

Precise Point Positioning Experiment by using QZSS LEX

Tomoji TAKASU

Tokyo University of Marine Science and Technology

Contents

- Introduction of QZSS LEX
- Evaluation of Real-time PPP with QZSS LEX
 - Estimation of GPS Orbit/Clock
 - Performance of Real-Time PPP
- Concept for PPP-RTK with QZSS LEX
- Future Plan of Experiment

Introduction of QZSS LEX

3

QZSS LEX

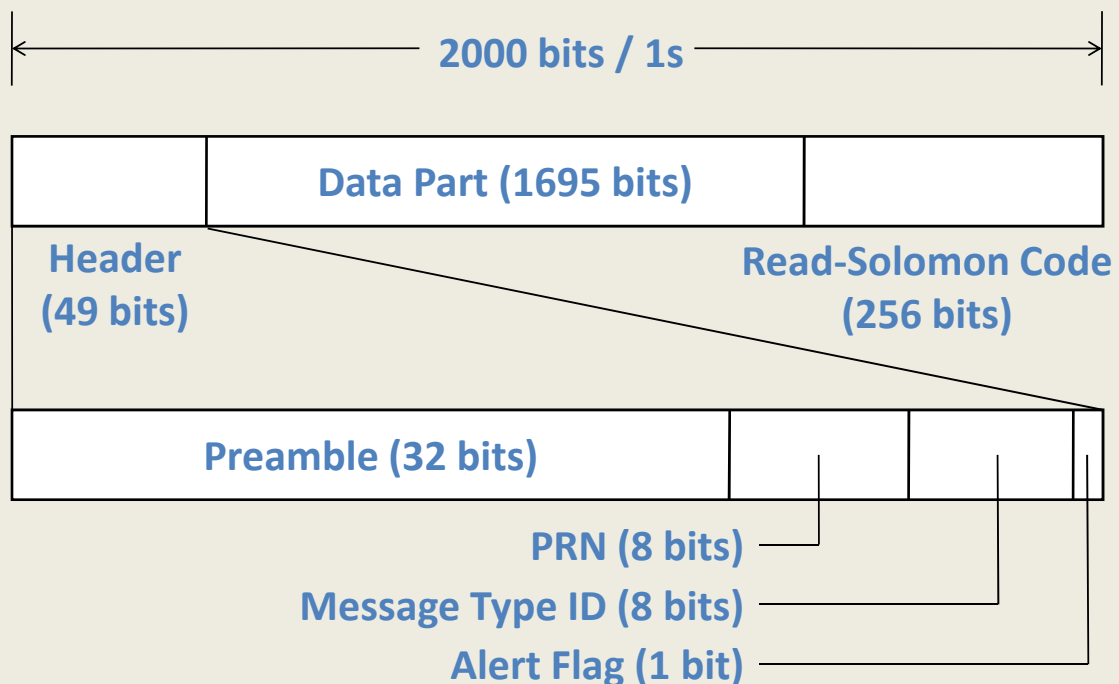
- QZSS signals
 - GPS Compatible Signal: L1-C/A, L1C, L2C, L5
 - GPS Augmentation: L1-SAIF, **LEX**
- LEX (L-band experimental signal)
 - Experiments for Novel Positioning Technologies
 - Frequency: 1278.75MHz (same as Galileo E6)
 - Message Rate: **2Kbps**
 - For decimeter, cm-class positioning experiments

4

Specifications

Item	Specification
Center Frequency	1278.75MHz
Bandwidth	42.0MHz
Min Signal Level	-155.7dBW (total)
Modulation	Kasami-sequences, BPSK (5) short-code/long-code
Short Code	period: 4ms, chip-rate: 10,230
Long Code	period: 410ms, chip-rate: 1,048,575
Navigation Message	short-code: 2000 bits/frame long-code: data-less

QZSS LEX Message



Message Types

Type ID	Contents
0-9	Reserved for system use
10-19	JAXA Experiment
10	Signal health (for 35 satellites) Ephemeris and SV clock (for 3 satellites)
11	Signal health (for 35 satellites) Ephemeris and SV clock (for 2 satellites) Ionospheric model corrections
12-19	Reserved
20	GSI Experiment
21-255	Reserved for other agencies

7

JAXA Experiment

- Objective
 - Real-Time Precise Point Positioning (PPP)
- Precise Ephemeris/SV Clock (Type 10, 11)
 - 35 Satellites (GPS 32 + QZSS 3)
 - ECEF Position of Satellite Antenna Phase Center:
3rd-Order Polynomial +URA
 - SV Clock Bias/Drift + TGD
- Ionospheric Model Corrections (Type 11)
 - Thin Shell Model (Single-Layer Model)
 - L1 Vertical Delay: 1 x 2 degrees Polynomial
 - Only Covered for Near Japan Area

8

JAXA Experiment (cond.)

- Signal Health
 - 35 Satellites (GPS 32 + QZSS 3)
 - Each Signals (L1, L2, L5, L1C, LEX)

Message Periods

Message	Broadcast (nominal)	Update (nominal)	Effective (nominal)
Signal Health	1 s	1 s	-
Ephemeris	12 s	3 min	6 min
SV Clock	12 s	3 min	6 min
Ionosphere	12 s	30 min	-

9

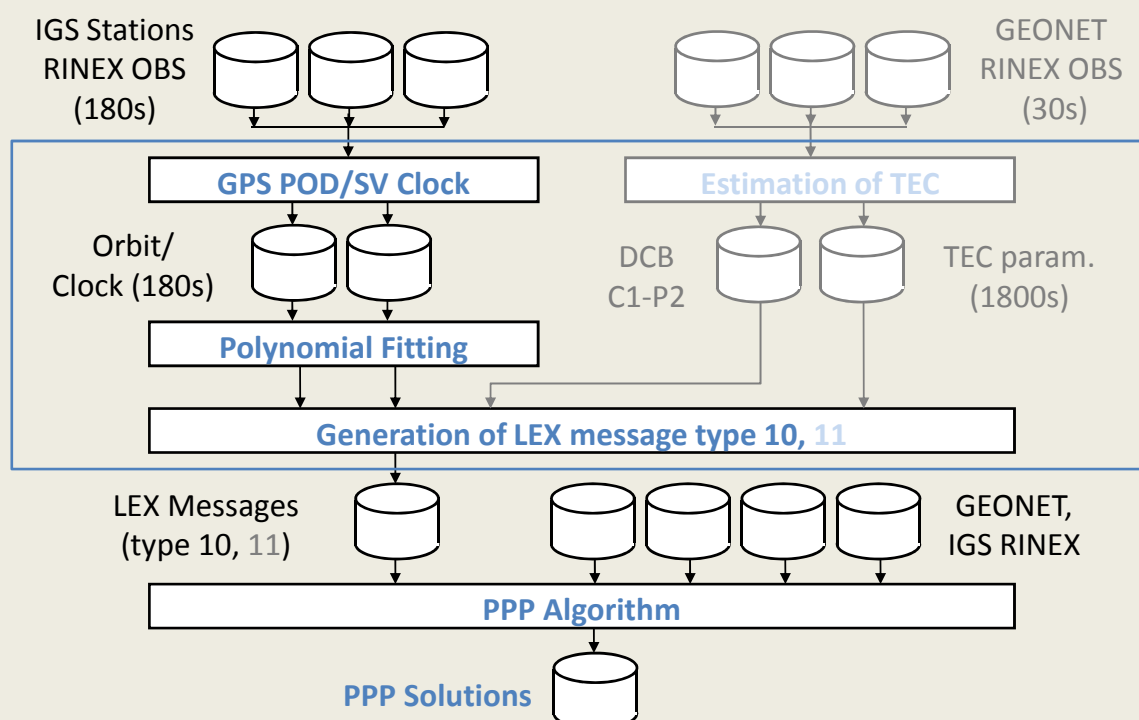
Evaluation of Real-time PPP with QZSS LEX

Objectives

- Evaluation of PPP Experiment
 - To verify message format and contents
 - To identify optimal operation parameters
 - To clarify issues to be solved
 - To plan future extensions
- Evaluation of Real-Time PPP Performance
 - To evaluate quality of ephemeris, SV clock for LEX
 - To evaluate ionospheric model correction model
 - To evaluate user positioning accuracy

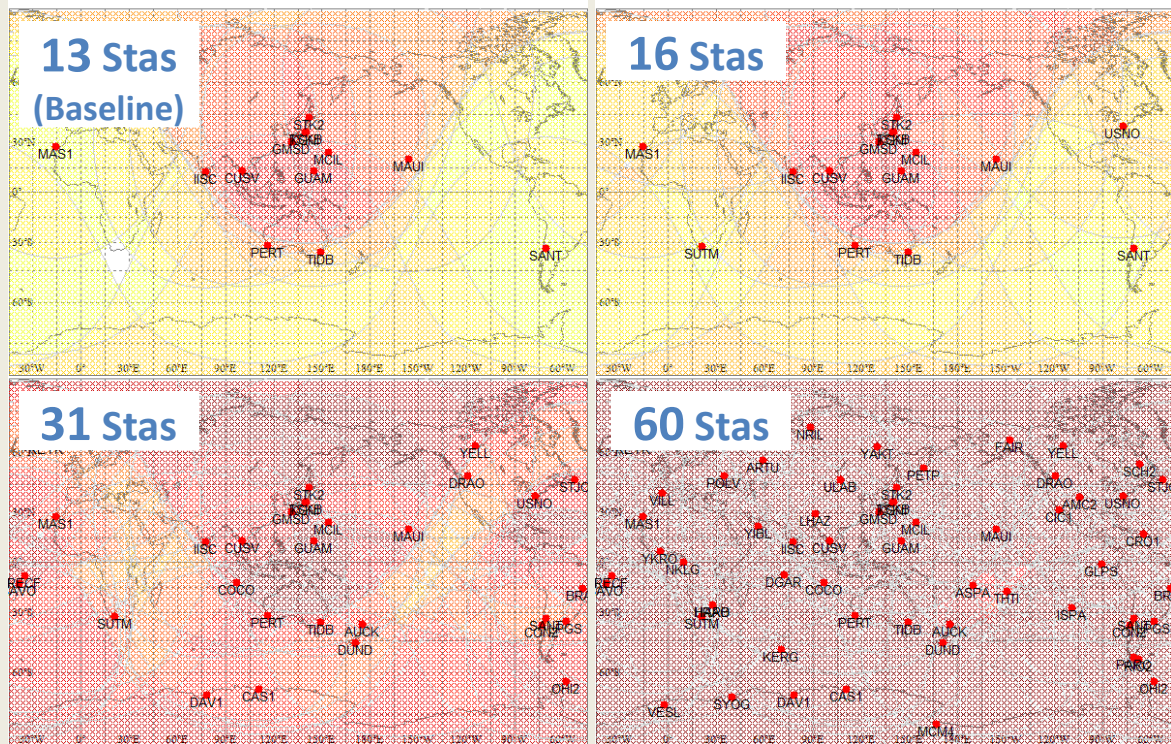
11

Evaluation Flow



12

Stations for Orbit/Clock Estimation



13

Strategy of Orbit/Clock Estimation

Item	Condition
Period	2009/5/25 0:00:00-5/31 23:57:00
Estimation Interval	180 s
Estimation Scheme	Extended Kalman Filter
Satellites	GPS 30 satellites (except for PRN 1,5)
Orbit Model	Geopotential: JGM3 8th, 3rd-body: Moon and Sun Solar Radiation: CODE RPR, Relativity: IERS 1996
Clock Model	Satellite: 1st-order Gauss-Marcov Receiver: White Noise
Measurement Model	Troposphere: ZTD/Gradient estimation + GMF Ionosphere: L1-L2 Ionosphere-Free LC Antenna PCV: IGS05.ATX Site Displacement: Solid Earth Tide etc., Phase-windup
Precession/Nutation	IAU1976 + IERS1996
ERP	Estimate, Initial: IGS Final
Analysis S/W	GpsTools ver. 0.6.4

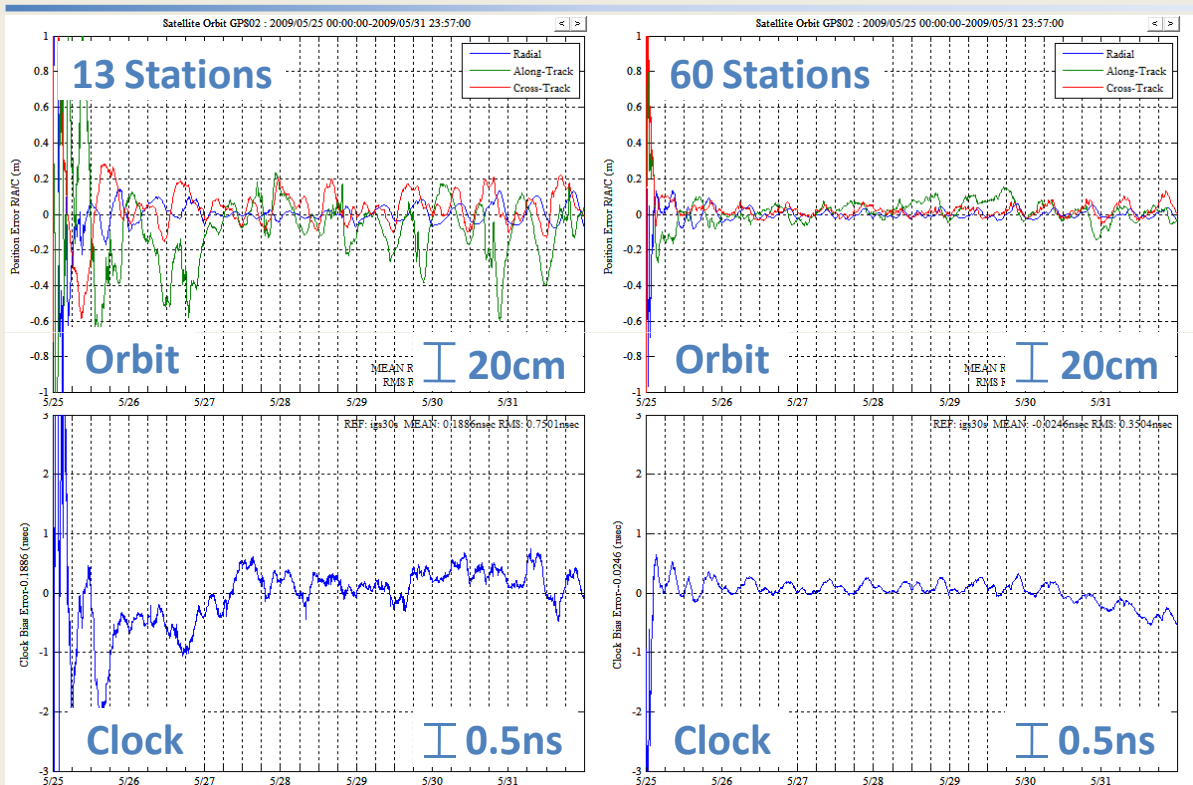
14

Orbit/Clock Accuracy wrt IGS Final

Strategy	Orbit RMS Error (cm)				Clock Error (ns)		Processing Time (/Epoch)
	3D	Radial	Along-Track	Cross-Track	with Bias	without Bias	
13 stations	30.1	4.3	24.7	16.3	0.58	0.38	35' 56" (0.64s)
16 stations	17.2	3.0	14.3	8.9	0.48	0.34	37' 11" (0.66s)
31 stations	11.4	2.4	9.7	5.2	0.60	0.26	54' 8" (0.97s)
60 stations	7.6	2.0	6.1	3.9	0.42	0.20	105' 42" (1.89s)
IGU (pred) + Clock Est	5.7	1.3	4.8	2.6	0.60	0.36	-
IGU (pred)	5.7	1.3	4.8	2.6	1.29	1.21	-
StarFire™ *	18.5	9.7	12.2	9.3	-	0.34	-

* K. Dixon, StarFire™: A Global SBAS for Sub-decimeter Precise Point Positioning, ION GNSS 2006

Orbit/Clock of PRN02



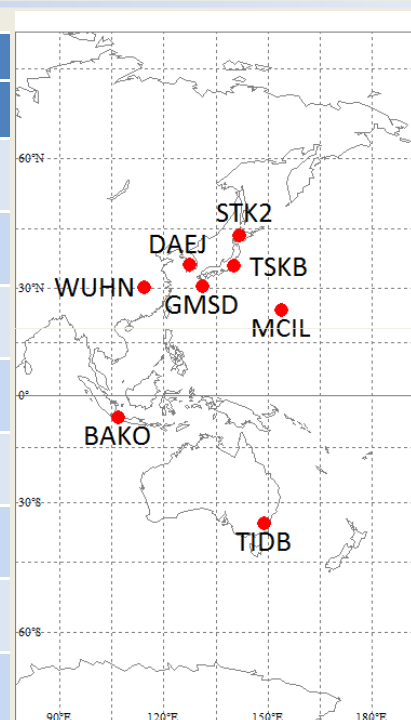
PPP Parameters

Item	Condition
Period	2009/5/27 0:00:00-5/27 23:59:30
Interval	30 s
OBS data	IGS 8 stations
Elevation Mask	15 deg
Sat Orbit/Clock	QZSS LEX message 10 (interval 180 s)
Ionosphere	Dual-frequency Iono-Free LC
Troposphere	GPT+GMF, ZTD and Gradient Estimation
Antenna Model	IGS_05.ATX
Earth Tide	Solid Earth Tide (IERS Conv. 2003)
Phase Wind-Up	Nominal Satellite Attitude

17

PPP Accuracy with QZSS LEX

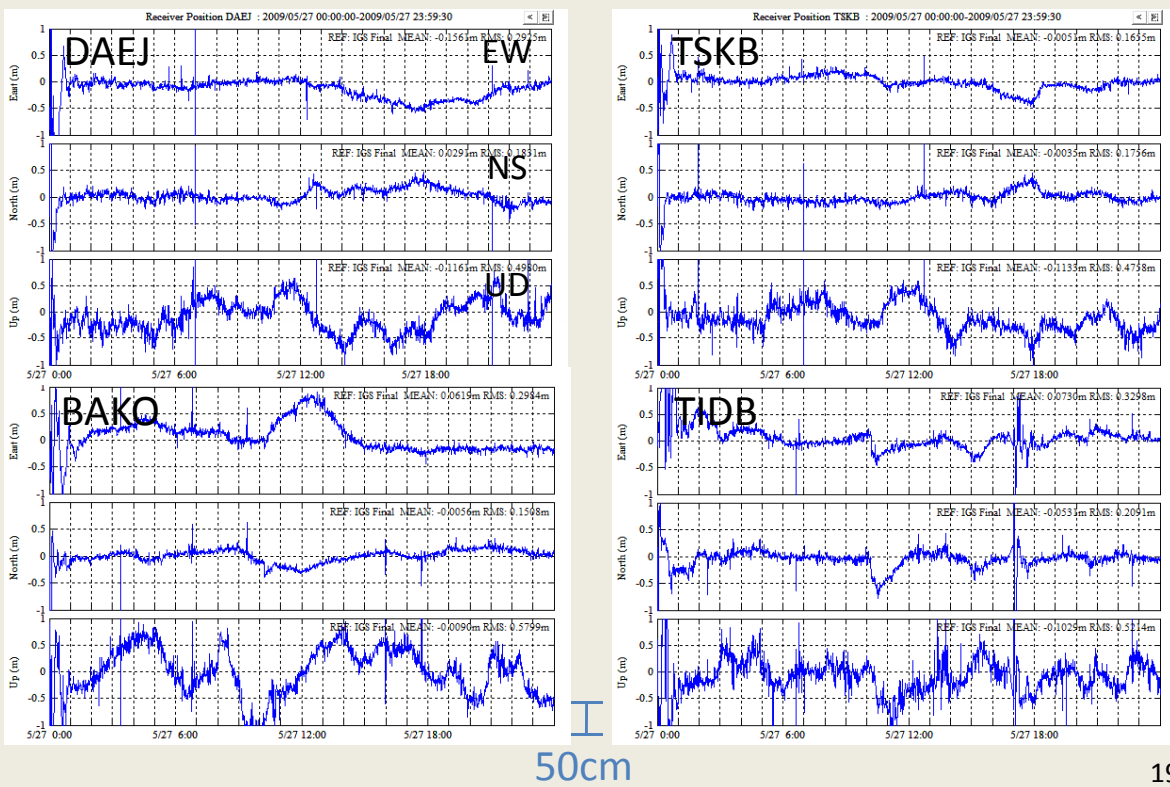
ID	City	Country	RMS Error (cm)		
			E-W	N-S	U-D
STK2	Shin-totsukawa	Japan	13.8	12.1	31.9
TSKB	Tsukuba	Japan	12.7	13.4	42.7
GMSD	Nakatane	Japan	25.8	15.8	45.6
MCIL	Ogasawara	Japan	12.7	9.2	28.1
DAEJ	Daejeon	South Korea	22.3	13.0	41.3
WUHN	Wuhan	China	62.0	55.1	80.6
BAKO	Cibinong	Indonesia	27.8	12.9	57.1
TIDB	Tidbinbilla	Australia	21.4	19.3	36.1



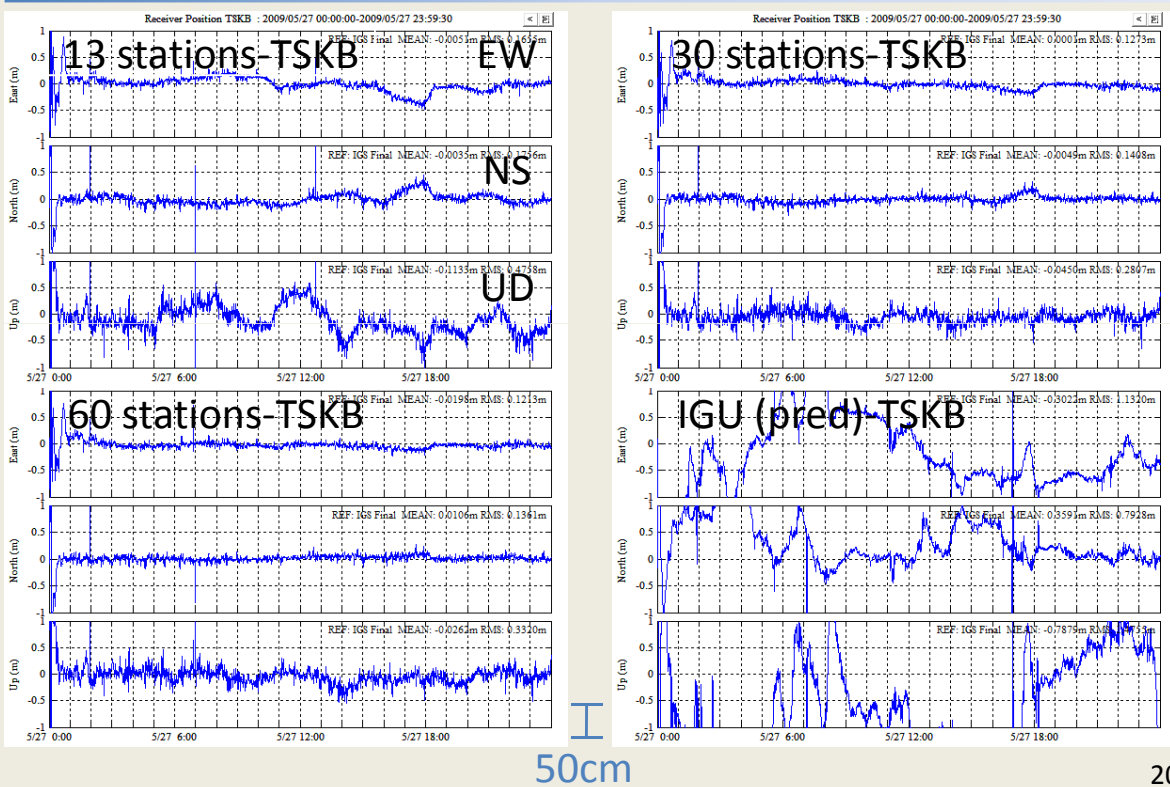
After 1 hour initialization, Orbit/Clock is estimated with 13 stations

18

PPP Errors



Comparisons of Various Ephemerides



Concept of PPP-RTK with QZSS LEX

21

PPP-RTK with QZSS LEX

- Next Phase Experiment with QZSS LEX
 - Extension of First Phase PPP Experiment
 - Precise Position with cm-Class Accuracy
 - For Users Outside of Current Network RTK Service Areas
 - For Precision Agriculture, Construction, Mapping,...
- PPP-RTK
 - Very Compact Messages by Optimized Corrections
 - Fast Convergence by Integer Ambiguity Resolution
 - Dense Corrections of Ionosphere and Troposphere
 - Single Frequency Users by Ionosphere Correction

22

Correction Message Bandwidth

Corrections	Bits	(LSB)	Range	# Sat	# Grid	Interval	bps
Orbit	15×3	2mm	-33-33m	12	-	30 s	18
	15×3	.02mm/s	-.3-.3m/s	12	-	30 s	18
Clock	15	0.006ns	-98-98ns	12	-	3 s	60
Ionosphere	15	2mm	0-66m	12	70 ○	30 s	420
	13	2mm	-8-8m	12	210 ○	30 s	1092
Troposphere	11	0.5mm	0-1m	-	70 ○	30 s	26
Phase Bias	11×3	0.01cyc	-10-10cyc	12	-	30 s	13
Code Bias	8×3	0.1m	-13-13m	12	-	30 s	10
Sat ID+IOD	8+8	-	-	12	-	30 s	6
Others	-	-	-	-	-	1-30 s	32
Total							1695

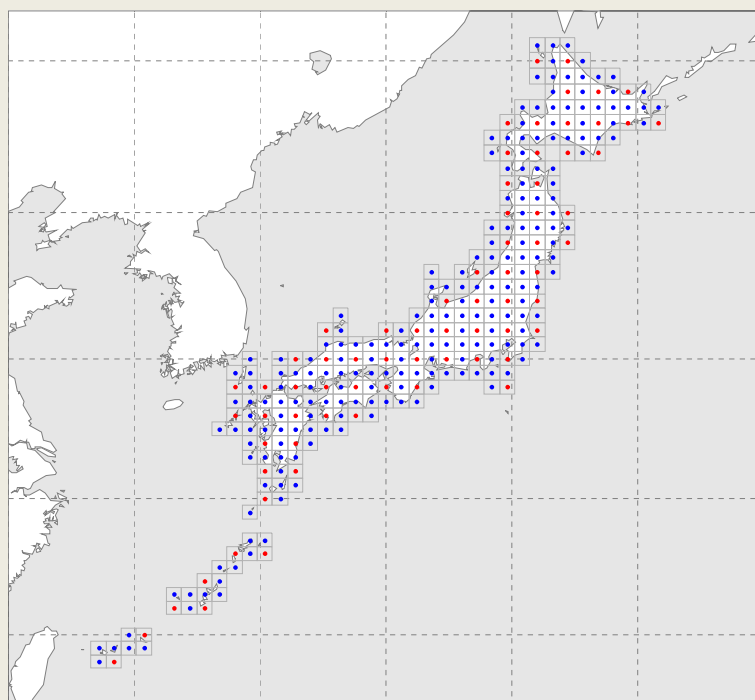
23

Grids for Ionos/Tropos Corrections

Coverage:
Land of Japan

Grid Interval:
 $0.5 \times 0.6^\circ$
(55km)

of Grid
Point:
280



24

Error Budget of PPP-RTK

Error factor		Single-Freq	Dual-Freq
Satellite Orbit/Clock		1.5 cm	1.5 cm
Ionosphere Correction		2.0 cm	-
Troposphere Correction		0.6 cm	0.6 cm
Phase Bias Correction		0.0 cm	0.0 cm
Multipath + Noise		0.3 cm	0.9 cm
Geometry	HDOP	1.5	1.5
	VDOP	3.0	3.0
RMS Error	Horizontal	3.9 cm	2.8 cm
	Vertical	7.8 cm	5.5 cm

25

Future Plan of Experiment

26

Future Plan of Experiment

- Experiment with Actual QZSS LEX
 - After QZSS Launch in Summer 2010
 - Extension of RTKLIB ver. 2.3.0
 - Real-time PPP Functions
 - Decoder for LEX Message 10, 11
- Prototype System for PPP-RTK with QZSS LEX
 - Evaluation by Post Processing
 - Detailed Design for Correction Messages
 - Optimization of Message Rate and Grid Interval