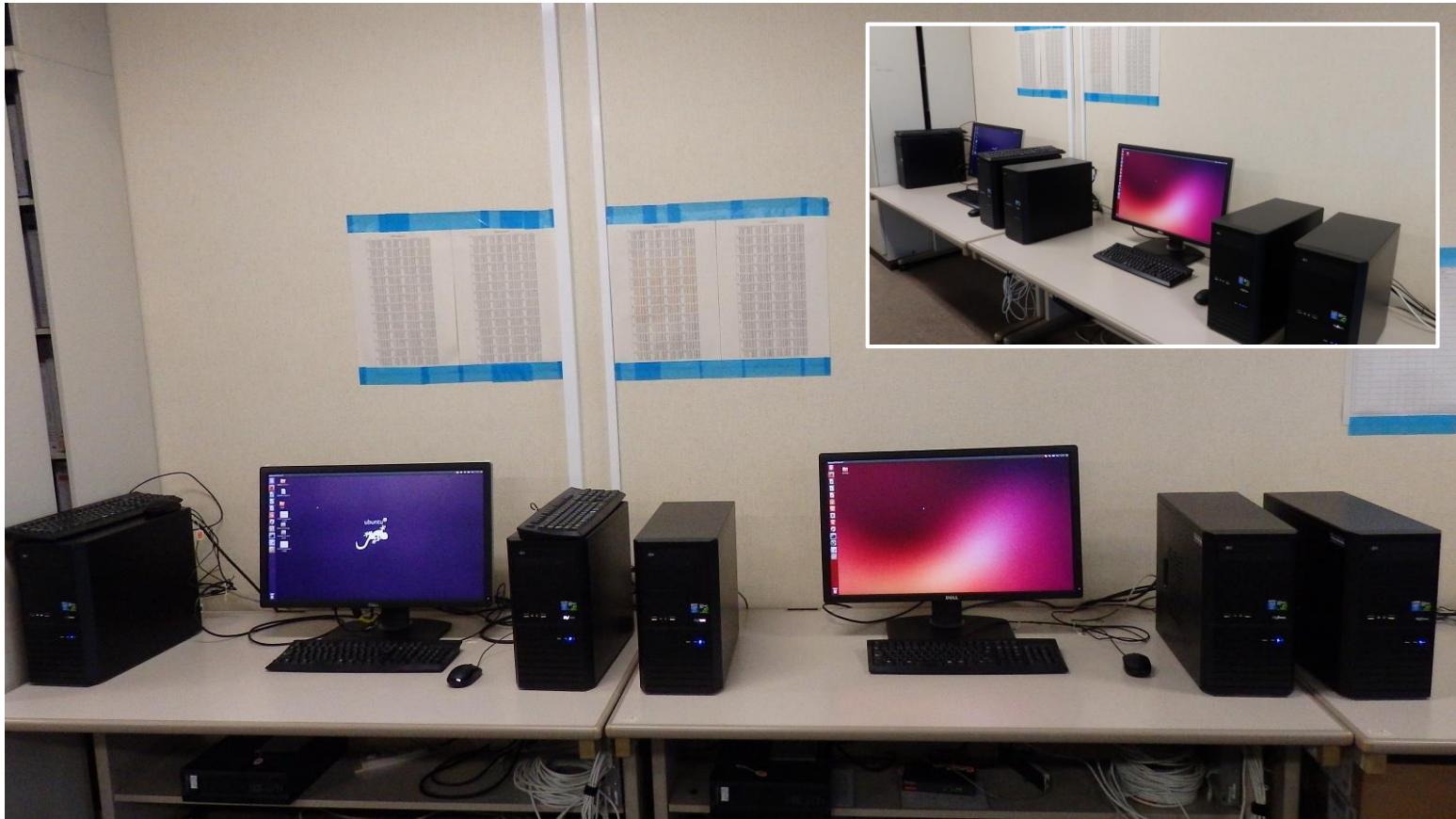
- Provide environment for long-term system test and track existing and remaining issues
- Improve product quality (accuracy, stability and reliability) by tuning various optional parameters
- Verify newly implemented algorithms and models
- Accumulate operational experience for practical use



MADOCA Evaluation System (2)



MADOCA Evaluation System (3)



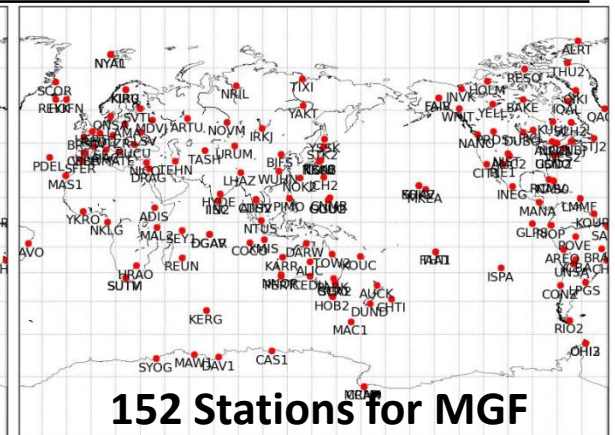
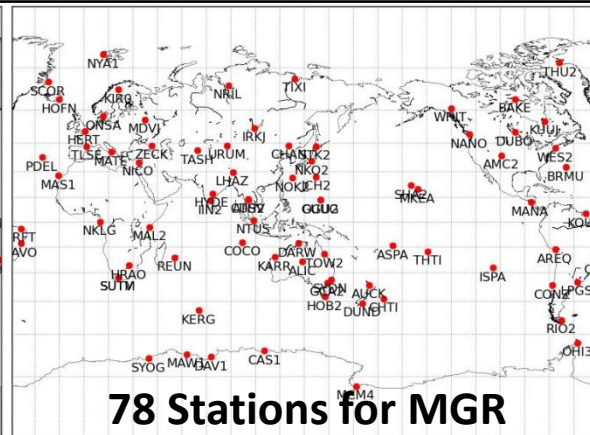
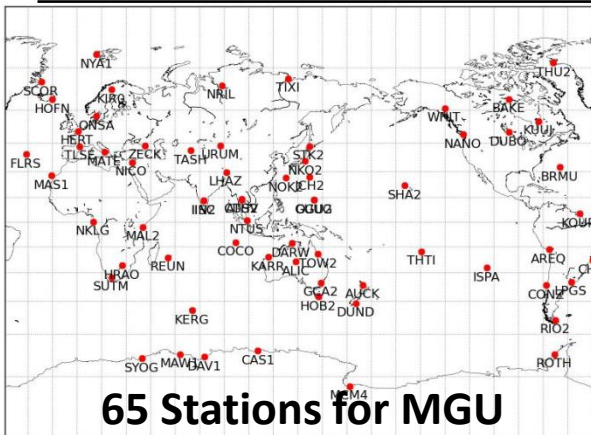
SVR-5

SVR-4 SVR-3

SVR-2 SVR-1

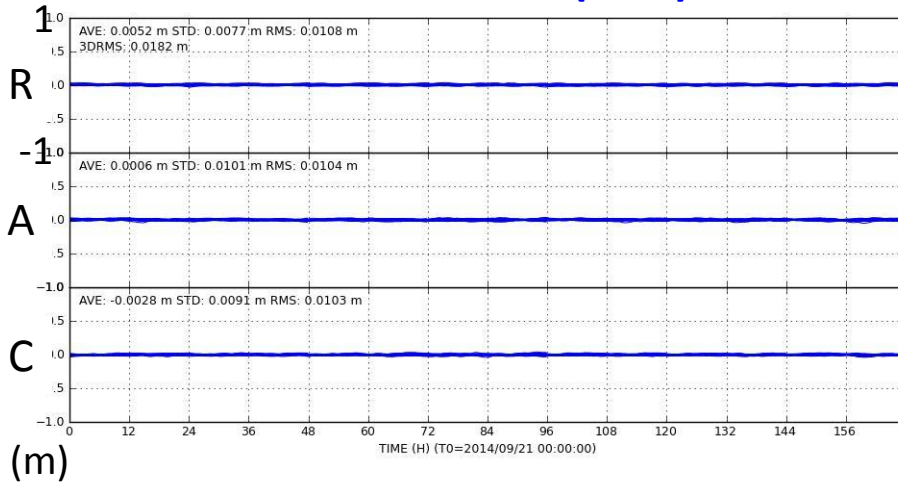
PP-Products

	MGU (Ultra-rapid)	MGR (Rapid)	MGF (Final)
Update Interval	6H	24H	24H
Latency	1 - 31 H / 0 H	10 - 34 H	37 - 67 H
Est/Predict Arc	24H / 24H	24 H / -	3H + 24H + 3H / -
Satellites	GPS, GLONASS, QZSS , (Galileo not yet included)		
Products	Orbit/Clock (SP3), Clock (RNX CLK), EOP, AMB, FCB		
Sample Interval	300 s (SP3), 30 s (RNX CLK, FCB), 1 day (EOP)		
Processing Time	~ 20 min	~ 30 min	~ 185 min

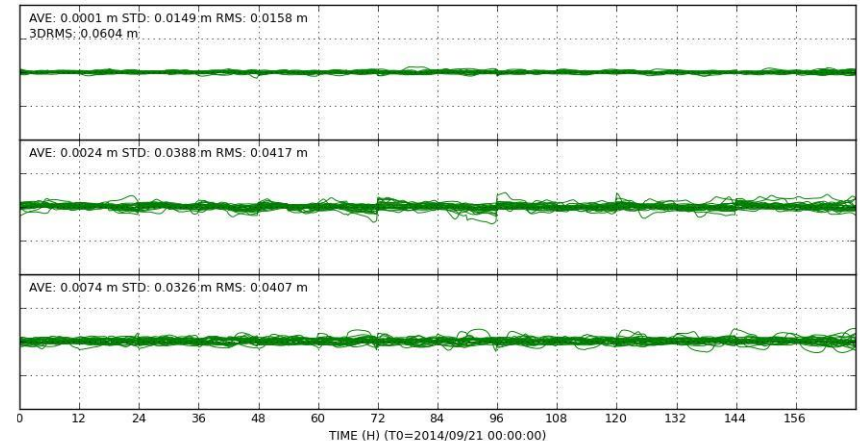


Accuracy of PP-Orbits

MGF wrt IGR (GPS)



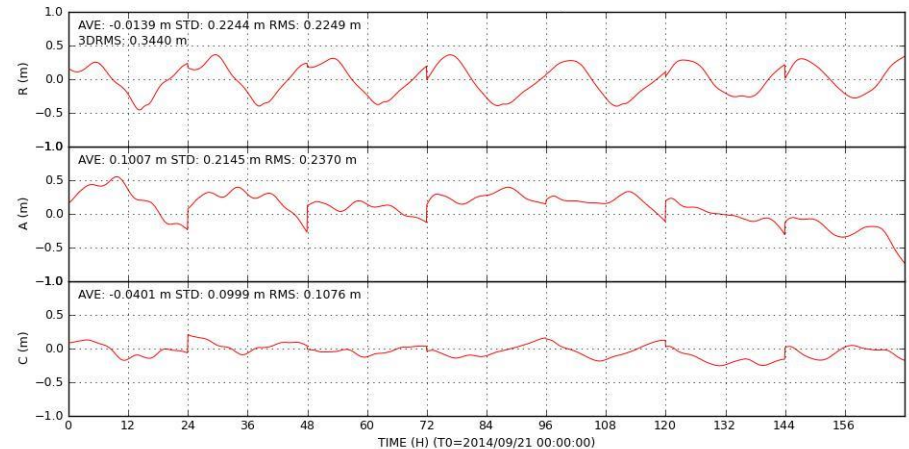
MGF wrt IGV (GLONASS)



Orbit Error

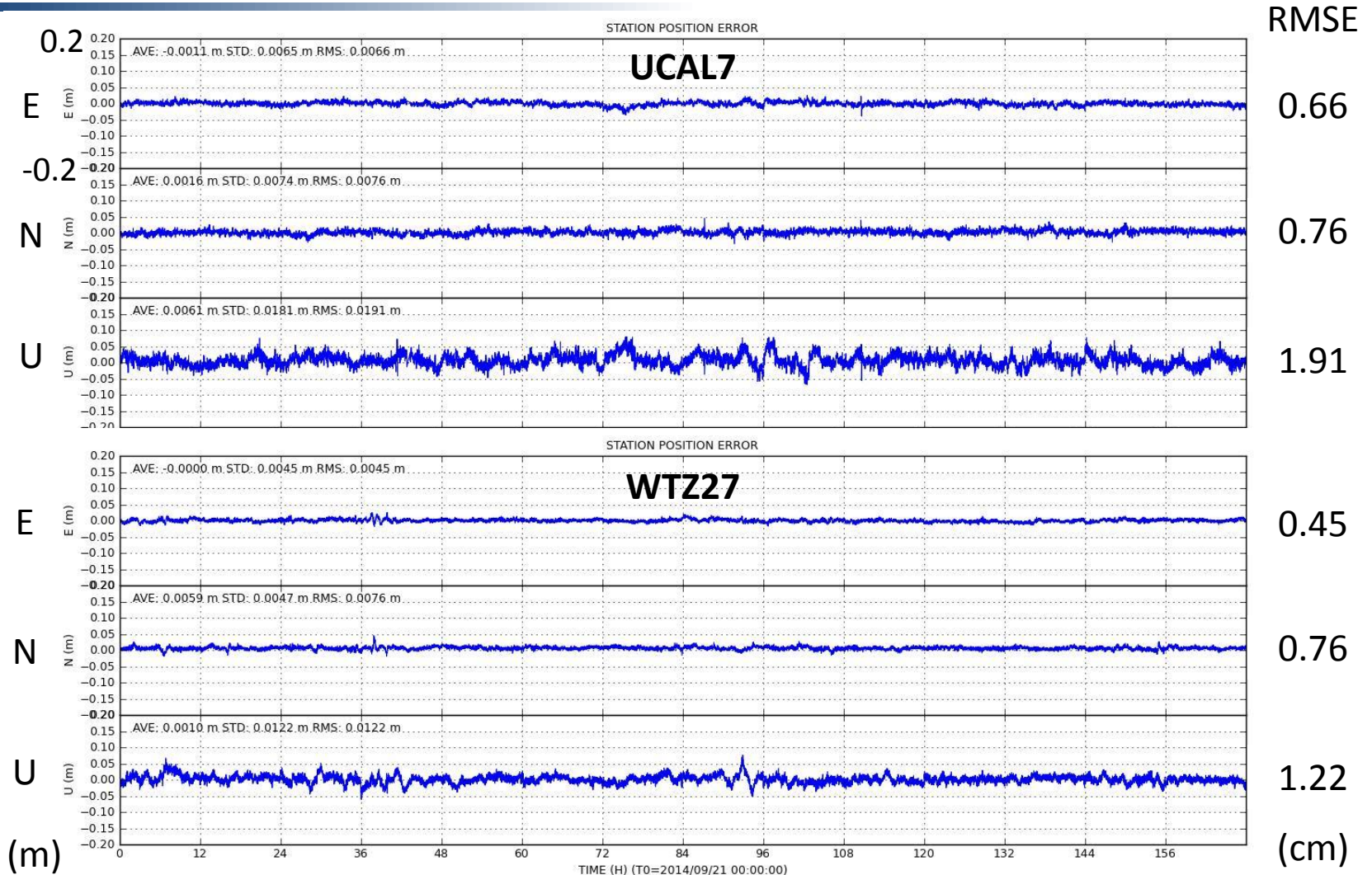
	RMS (cm)			
	R	A	C	3D
GPS	1.08	1.04	1.03	1.82
GLO	1.58	4.17	4.07	6.04
QZSS	22.49	23.70	10.76	34.40

MGF wrt QZF (QZSS)



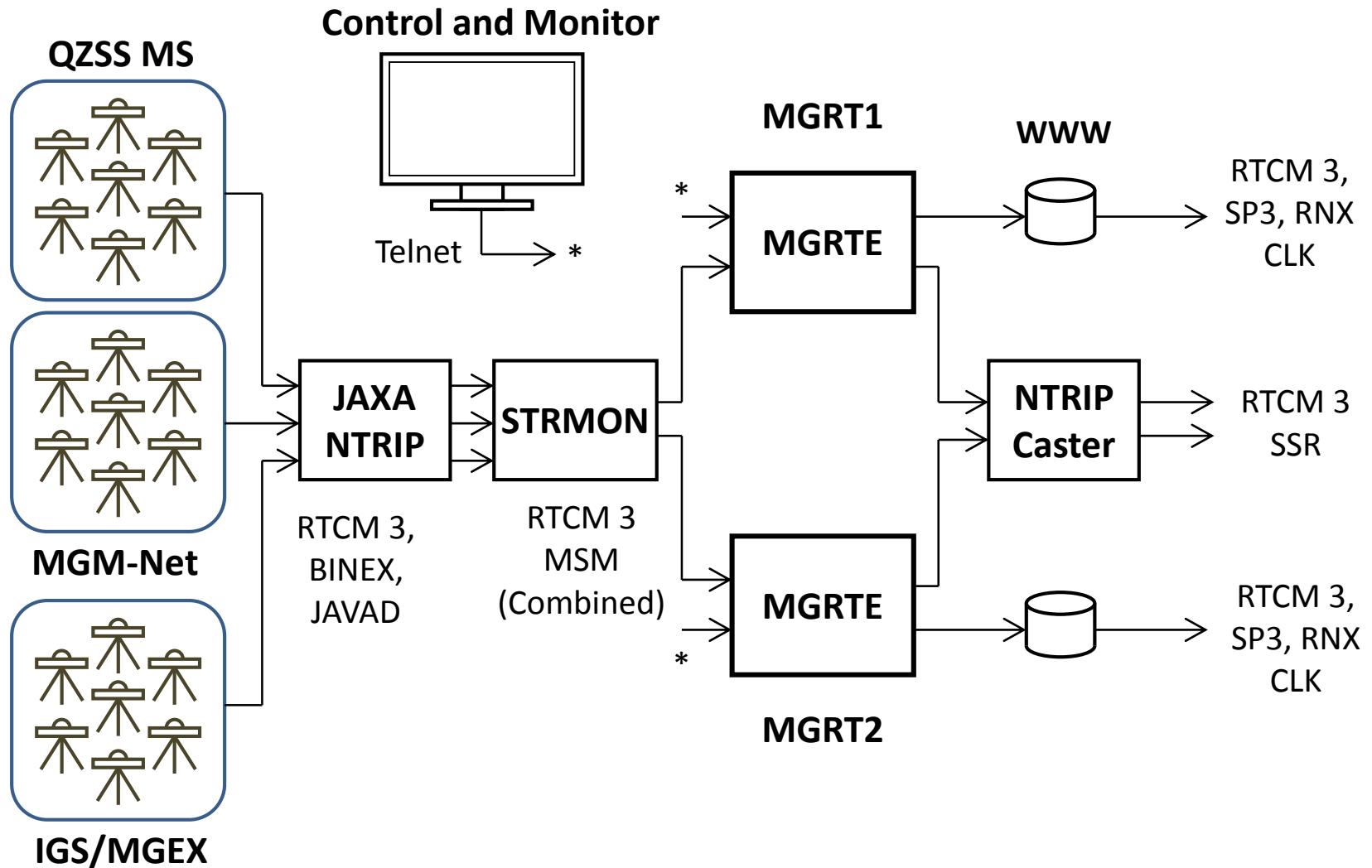
GPS Week 1811 (2014/9/21 - 27)

PPP Accuracy with PP-Products



Kinematic PPP with **MGF**, GPS Week 1811 (2014/9/21 - 27)

RT-Product (1)



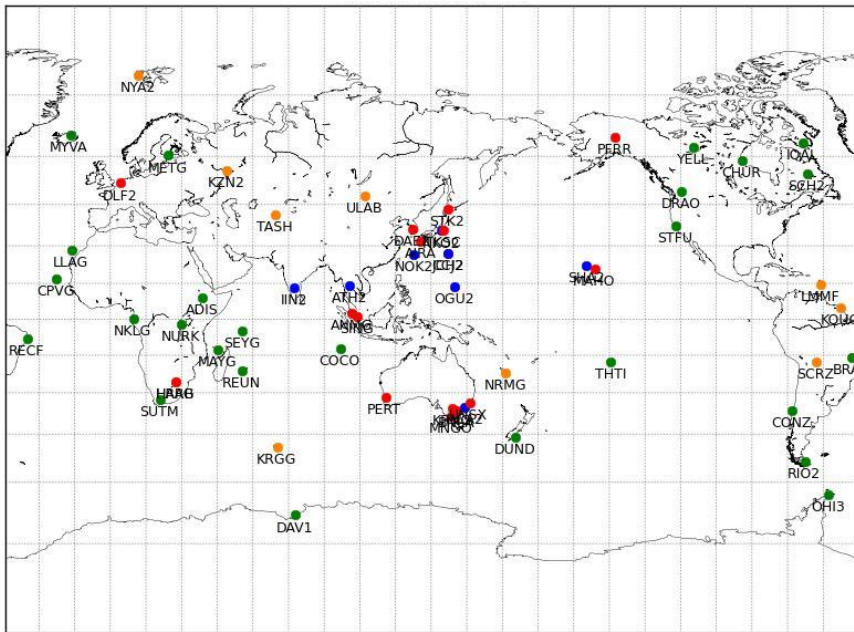
RT-Product (2)

RT-Products Messages

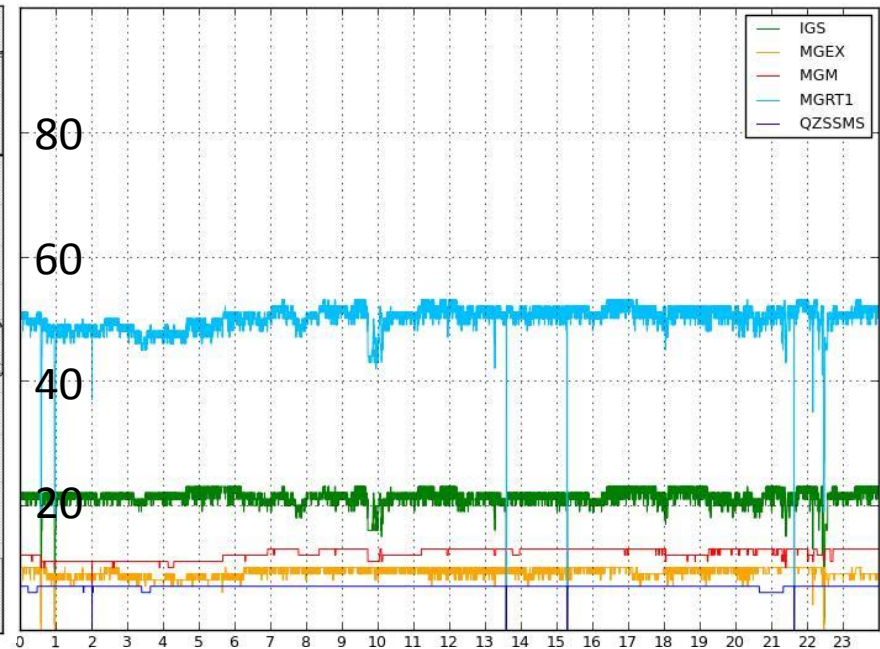
Product	Mount Point	Contents	RTCM MT				Update Interval	Latency
			GPS	GLO	QZSS	GAL		
MGRT1	MADOCA _SSR1	Orbit	1057	1063	1246	-	30 s	~ 5.3 s
		Clock	1058	1064	1247	-		
		Code Bias	-	-	-	-		
		URA	1061	1067	1250	-		
		HR-Clock	1062	1068	1251	-		
MGRT2	MADOCA _SSR2	same as above by different settings						

Ref. Stations for RT-Products

Station Position



of Valid Stations (latency < 5 s)

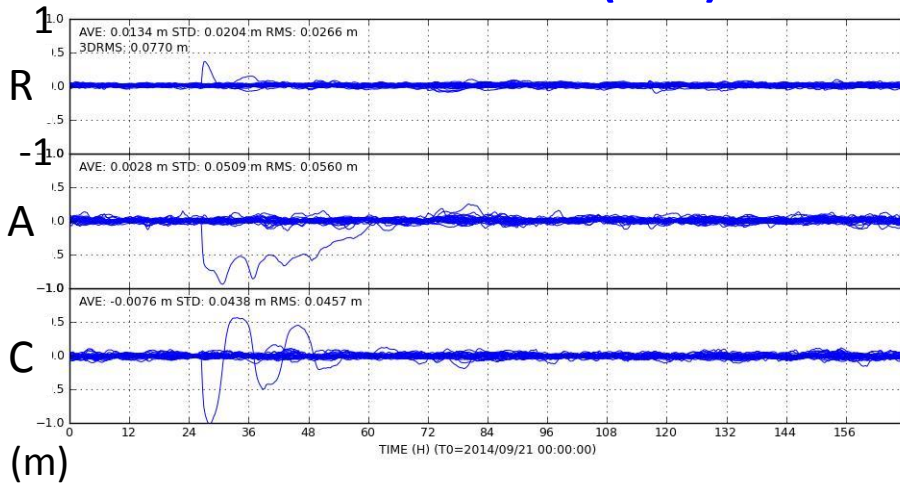


2014/10/05 00:00-24:00 GPST

- QZSS-MS
- MGM-Net
- IGS
- MGEX
- Total

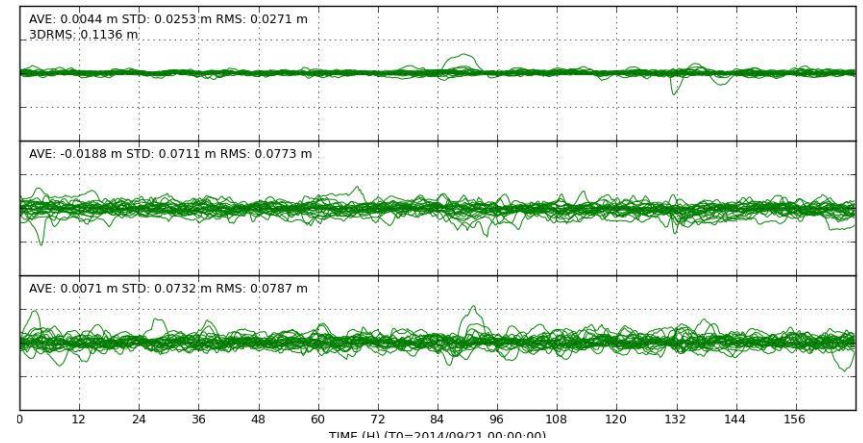
Accuracy of RT-Orbits

MGRT1 wrt IGR (GPS)

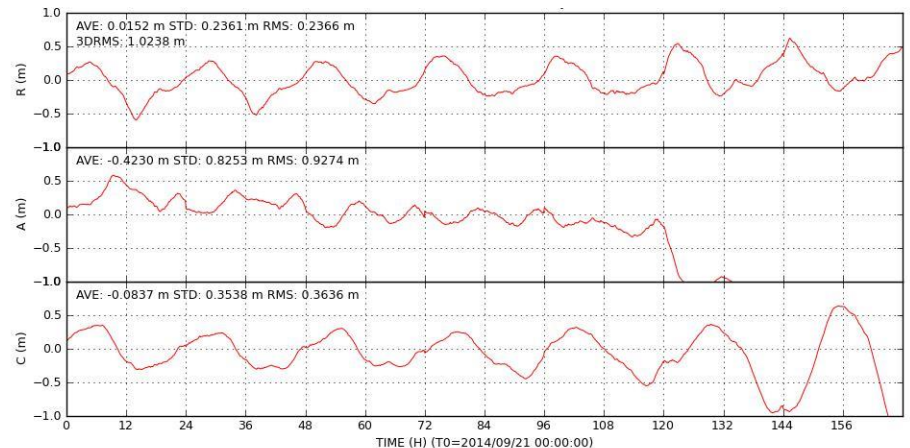


Orbit Error

MGRT1 wrt IGV (GLONASS)



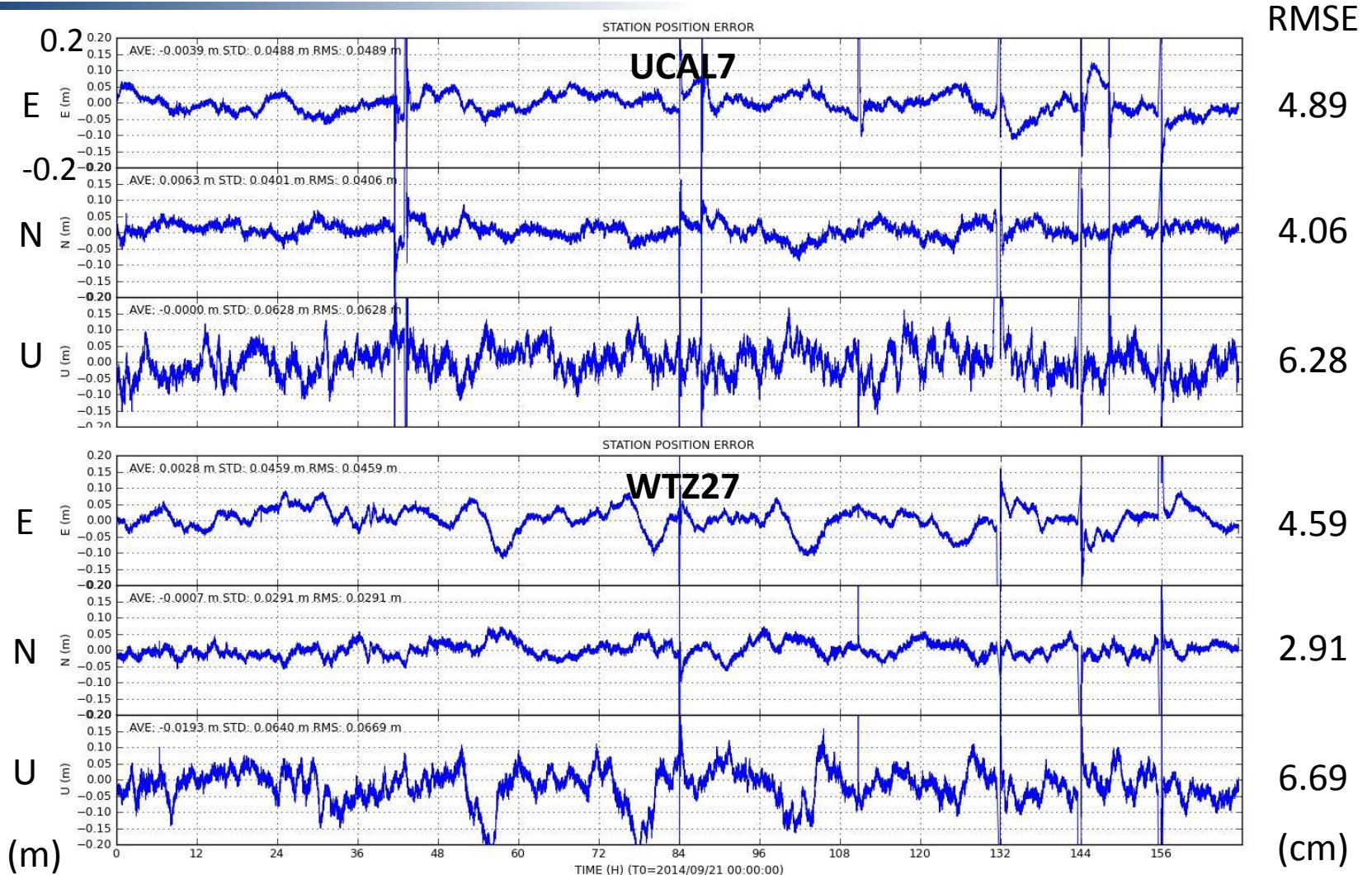
MGRT1 wrt QZF (QZSS)



	RMS (cm)			
	R	A	C	3D
GPS	2.66	5.60	4.57	7.70
GLO	2.71	7.73	7.87	11.36
QZSS	23.66	92.74	36.36	102.4

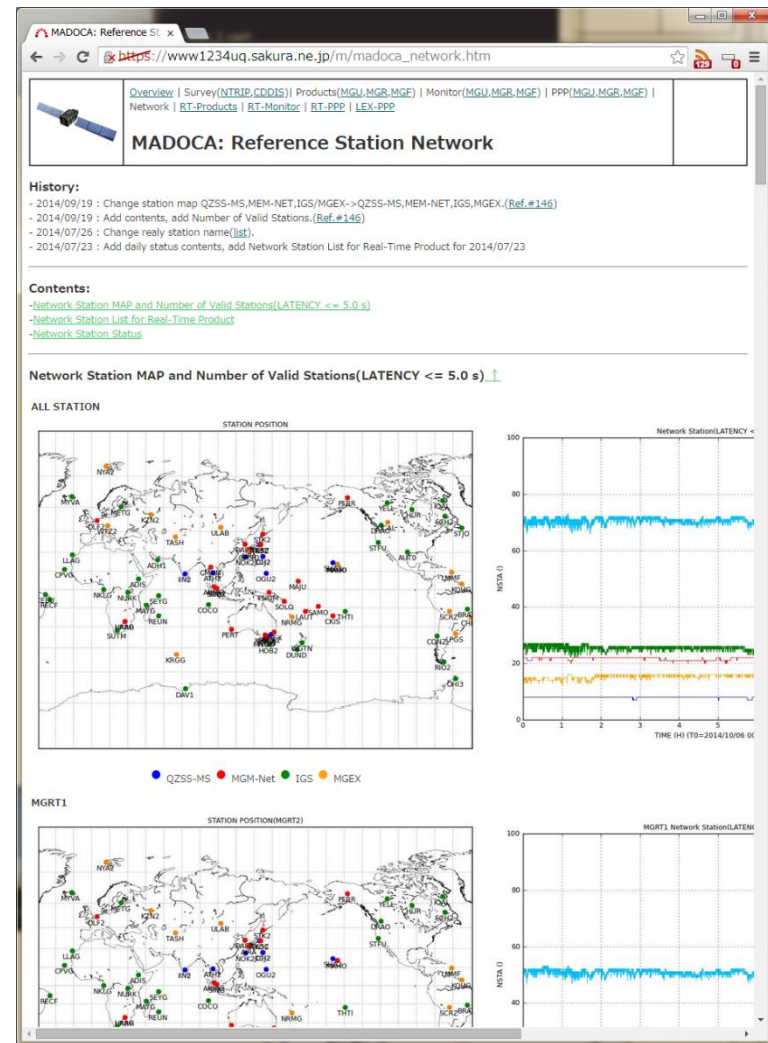
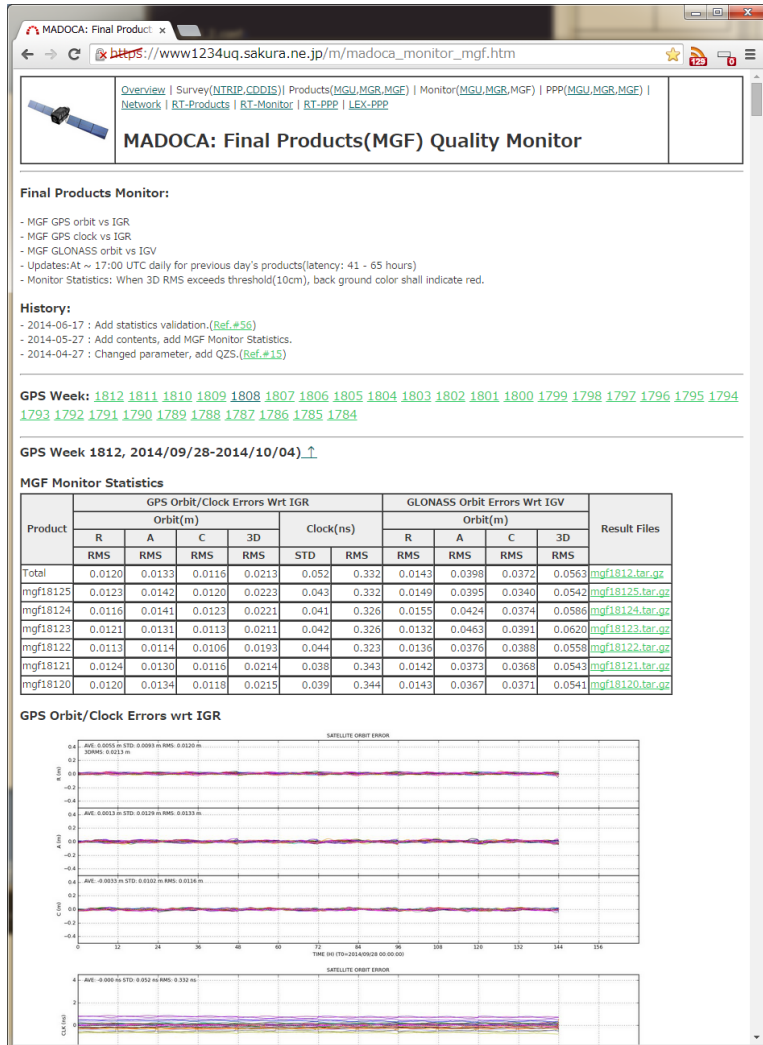
GPS Week 1811 (2014/9/21 - 27)

PPP Accuracy with RT-Products



Kinematic PPP with **MGRT1**, GPS Week 1811 (2014/9/21 - 27)

Product Quality Monitor

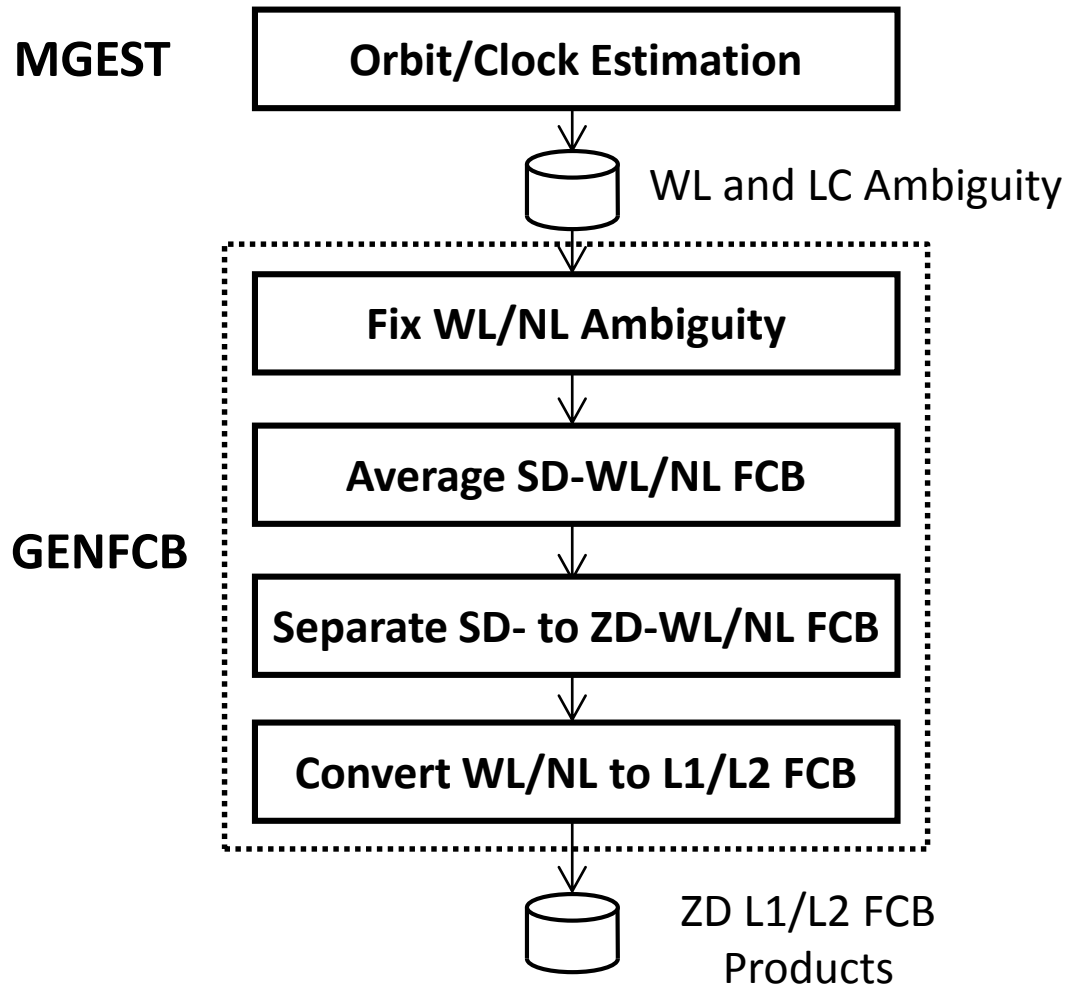


FCB Products for PPP-AR

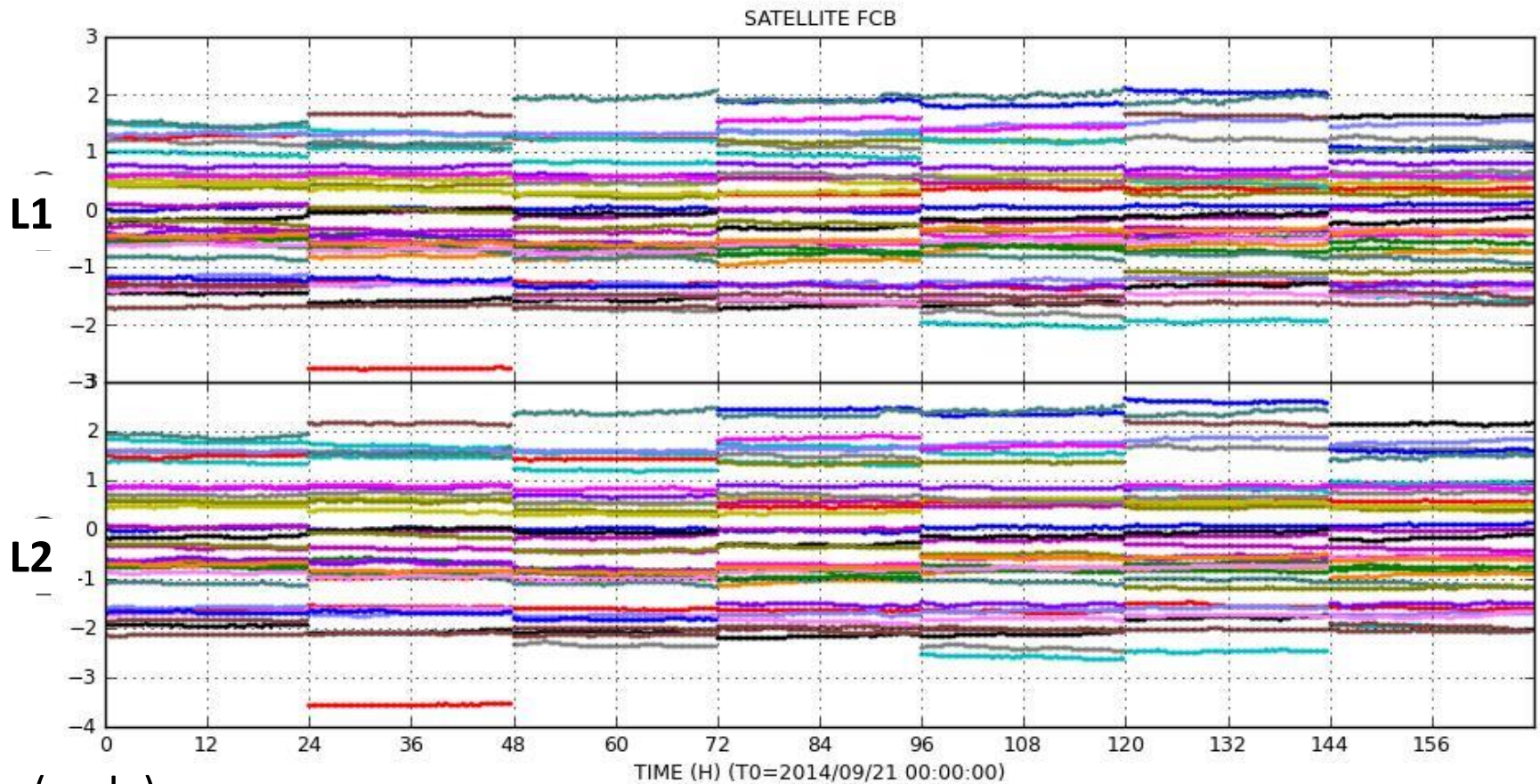
FCB Estimation for PPP-AR

- **PPP-AR (ambiguity resolution)**
 - Many research works in recent years (2007 -)
 - AR improves accuracy and convergence time in PPP
- **PP-FCB Products**
 - ZD-L1/L2 fractional bias in phase observables
 - GPS and QZSS (GLONASS not provided)
 - Interval: 30 s
 - Consistent to MADOCA PP-Orbit/Clock
- **RT-FCB Products**
 - Under development
 - Expect to use extended RTCM 3 SSR messages

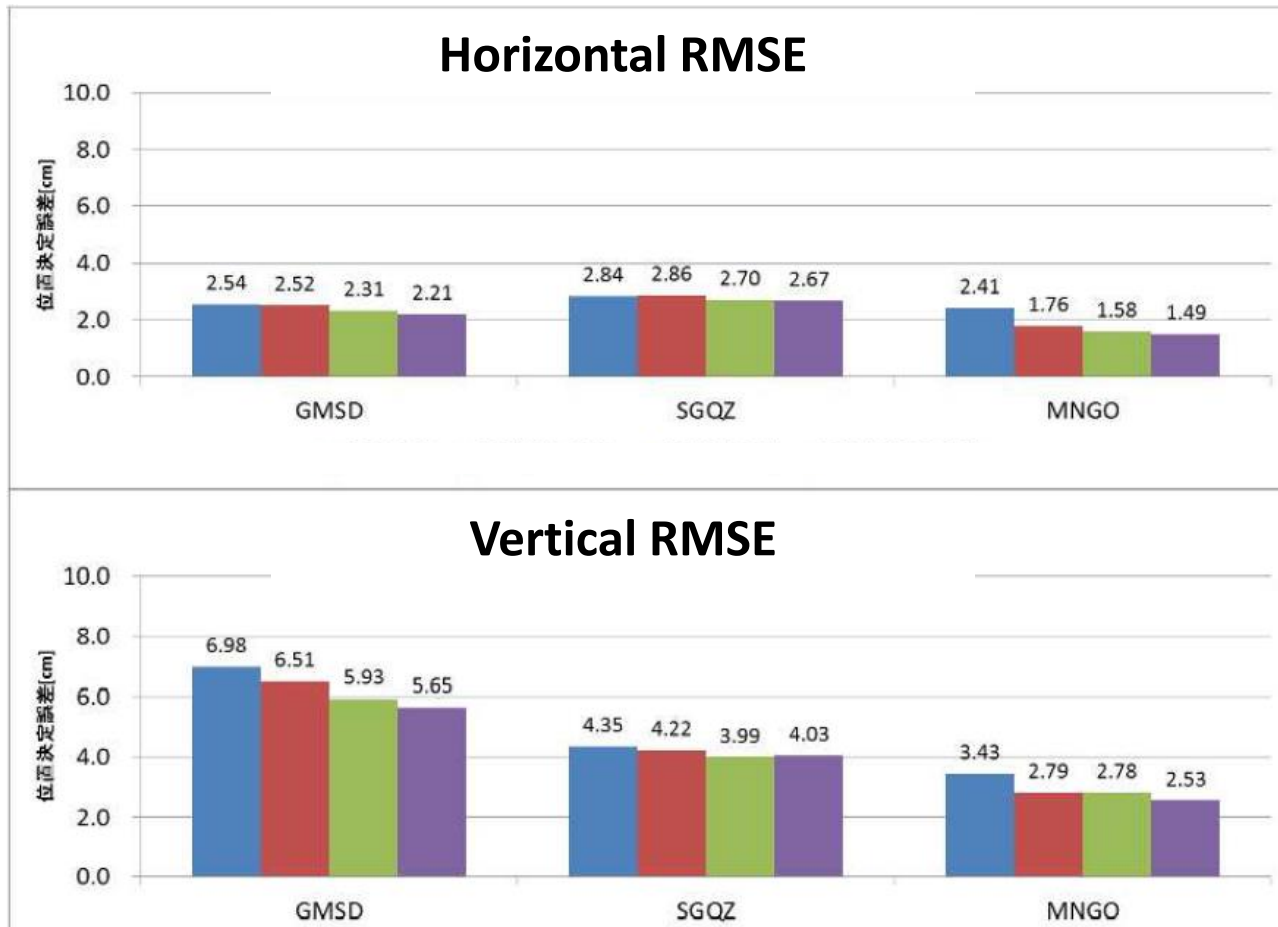
PP-FCB Generation Flow



Example of PP-FCB Estimation



PPP Accuracy with FCB



PPP (GPS), PPP (GPS+QZS), PPP-AR (GPS), PPP-AR (GPS+QZS)

Kinematic PPP, 2014/8/16 (24H, interval 30 s)

STEC/Tropos Products for Fast Convergence

STEC/Tropos Products

- **Objectives**
 - Fast convergence time of PPP solutions
 - Single-frequency PPP for mass-market receiver users
- **STEC Products**
 - STEC (slant-TEC) estimation in PPP process
 - 30 s interval product for each satellite-station pair
- **Troposphere Products**
 - Estimate ZTD and gradient in PPP process
 - 30 s interval product for each station
- **Interpolation to grid points (IGP/TGP) to broadcast**

STEC Estimation in PPP

- Slant iono-delay is derived from phase OBS - range, clock, tropos, bias and DCB terms
- Range, clocks, tropos term can be estimated in PPP process
- Ambiguity-resolved LC bias is separated to L1 and L2 by using WL biases

$$B_C = C_1 \lambda_1 B_1 + C_2 \lambda_2 B_2 + \varepsilon$$

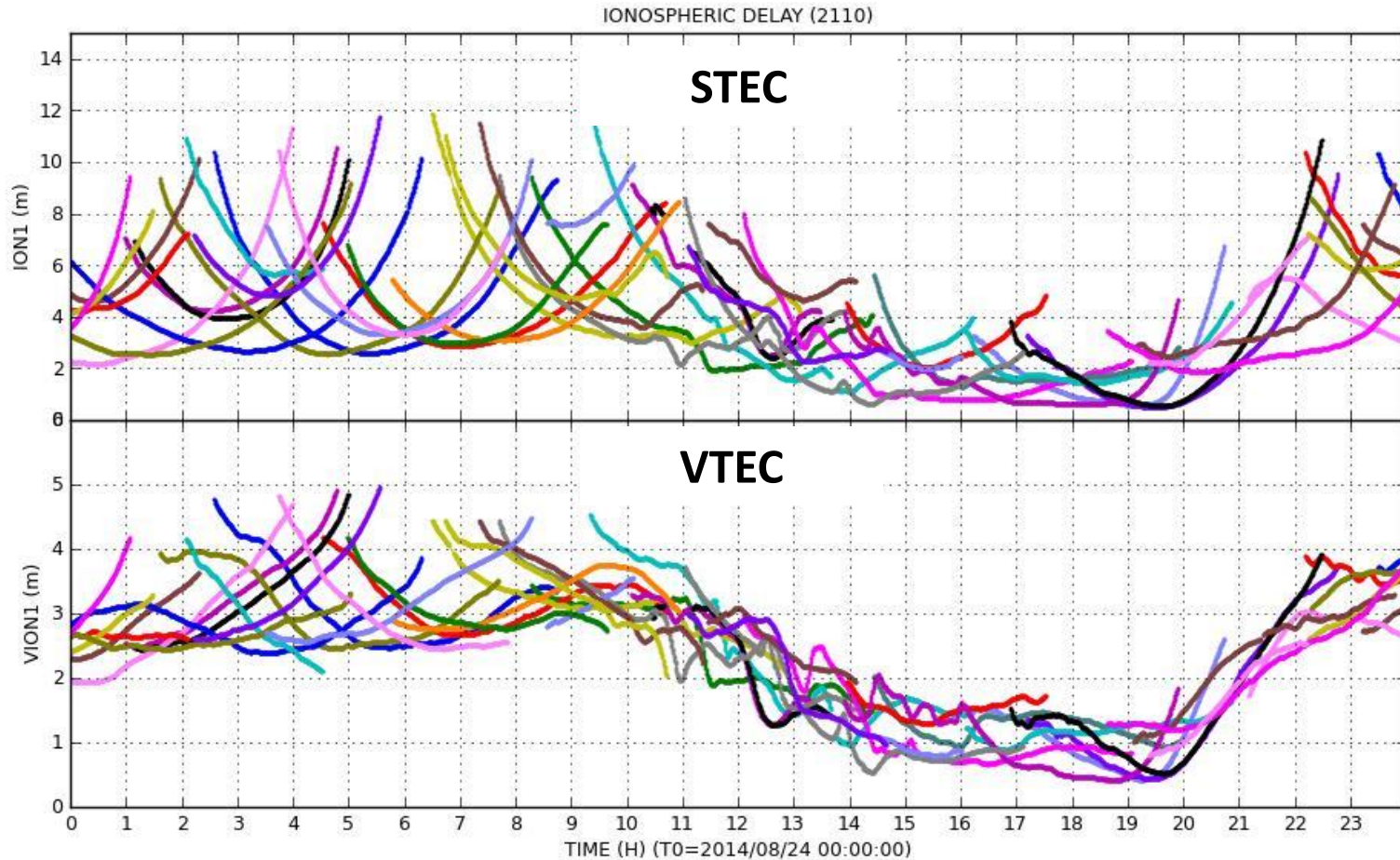
$$B_W = \overline{MW} / \lambda_W$$

$$B_1 = (B_C + C_2 \lambda_2 B_W) / \lambda_N, \quad B_2 = B_1 - B_W$$

$$\hat{I}_1 = (\rho + c(dt - dT) + T + \lambda_1 B_1 + d_1 + \phi_1 - C_2 D) - L_1$$

$$\hat{I}_2 = (\rho + c(dt - dT) + T + \lambda_2 B_2 + d_2 + \phi_2 + C_1 D) - L_2$$

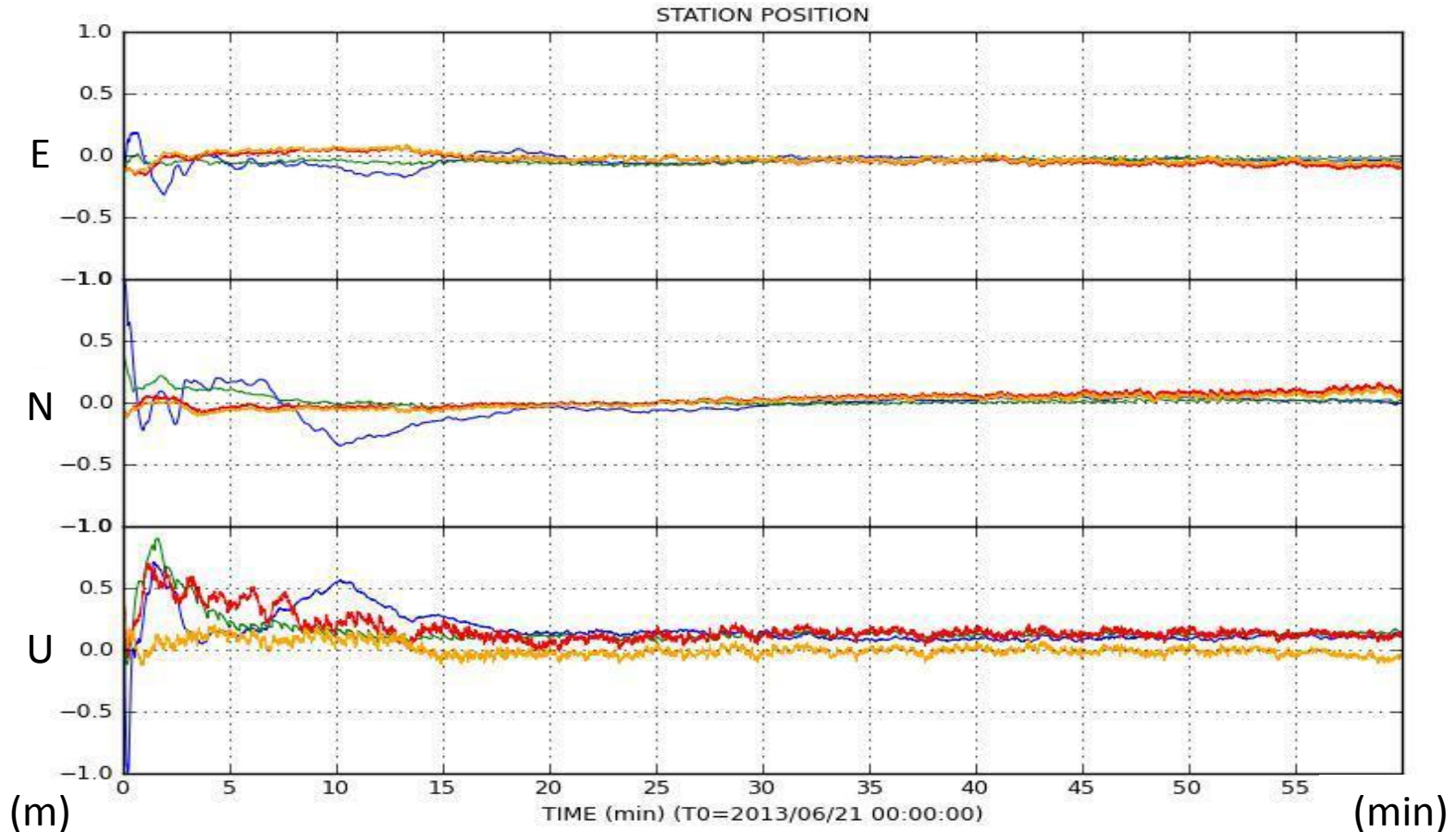
Example of STEC Estimation



2014/8/26 (24H, interval 30 s), GEONET Station 2110, Only GPS

Convergence Time of PPP

L1/L2, L1 with STEC, L1/L2 with STEC, L1/L2 with STEC/Tropos



Kinematic PPP, 2014/6/21 (1 H, interval 1 s), GEONET Station 2110

Future Work

- **Orbit/Clock Products**
 - Improve accuracy, stability and reliability continuously
 - Add BeiDou orbit/clock
- **FCB Products**
 - Add RT-Products
 - Support L5 FCB for triple frequency PPP-AR
- **STEC/Tropos Products**
 - Add RT-Products
 - Combine PPP-AR for much faster convergence
- **Multiple-sensor integration to PPP**
 - INS-PPP integration for severe environment