

3rd Asia Oceania Regional Workshop on GNSS

Development of A Real-time Multi-GNSS Precise Orbit and Clock Determination System

2011-11-1

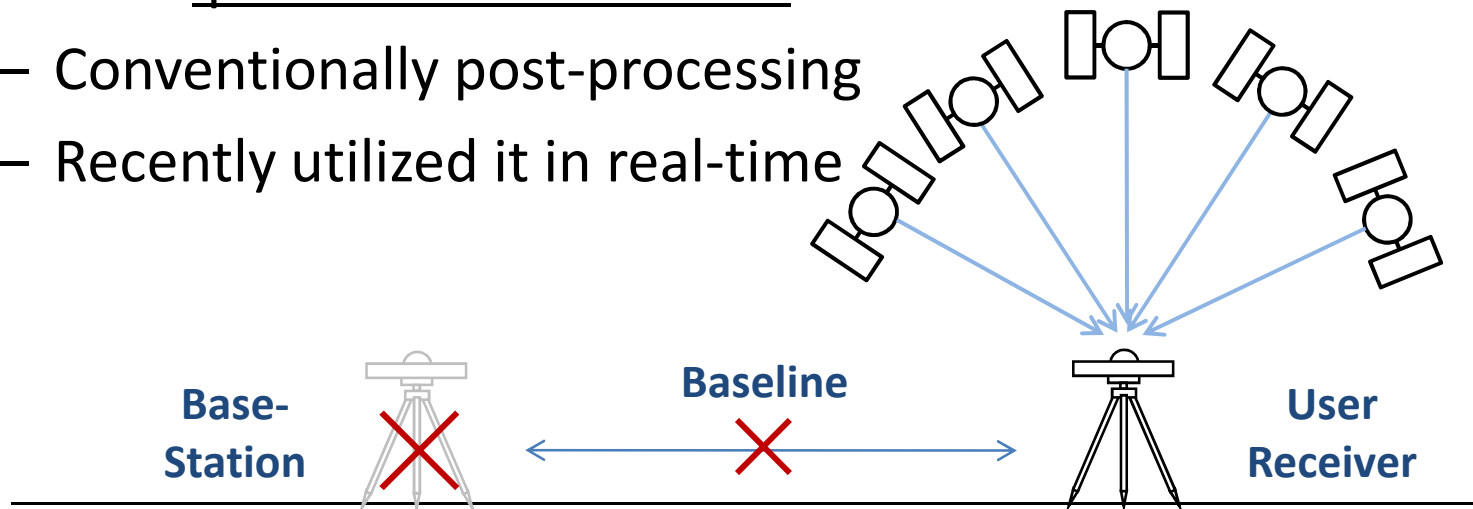
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Objectives

PPP: Precise Point Positioning

- Carrier-Based Single Positioning with GNSS
 - Dm to mm-level accuracy
 - No need base-station and baseline
 - Global coverage world-wide
 - Need precise orbit and clock
 - Conventionally post-processing
 - Recently utilized it in real-time

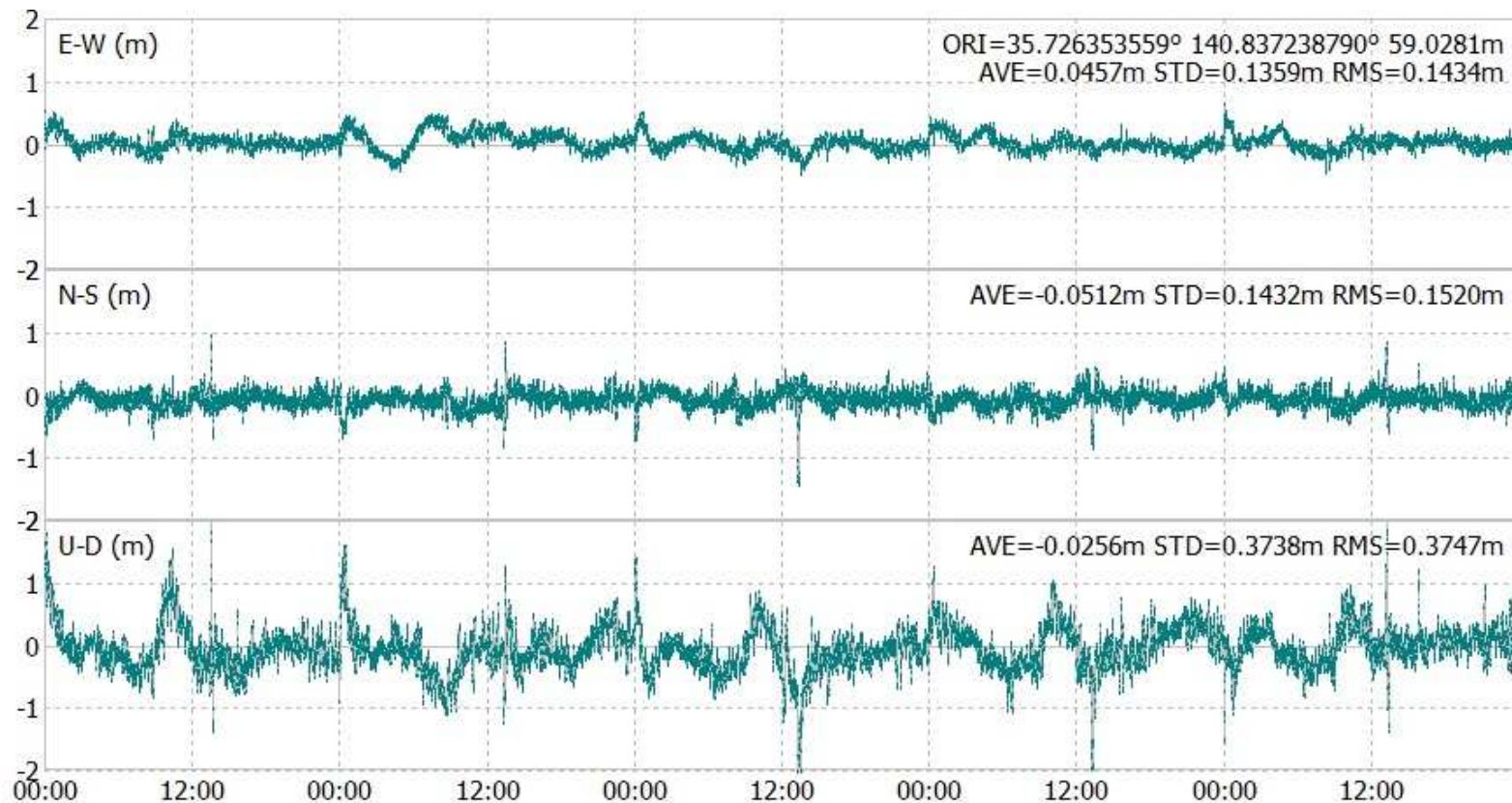


PPP-Experiments via QZSS LEX

- 1st Phase Experiment (2011/1~)
 - GPS+QZSS
 - Corrections: orbit/clock, Iono-correction and bias
 - Accuracy: < 30 cm (H-RMS)
 - Stations: 9 (GPS/QZSS) + 3 (GPS) QZSS-MS
- 2nd Phase Experiment (2013/4~)
 - GPS+QZSS+GLONASS+Galileo
 - Corrections: orbit/clock and bias (HR-clock)
 - Accuracy: < 10 cm (H-RMS)
 - Stations: 60 (?) (MGA network) (+ QZSS-MS + IGS)

Example of 1st phase Experiment

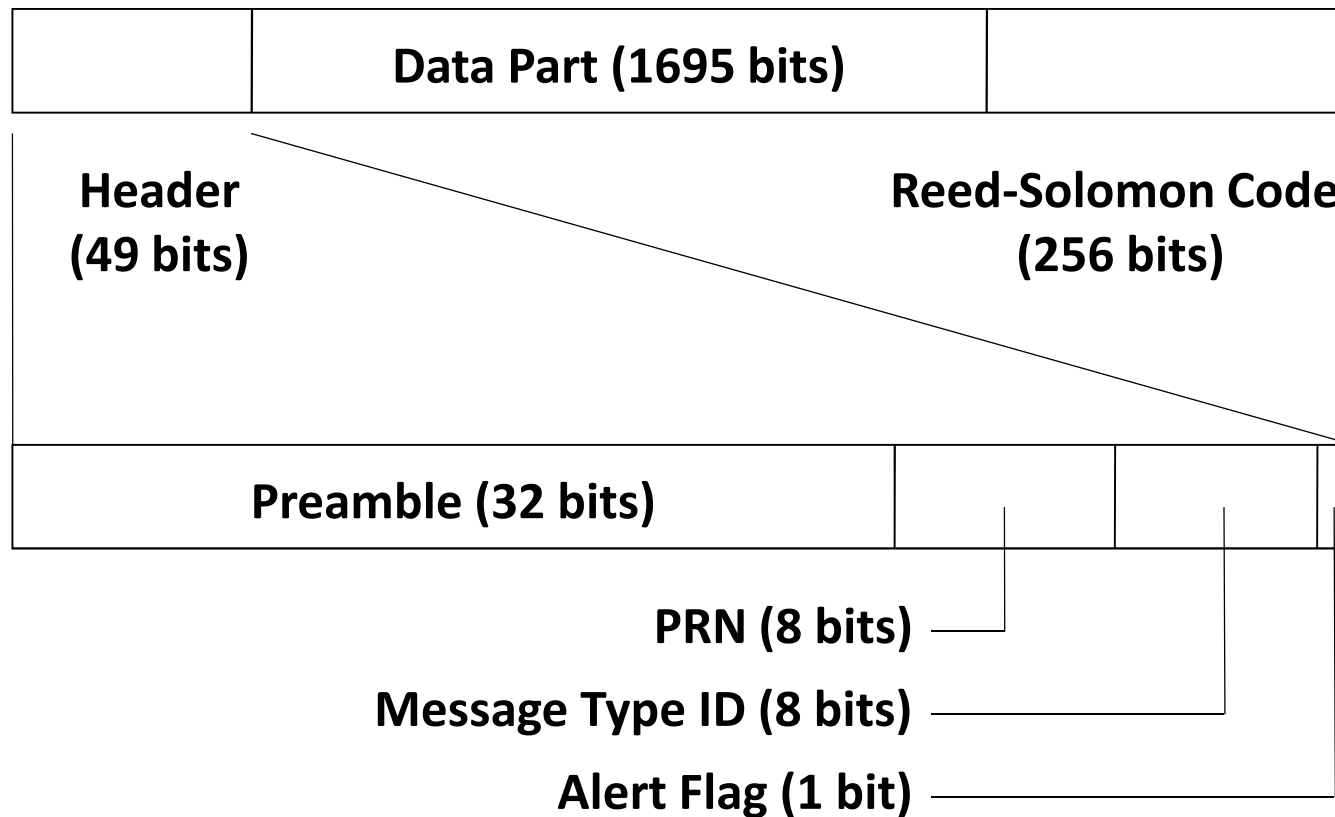
GEONET 3022 Choshi



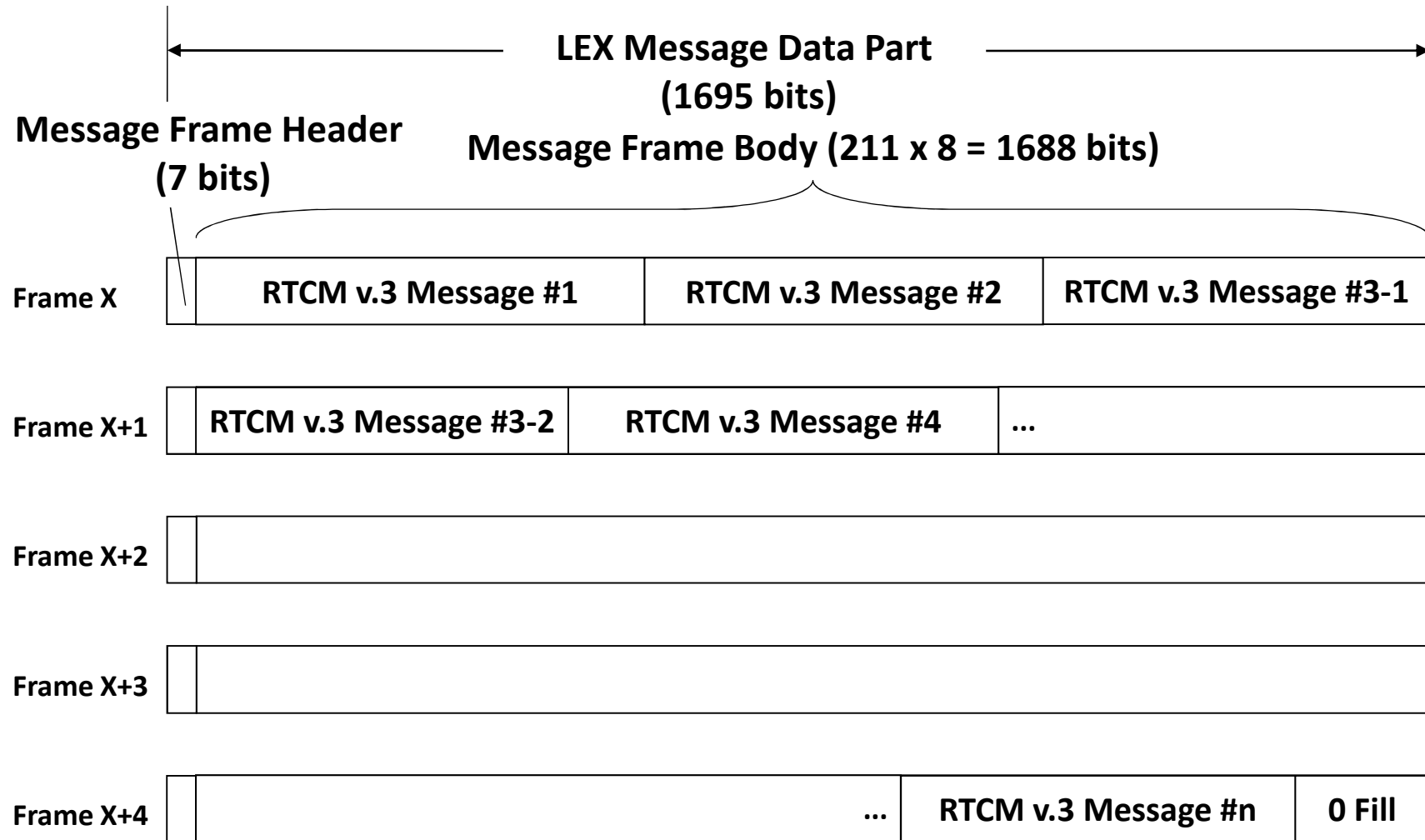
RMS E:14.34 cm, N:15.20 cm, U:37.47 cm

2011/6/23 00:00:00-6/26 23:59:30 GPST, Interval 30s

QZSS-LEX-Message Structure



2nd phase LEX Messages (draft)



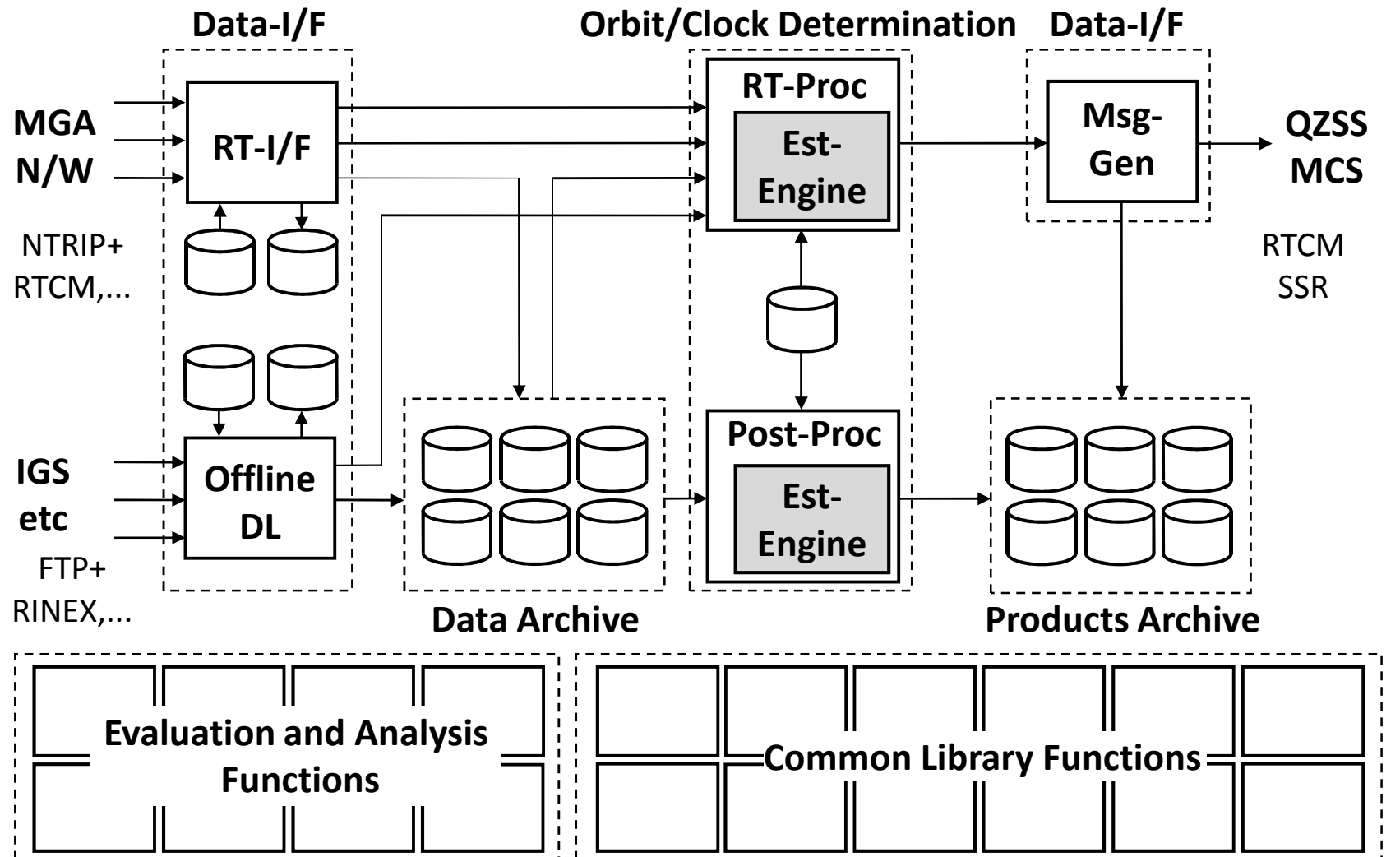
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Data Rate of RTCM SSR Messages

Type	GNSS	MT	# of Sats	Size (bits)	Interval (s)	Rate (bps)
Orbit/ Clock	GPS	1060	20	5728	15	381.9
	GLONASS	1066	16	4573	15	304.9
	QZSS	X+3	3	894	15	59.6
	Galileo	X+9	16	4592	15	306.1
High Rate Clock	GPS	1062	20	608	5	121.6
	GLO	1067	16	477	5	95.4
	QZSS	X+5	3	126	5	25.2
	Galileo	X+11	16	496	5	99.2
URA	GPS	1061	20	248	30	8.3
	GLO	1066	16	189	30	6.3
	QZSS	X+4	3	72	30	2.4
	Galileo	X+10	16	208	30	6.9
Code Bias	GPS	1059	20	1408	30	46.9
	GLO	1065	16	813	30	27.1
	QZSS	X+2	3	246	30	8.2
	Galileo	X+8	16	1136	30	37.9
Code-Phase Bias	GPS, GLO, ...	X+12,13,...	55	1946	30	64.9
Time Offset	GPS-GLO...	X+16,17,...	1	216	30	7.2
Total						1609.9

Real-time Multi-GNSS Precise Orbit/Clock Determination System

System Architecture



Orbit/Clock Estimation for GNSS

- Well-verified GNSS models
 - Many research works by IGS since 1990s
 - Precise geodetic models by IERS Conventions
 - Need more experiences for new coming GNSS especially SRP, attitude and receiver-bias
- A simple parameter estimation problem
 - **Very large problem** to involve multiple GNSSs
 - **Challenging in real-time environment**

Estimation-Engine Design

- Both of batch LSQ and EKF estimators
 - Mostly shared models and libraries
 - User-configurable with options file
- Batch LSQ estimator:
 - ZD-Measurement Equation
 - NEQ with epoch parameter elimination
 - Network mode ambiguity resolution (Ge 2005)
- EKF estimator: TBD

Prototype Implementation

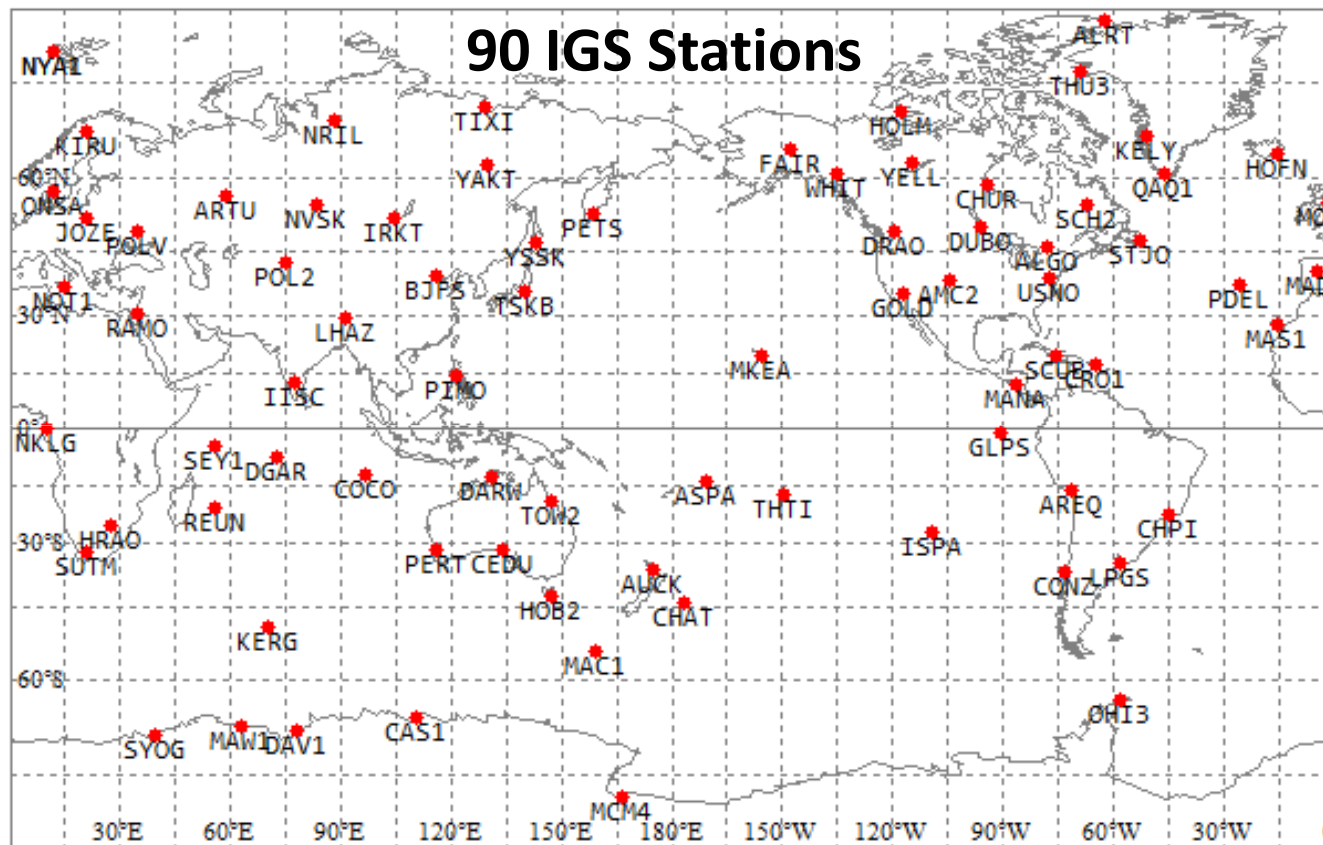
Prototype of Estimation-Engine

- v.0.0.2 was released (2011/10/13)
 - Supports only GPS
 - Supports only batch estimator
 - Includes critical and newer features
 - Optimized with LAPACK/BLAS and OpenMP
- Under evaluation with prototype
 - Design verification of critical and newer features
 - Orbit/clock accuracy and long-term stability
 - CPU/memory usage
 - PPP-accuracy with generated orbit/clock

Models

Option	Model	Option	Model
OBS Type	ZD-Carrier-Phase	Tidal Correction	IERS2010+FES2004
Adjustment	Weighted-least-square	3rd-Body	S+M+V+J (DE421)
Data Span	3H+24H+3H	Satellite Attitude	Nominal Yaw
Data Interval	300 s	SRP Parameters	D,B,Y/const+D,B/1-rev
Elevation Mask	10 deg	ODE Solver	RK4 (Step=60s)
GNSS	only GPS	Station Position	IGS SINEX, 1mm
Meas. Noise	6mm/sqrt(sin(el))	Site Disp.	IERS2010+FES2004
ECI to ECEF	IAU2000A (SOFA)	Troposphere	GPT+GMF
EOP	Xp, Yp, UT1 and rate	Tropos. Param.	ZTD+Grad, every 2H
Geopotential	EGM96 (Nmax=12)	Ambiguity	Fixed (< 6,000 km)

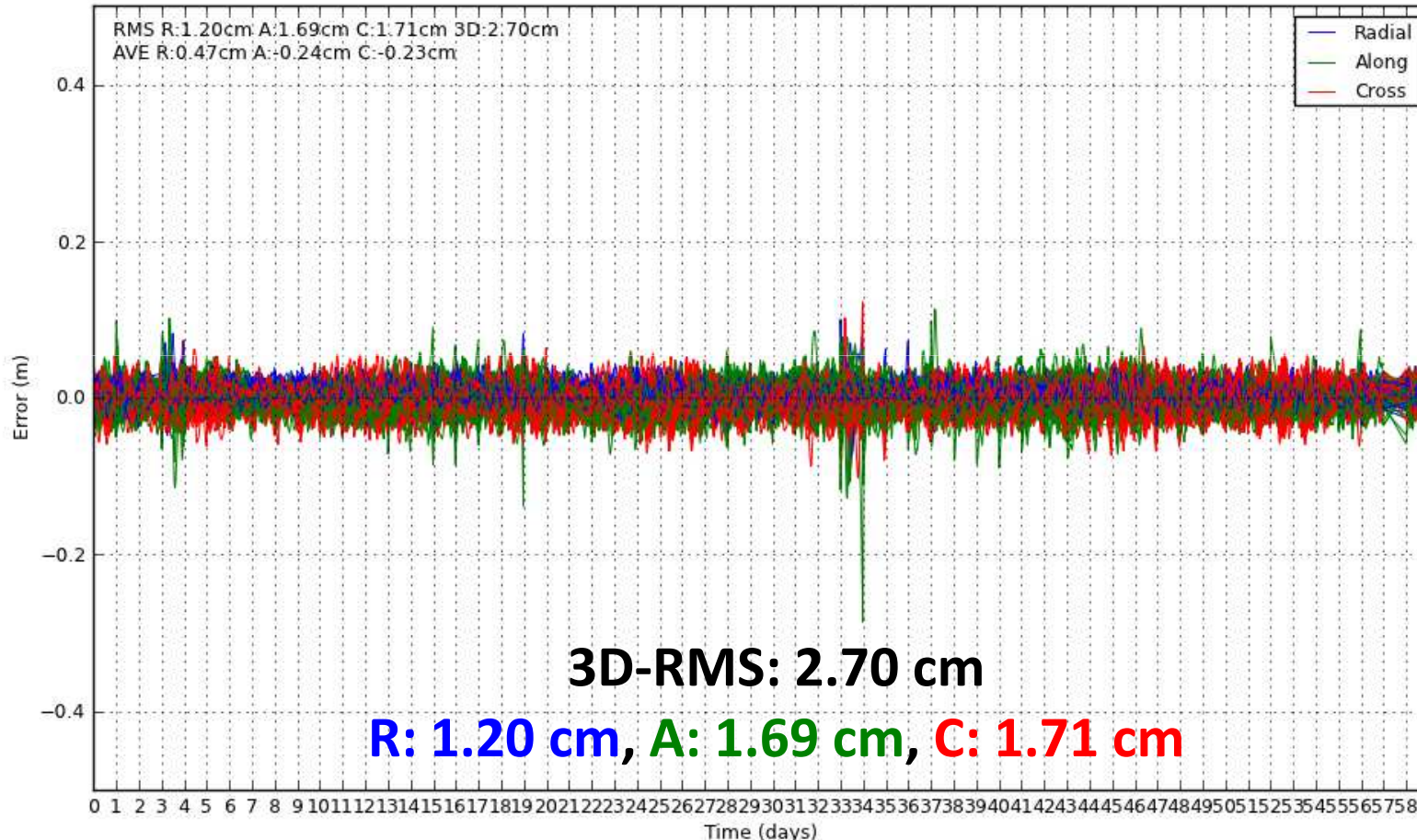
Reference Stations



ALGO ALRT AMC2 AREQ ARTU ASPA AUCK BJFS CAS1 CEDU CHAT CHPI CHUR COCO CONZ CRO1 CUSV DARW
 DAV1 DGAR DRAO DUBO DUM1 DUND FAIR GLPS GOLD GUUG HOB2 HOFN HOLM HRAO IISC IRKT ISPA JOZE
 KELY KERG KIRU LHAZ LPGS MAC1 MADR MAL2 MANA MAS1 MAW1 MCM4 MKEA MORP NKLG NOT1 NRIL NVSK
 NYA1 NYAL OHI3 ONSA PDEL PERT PETS PIMO POL2 POLV QAQ1 RAMO REUN RIO2 SALU SAVO SCH2 SCOR
 SCUB SEY1 STJO STK2 SUTM SYOG TEHN THTI THU3 TIXI TOW2 TSKB USNO WHIT WIND YAKT YELL YSSK

GPS Orbit Accuracy

2011/1/1 - 2/28 GPST (59 days)



Average of 31 GPS satellites wrt IGS Final

Manually excluded: 1/4 G23, 2/5 G21, 2/6-7 G23, 2/27 All (NEQ error)

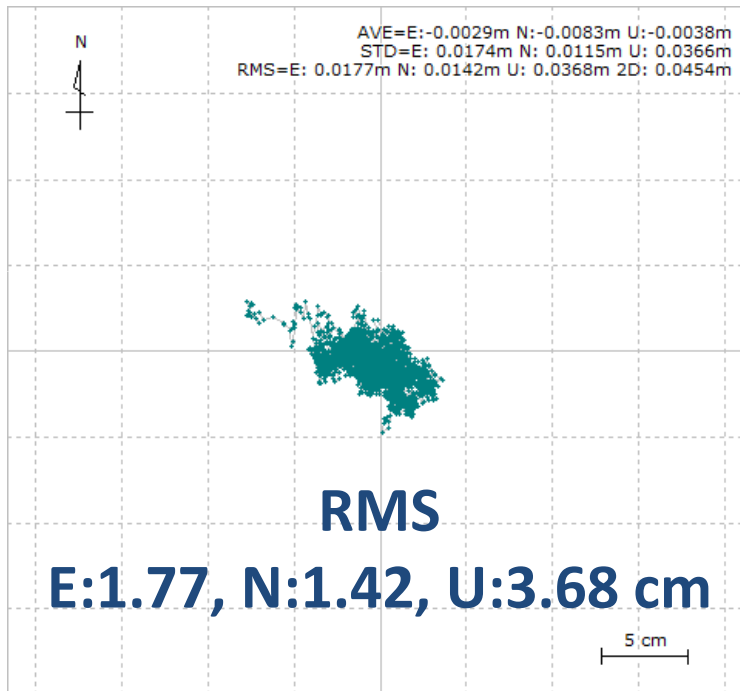
Comparison with IGS ACs

IGS AC	Analysis Software	# of Station	RMS Error (cm)			
			Radial	Along-Track	Cross-Track	3D
	Prototype v.0.0.2 (2011-10-13-version)	90	1.20	1.69	1.71	2.70
ESA	NAPEOS 3.5	110	0.90	1.17	1.02	1.81
CODE	Bernese 5.1	231	0.93	1.43	1.19	2.09
NGS	arc, orb, pages, gpscom	199	0.90	1.50	1.36	2.22
GFZ	EPOS.PV2	191	1.13	1.60	1.55	2.51
MIT	GAMIT 10.33, GLOBK 5.16	263	1.27	1.68	1.38	2.54
NRCan	GIPSY/OASIS-II 5.0	91	2.52	1.71	1.67	3.52
SIO	GAMIT 10.20, GLOBK 5.08	258	2.39	1.94	1.66	3.55
JPL	GIPSY/OASIS-II 5.0	142	2.63	1.75	1.99	3.79
GRG	GINS, DYNAMO	134	2.53	2.79	1.99	4.38

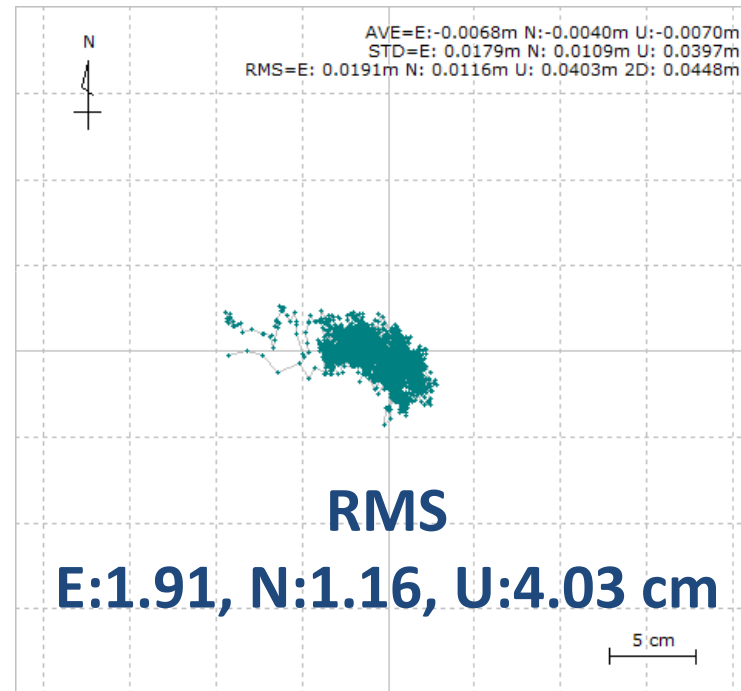
2011/1/1 - 2/28 (59 days), Average of 31 GPS satellites wrt IGS Final

Kinematic-PPP Accuracy

with orbit/clock
(30s-clock) by v.0.0.2



with IGS Final
(30s-clock)



IGS TSKB by RTKPOST v.2.4.1
2011/1/2 00:00:00-23:59:30 GPST, Interval 30s
(first 1H solutions are omitted for convergence)

Summary

Summary

- PPP Experiments via QZSS-LEX
 - 1st-phase (2011/1~)
 - 2nd-phase (2013/4~) with MGA network
- Real-time Precise Orbit/Clock Determination System
 - For 2nd-phase PPP experiment
 - Support GPS, GLONASS, Galileo and QZSS
 - Combination of Near-RT-LSQ and RT-EKF
- Prototype of Estimation-Engine
 - Almost the same accuracy as IGS AC for GPS
 - Need more investigation for other GNSS