Performance Evaluation and Future Application of Real-Time PPP Product in Japan

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Eiko Saito, Nobuaki Kubo and Kazumasa Shimoda
Tokyo University of Marine Science and Technology
National Institute for Sea Training

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Motivation

- **Quasi-Zenith Satellite System (QZSS)**

Previous research :

Masayuki Saito, Junichi Takiguchi and Takeshi Okamoto, "Establishment of Regional Navigation Satellite System Utilizing Quasi-Zenith Satellite System", TECHNICAL REPORTS, Mitsubishi Electric ADVANCE, 2014.

QZSS enhances GNSS services from both availability and reliability perspective.

QZSS transmits augmentation signals.

→L-band experimental (LEX) signal

LEX signal

LEX signal

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Real-time GNSS satellite ephemeris and clock correction for
Precise Point Positioning (PPP) (2011/06~)
Centimeter Level Augmentation Service (CLAS) (2018/01~)

Issues of CLAS :

The coverage area of CLAS is restricted to the territorial land and the Sea of Japan

→ Coverage of all QZSS orbit areas are impossible

Improvements in this research :

Transmitting precise orbit and clock correction from QZSS

→ It can be used in entire Asia-Oceania regions

MADOCA : Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

Previous researches on verifications of MADOCA :

Vehicles → Taro Suzuki, Nobuaki Kubo and Tomoji Takasu, "Evaluation of Precise Point Positioning Using MADOCA-LEX via Quasi-Zenith Satellite System", Proc. of ION ITM 2014, 2014.

Agriculture →Japan Aerospace Exploration Agency : Automating the Japanese Farm, http://global.jaxa.jp/article/special/michibiki/noguchi_e.html

Issues of Previous researches :

Verifications using ships at sea do not exist.

What's new in the present work :

Performance evaluation of long-term voyage at sea

About MADOCA and International GNSS Service (IGS)

Users can download precise orbit and clock correction for free from them.

Previous researches about IGS products :

M.Schenewerk, “A brief review of basic GPS orbit interpolation strategies”, GPS Solutions, pp.265-267, 2003.

Kenneth L. Senior, Jim R. Ray and Ronald L. Beard, “Characterization of periodic variations in the GPS satellite clocks”, GPS Solutions, pp.211-225, 2008.

Issues of IGS products :

Only GPS → It is impossible to carry out the analysis by Multi-GNSS.

15 minutes data interval → Users have to interpolate orbit and clock.

What’s new in the present work :

Analysis of benefits using precise orbit and clock by MADOCA products

Objective

We considered the utilization of MADOCA products.

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1. **Performance evaluation of long-term voyage at sea**

2. **Analysis of benefits using precise orbit and clock**

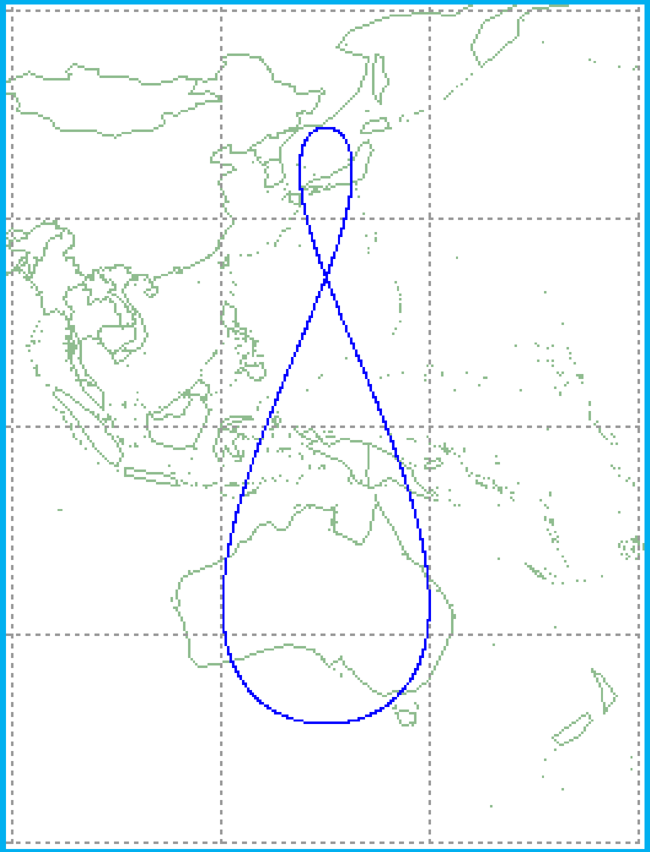
Theory : QZSS overview

- **QZSS Orbit**

First QZSS named "MICHIBIKI" was launched in September, 2010.

QZSS orbit is elliptical and known as "high-inclined elliptical orbit (HEO)".

When QZSS orbit is viewed from Japan, it draws an asymmetric figure-of-eight trajectory that comes back to the same position in about one day.



QZSS always enables users to receive signals from a high elevation angle.

QZSS Program Schedule

year	2015	2017	2018	2019	~2022	2023~
1st Michibiki	Post-Michibiki					
	In-Operation					
QZSS 4-Sat.	Launch No.2,3,4					
			Service			
					SBAS Service	
QZSS 7-Sat.		Development/Design (Additional 3 Sats.)				Service

Two Augmentation Signals

1. **Sub-meter Augmentation with Integrity Function (L1-SAIF)**

Providing wide-area differential corrections

Allowing sub-meter level positioning accuracy

2. **LEX signal**

Achieving positioning accuracy for both sub-meter and centimeter level augmentation service

These signals are under investigation for overseas users!

Theory : Status of MADOCA

- Developed by JAXA (2011/06~)
- Test transmission of MADOCA-LEX signal (2013/04/09~)
- Internet broadcasting of real-time products (2014/09/11~)
- Both of off-line and real-time processing
- Satellite orbit and clock determination for multi-GNSS constellation

GPS, GLONASS, QZSS, Galileo and Beidou

Processing Pattern	System	RMS error		Notes
Off-line	GPS	orbit (3D)	1.81cm	wrt by IGS Final
		clock	0.131ns	
	GLONASS	orbit (3D)	4.92cm	
	QZSS	orbit (3D)	5.99cm	24H overlap
Real-time	GPS	orbit (3D)	3.44cm	wrt by IGS Final
		clock	0.184ns	by Simulation

Experiments and results

- Both of off-line and real-time processing
- Access real-time PPP products freely

↓

- Two experiments and results

1. Use of real-time PPP product by MADOCA at sea
2. Use of precise orbit and clock for code-based positioning

Use of real-time PPP product by MADOCA at sea

- **Experiment Setup : 40 days (Tokyo~Cairns~Singapore~Kobe)**

Receiver	JAVAD DELTA-3
Antenna	Trimble Zephyr Geodetic 2
Satellites	GPS, GLONASS and QZSS
Mode	Kinematic
Elevation Mask	15°

Results and Discussion

- **Performance evaluation of PPP at sea**

  Positioning rate

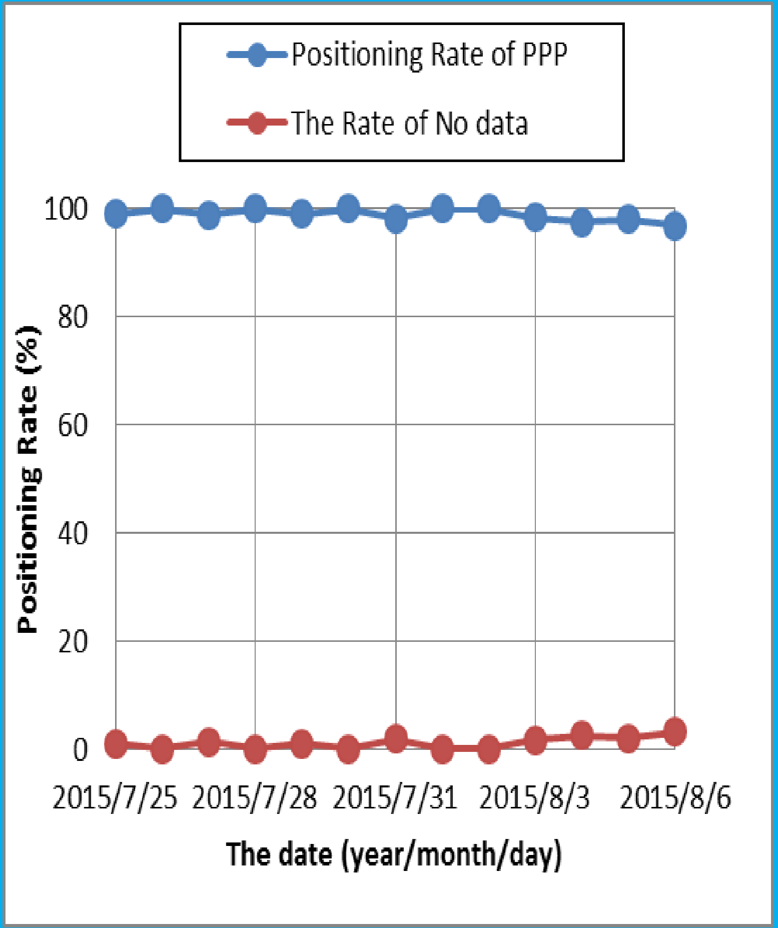
  Comparison of relative positioning solution

- **It is impossible to process an ambiguity resolution for real-time PPP product by MADOCA. → PPP float solution**

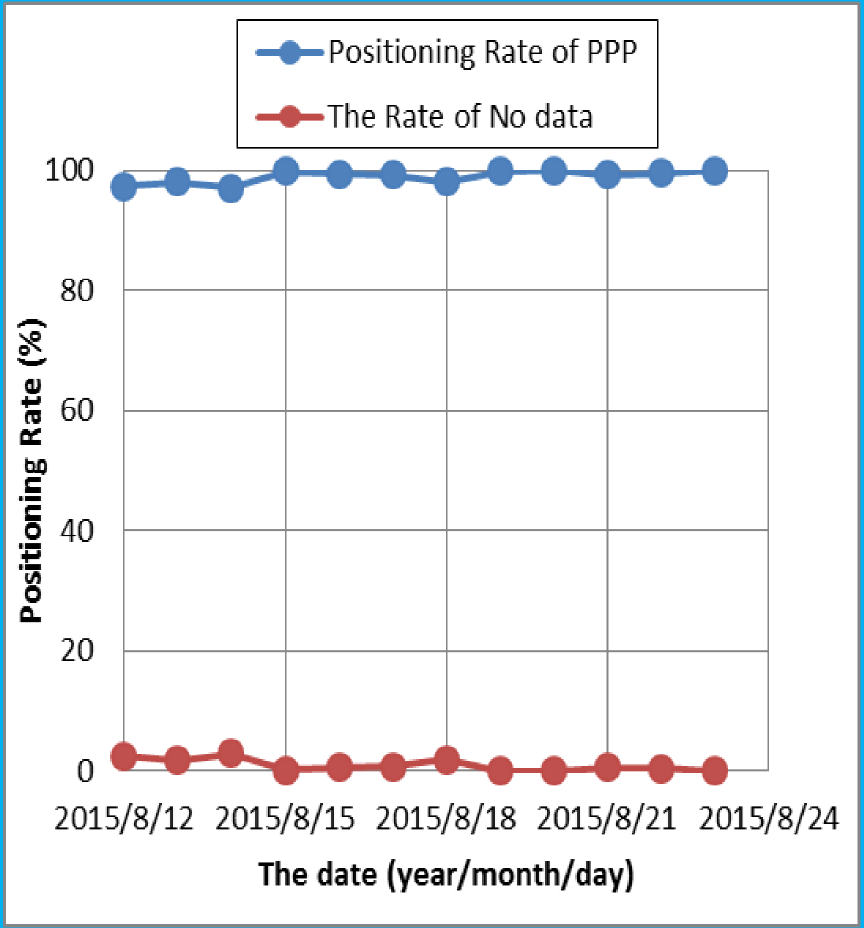
- **We analyzed results of positioning accuracy after convergence.**

Changes in Positioning Rate

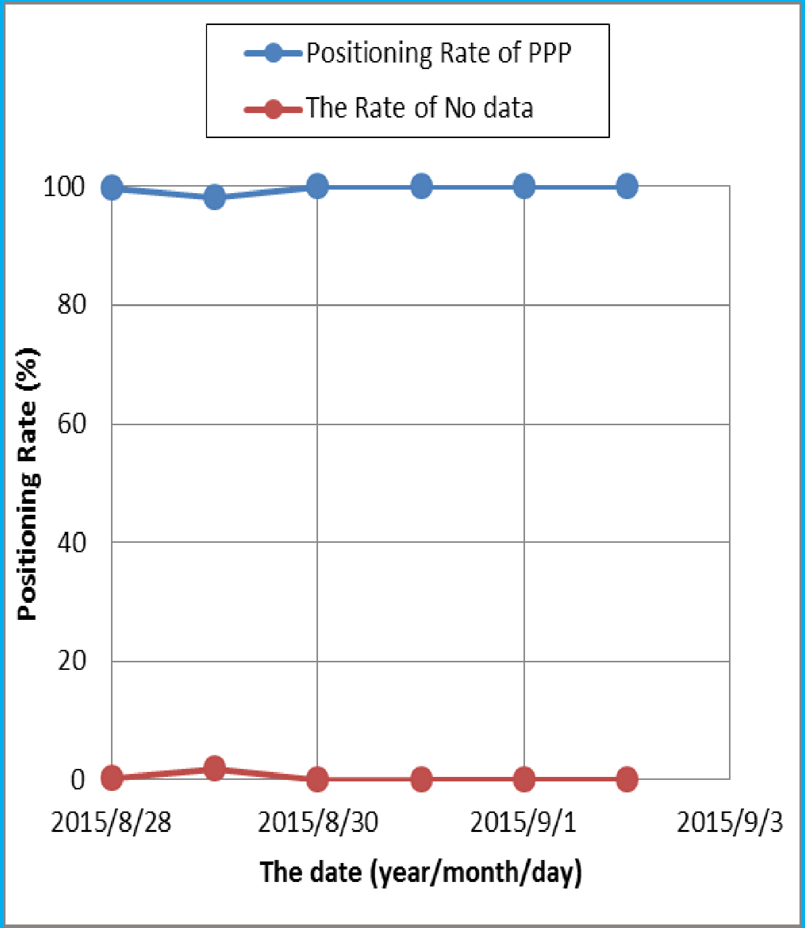
Tokyo ~ Cairns



Cairns ~ Singapore

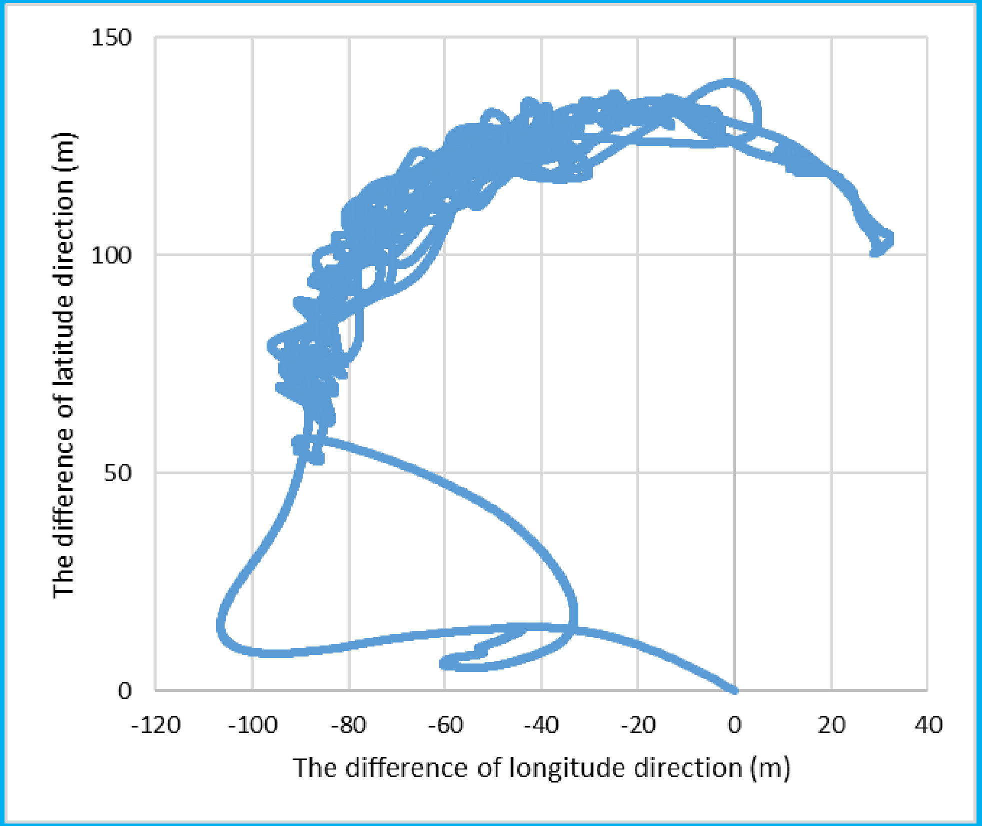


Singapore ~ Kobe

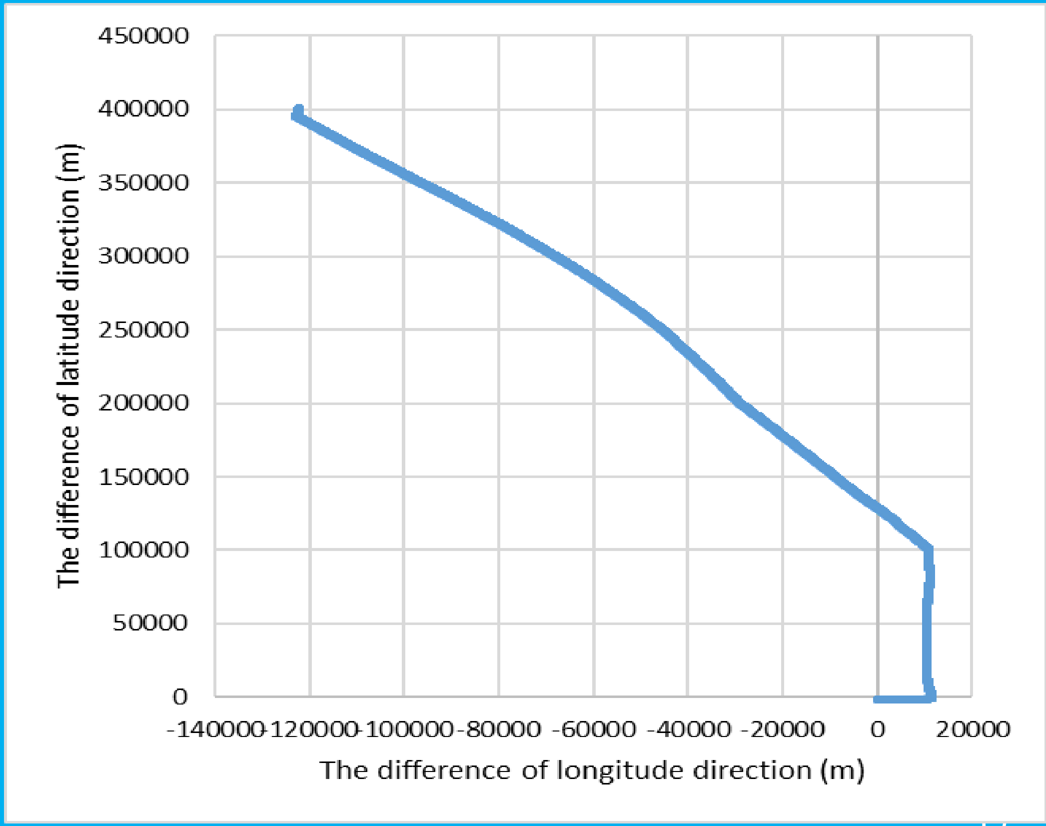


The Track in Horizontal Direction

Anchored State

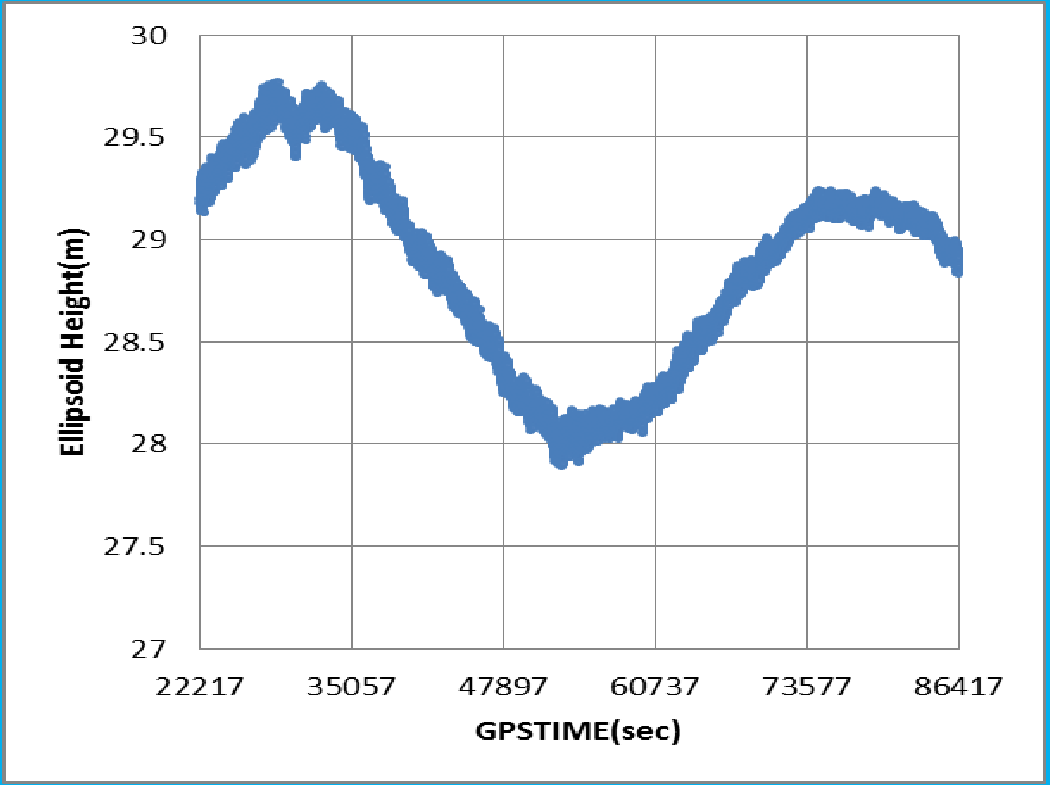


Navigational State

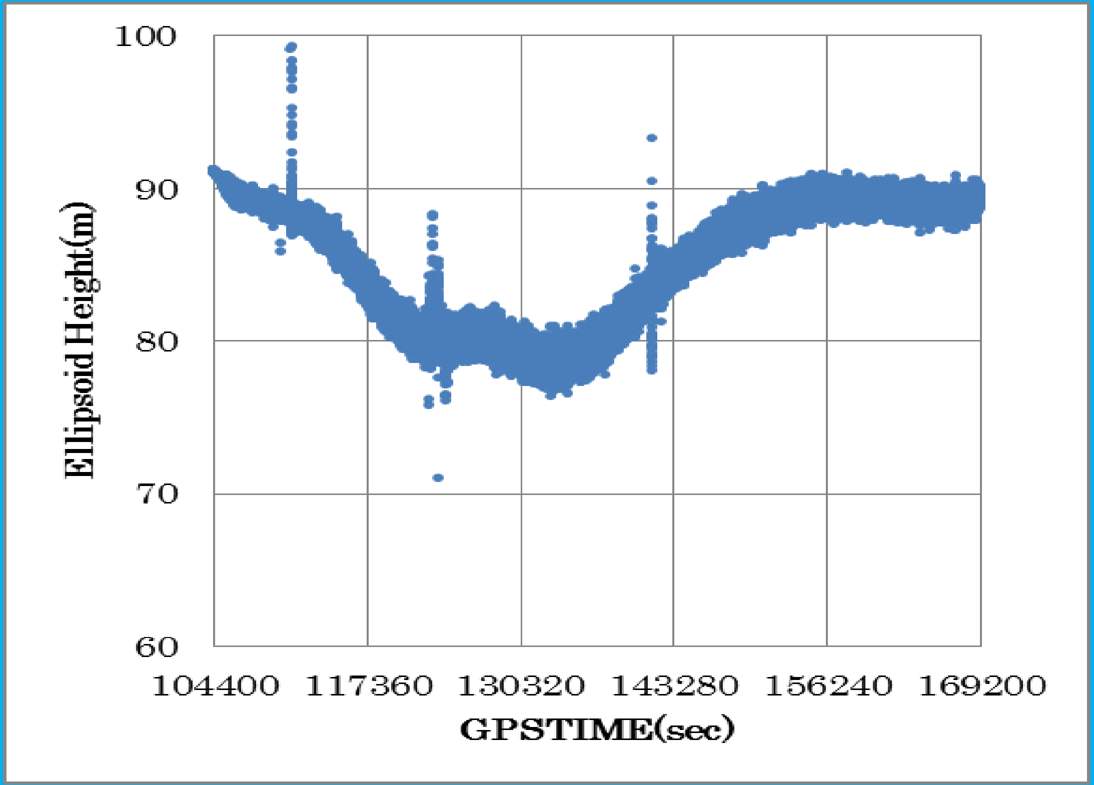


The Track in Vertical Direction

Anchored State

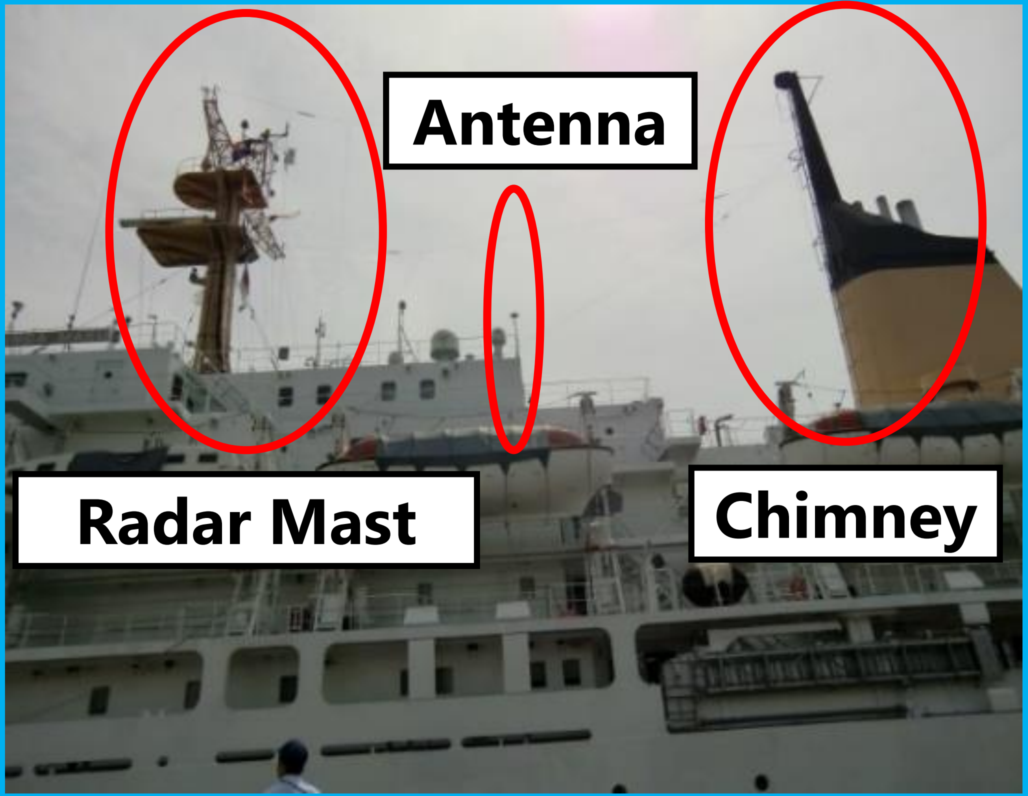


Navigational State

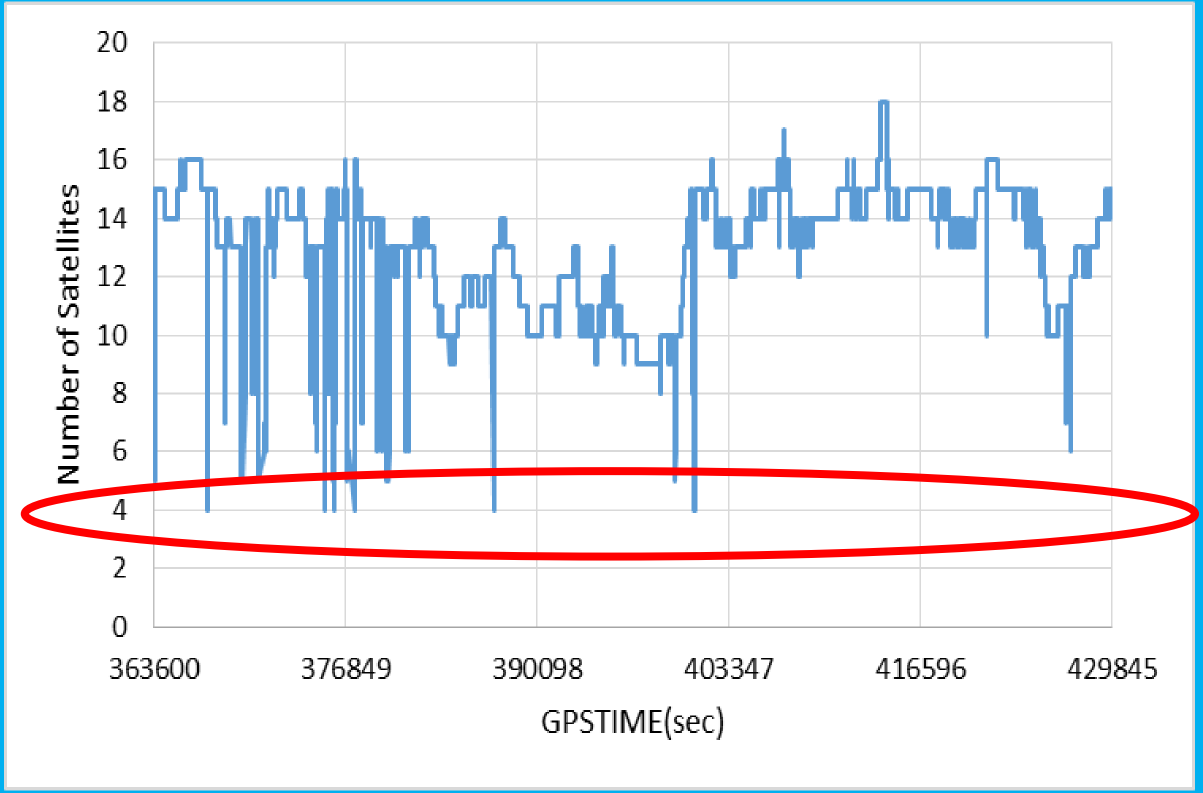


Experimental Environment and Change in the Number of Satellites

Experimental Environment



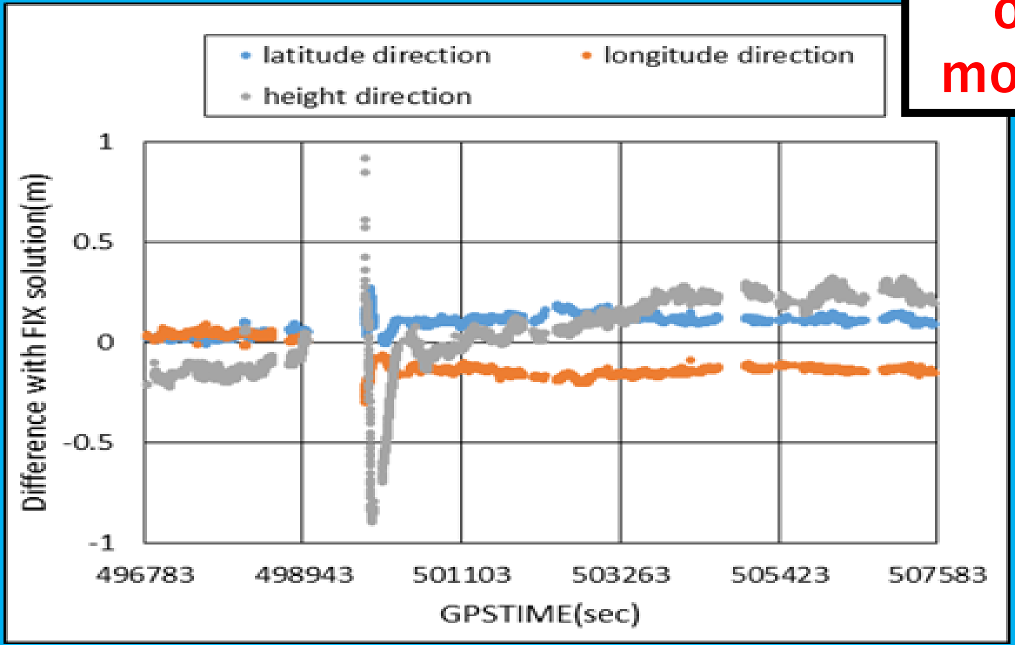
Change in the Number of Satellites



Comparison of Relative Positioning Solution
at Tokyo Bay

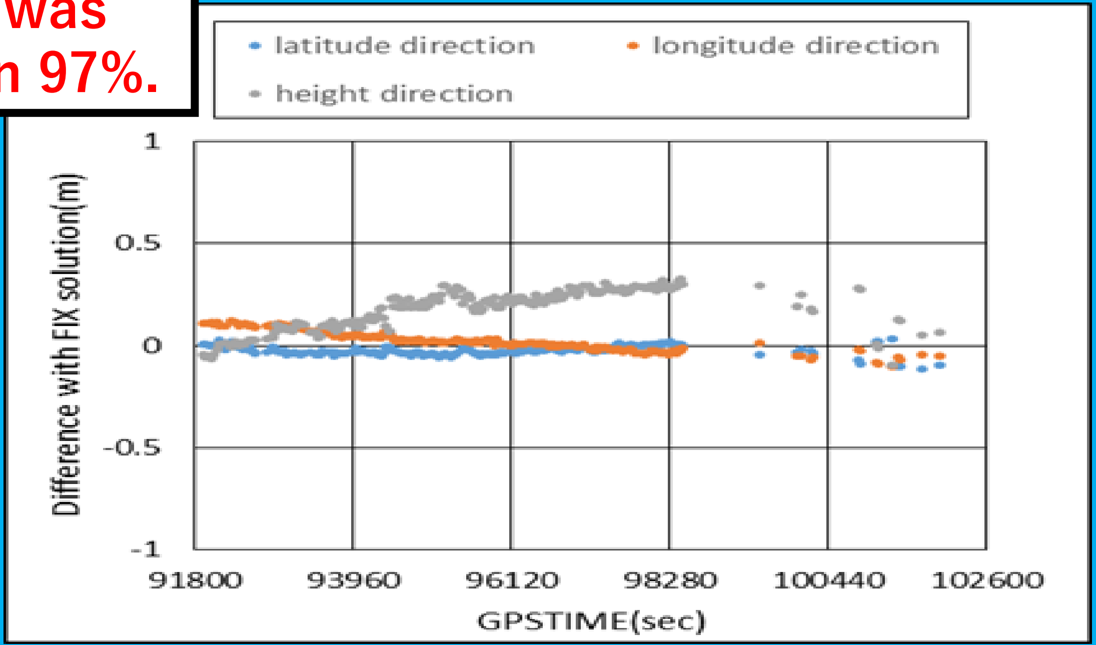
Positioning Rate of PPP was more than 97%.

Anchored State



	Latitude (m)	Longitude (m)	Height (m)
Standard Deviation	0.043	0.077	0.186
Average	0.102	-0.100	0.056
RMS	0.111	0.125	0.194

Navigational State



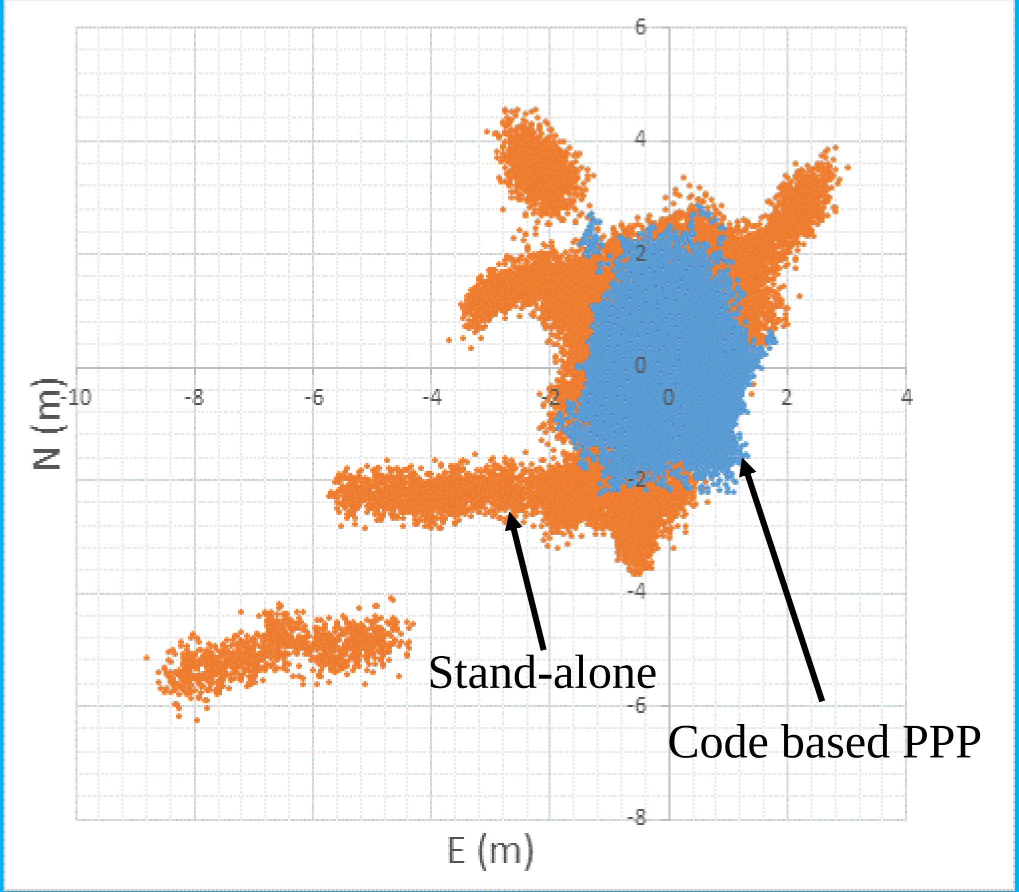
	Latitude (m)	Longitude (m)	Height (m)
Standard Deviation	0.022	0.046	0.098
Average	-0.025	0.023	0.178
RMS	0.033	0.052	0.203

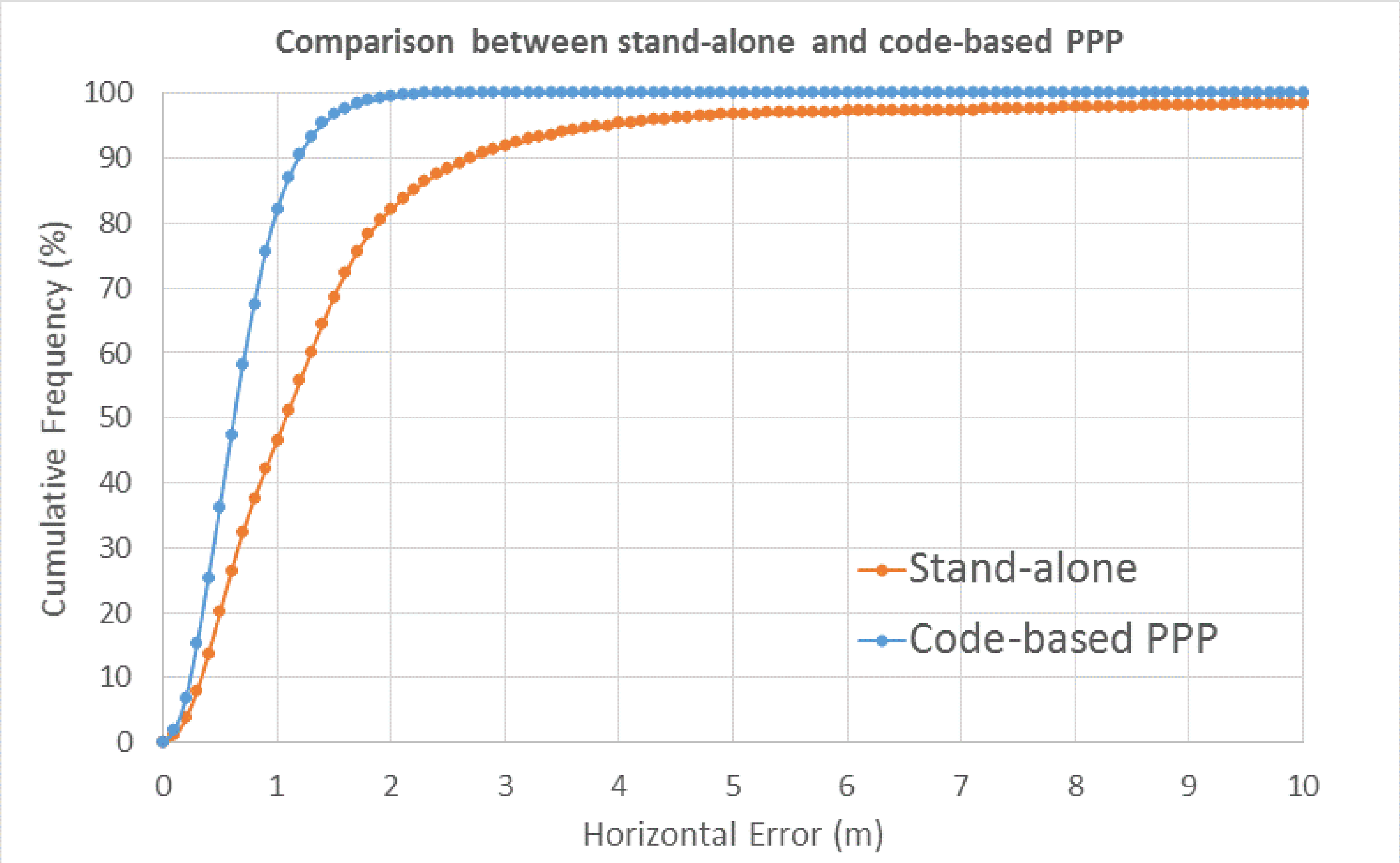
Use of Precise Orbit and Clock for Code-based Positioning

- Code-based positioning with precise orbit, clock and dual-frequency observation has a potential to provide decimeter level navigation.
- DGNSS is regional service but this is world-wide.

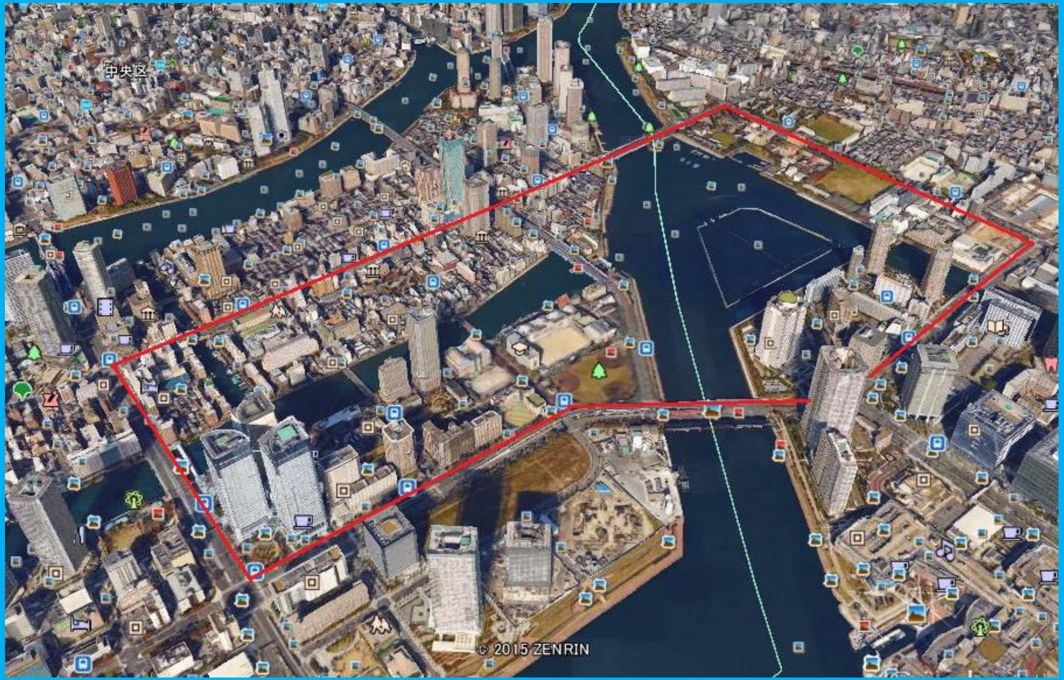
	Carrier-phased PPP	Code-based PPP
Positioning Accuracy	1-10 cm	50-100 cm
Convergence	0.5-1 hour	Instant Robustness

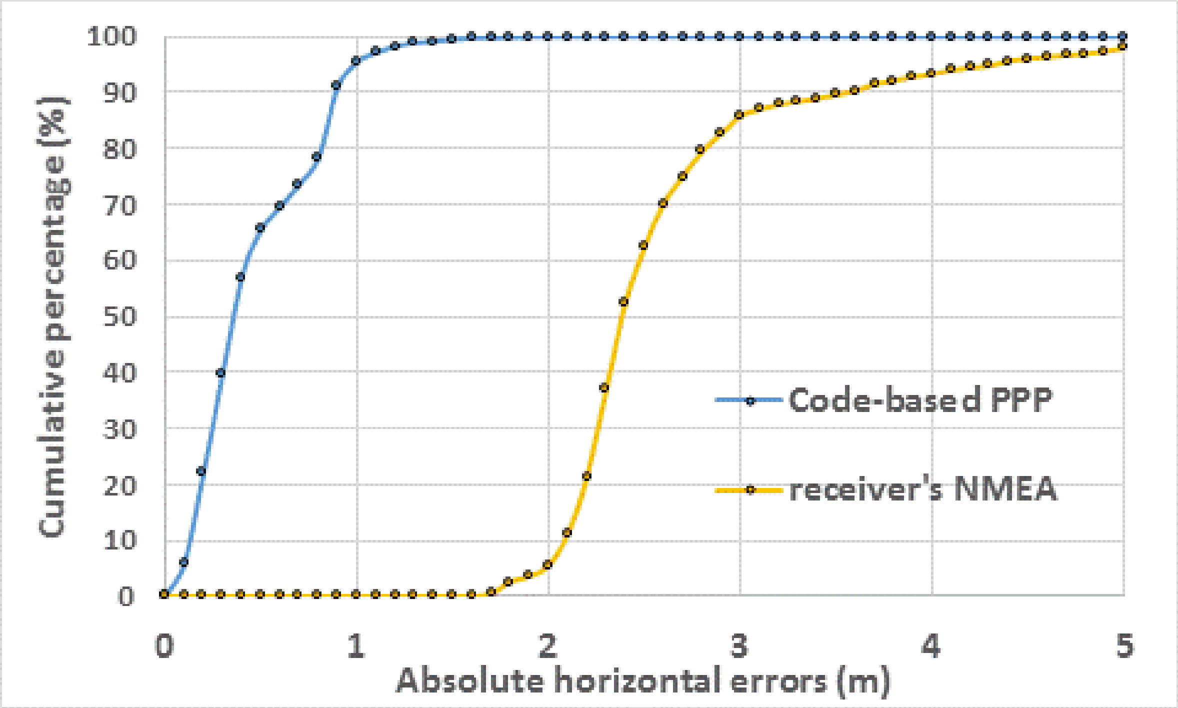
Test Results in Horizontal Direction on Land Fixed Point
24 hours of January 3rd, 2016





Test Results using Car in Urban Environment





- August 2015
- Tsukishima, Tokyo (near university)
- Semi-urban with high-rise buildings
- 20 minutes with 5Hz
- References : POS/LV

	Maximum error	% within 1.5 m
Code-base PPP	1.86 m	99.5 %
Receiver's NMEA	5.31 m	0 %

Receiver's NMEA is not able to use corrections (only stand-alone)
Big difference in terms of precise orbit, clock and ionosphere errors

Conclusion

- Positioning rate of PPP was very high 97%-100%. Positioning accuracy on board was approximately 10cm. It is possible to use all over the world.

- We achieved a decimeter level accuracy only code-based positioning by use of precise orbit and clock correction. We can widely extend service areas of a decimeter level accuracy without installing reference stations.

- MADOCA product is capable of a wide range of utilization in both land and sea applications. It will bring several benefits to users.