GNSS R&D in Japan and QZSS

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Contents

- GNSS R&D in JAPAN
  - several topics
  - university, research institute and company
- QZSS
  - system overview and program status, mission
- Activities of IPNTJ (The Institute of Positioning, Navigation and Timing of Japan)
  - IS-GNSS and summer school Introduction

GNSS activities in Japan

CABINET OFFICE
National Space Policy

University

TUMSAT, Ritsumeikan
Waseda, Keio
Tokyo, Chubu
+several universities
related to ITS

Research Institute

JAXA
ENRI
GSI

Company

Mitsubishi, NEC, TOSHIBA
FURUNO, JRC, Hitachi Zosen
EPSON, SONY, CORE
+several companies related
to ITS

The Institute of Positioning, Navigation and Timing of Japan

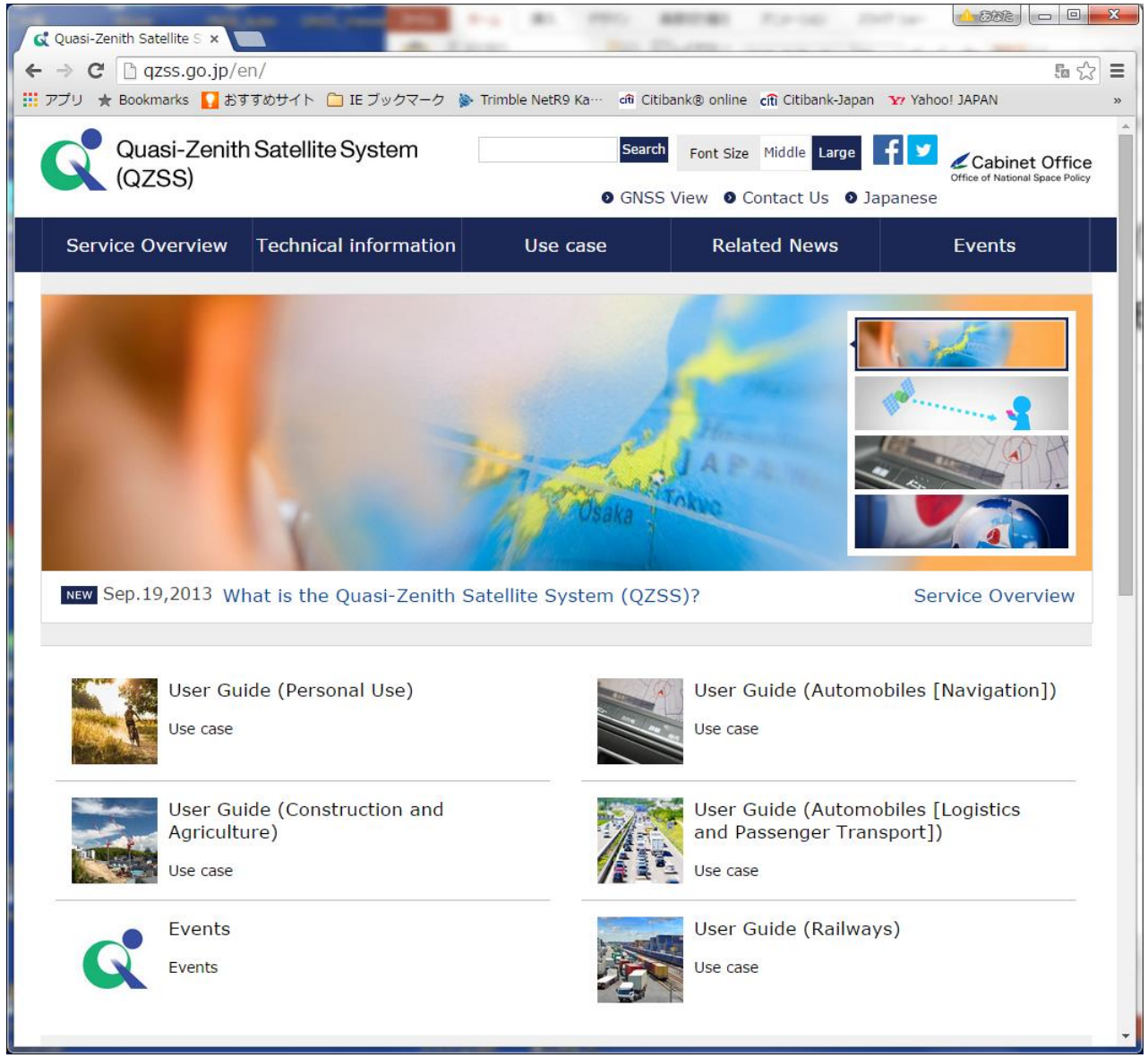
CABINET OFFICE
National Space Policy

Office at national space policy controls the activity of QZSS as well as satellite based navigation services at all points.

QZSS is one of the important space technologies for Japanese government.

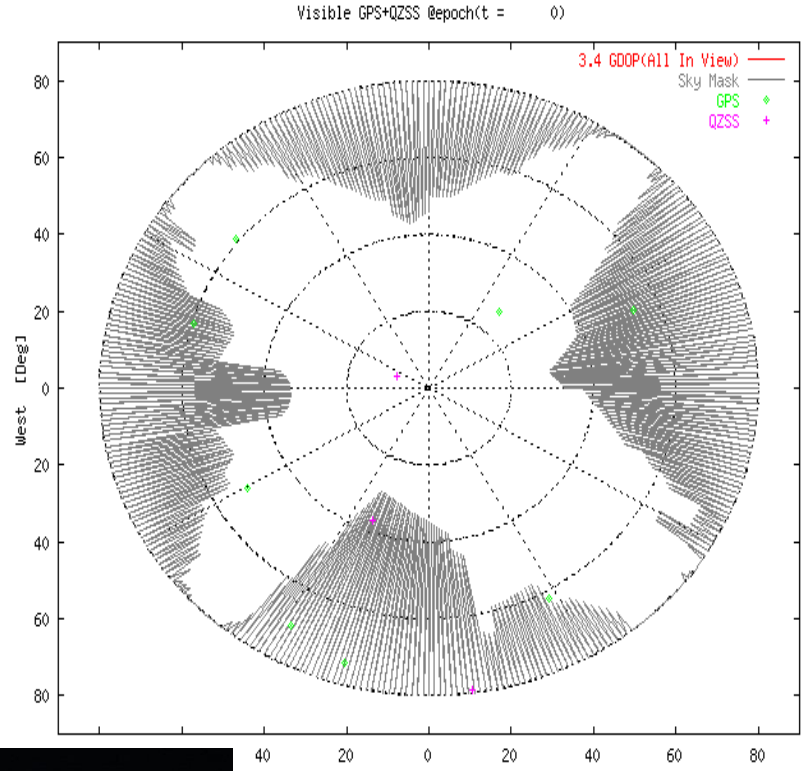
They decided to operate 7 navigation satellites.

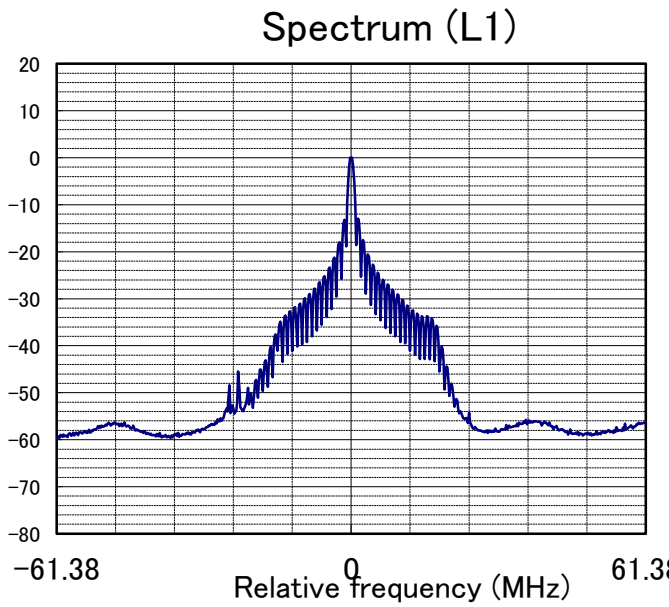
We (university, research institute and company) are somewhat involved in the activity of this office.



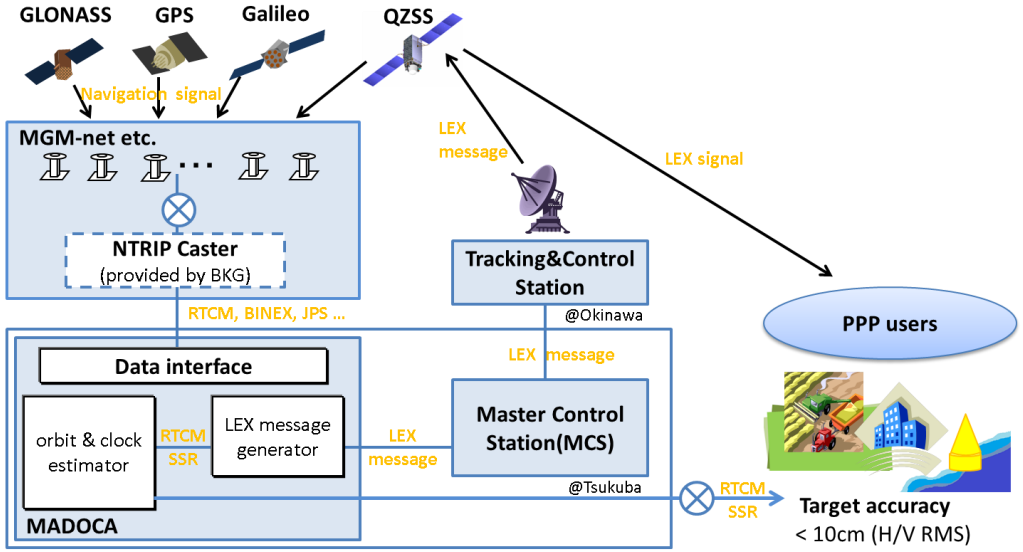
JAXA

- JAXA has developed and operated QZSS for many years.
- QZSS would not be realized without JAXA.
- Recently, the operation has been transited into QSS (NEC) from JAXA.
- Asia Oceania Multi-GNSS Demonstration Campaign has been held by JAXA since 2010.
- **Real-time PPP service** (called MADOCA) has been developed by JAXA. **Mr. Takasu** (TUMSAT) is a key developer for this project.

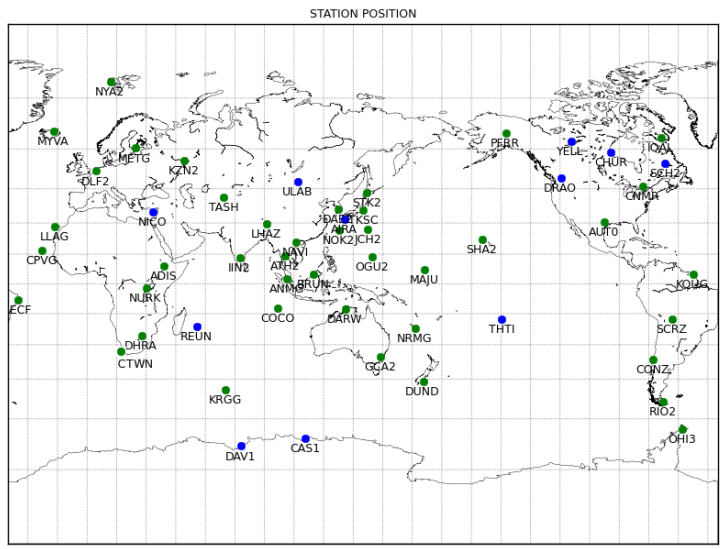




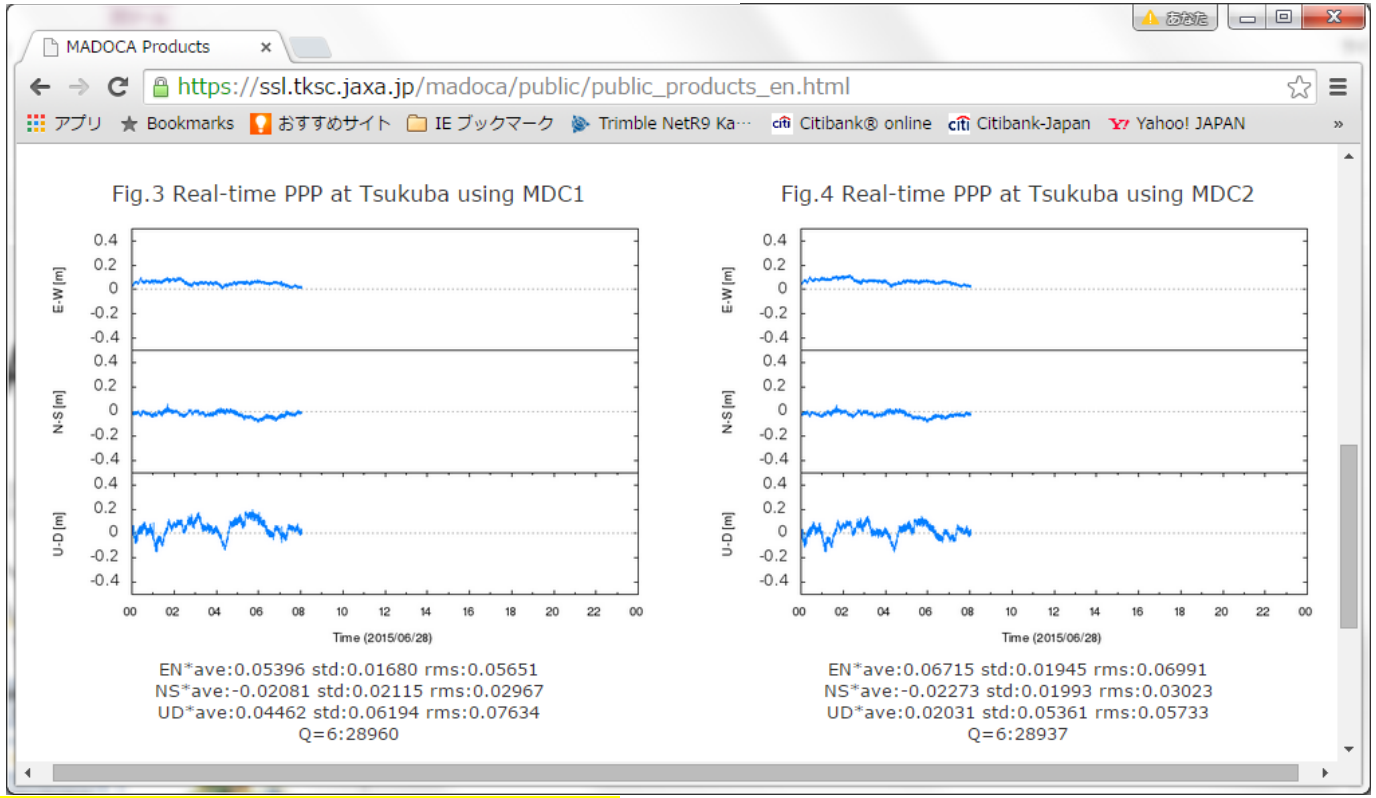
MADOCA PPP



Product	Offline			Real-Time		
	GPS	GLO	QZS	GPS	GLO	QZS
OBT	3cm	7cm		4cm	9cm	
CLK	0.1ns	0.25ns		0.1ns	0.25ns	



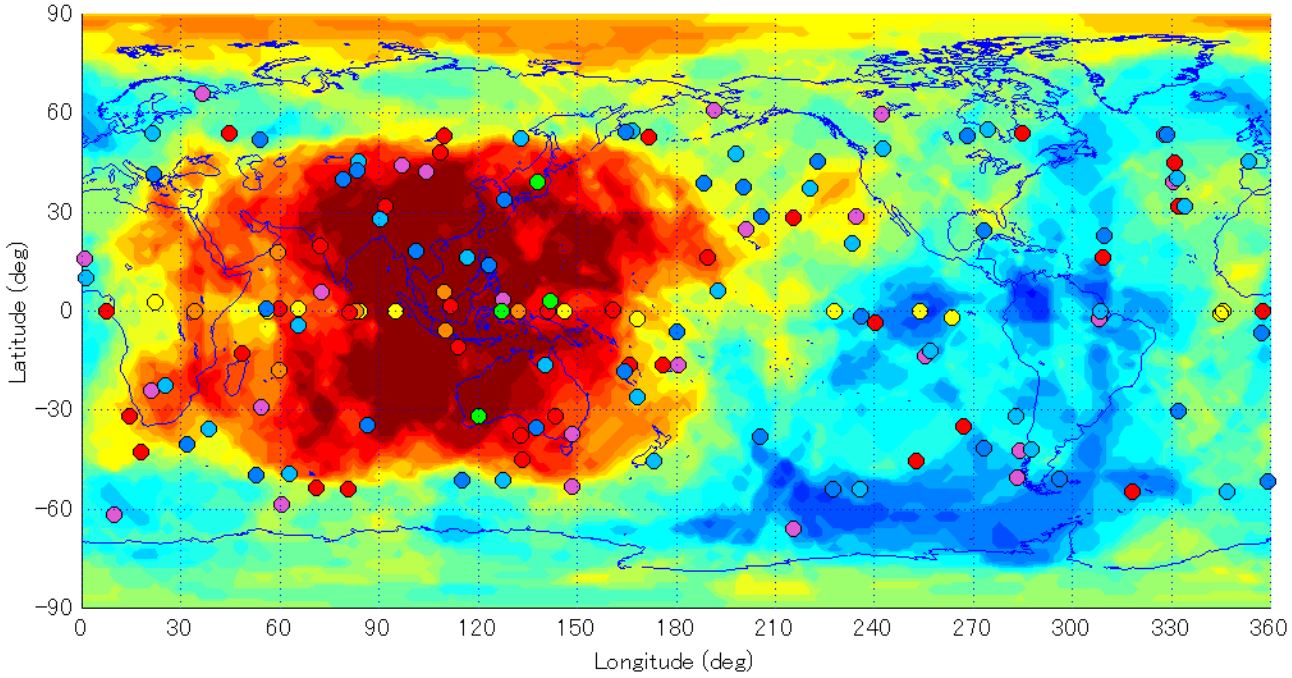
QZSS LEX signal is used to transmit correction data for PPP at present.



https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html

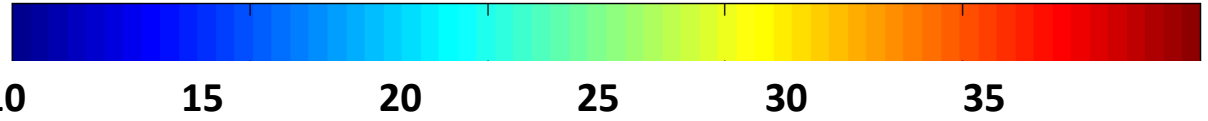
New GNSS Era : many more satellites in Asia

Visible satellite number (mask angle 30 degrees) 24 hours Disp.



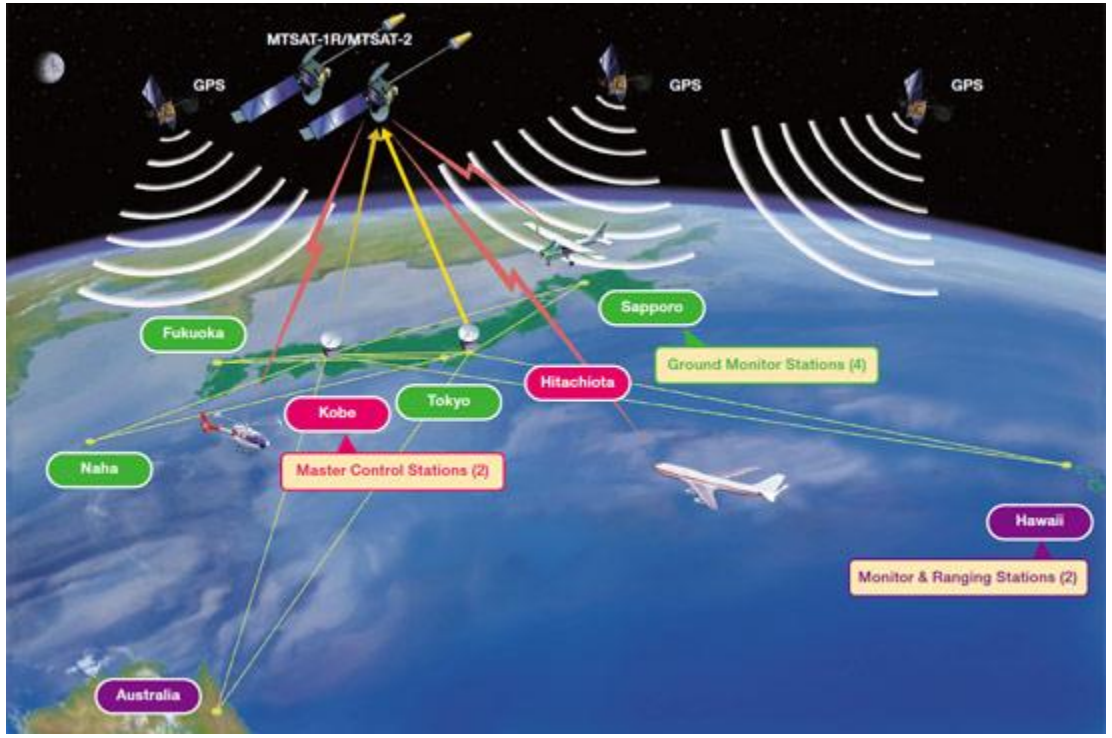
2020:

○ GPS(32)+ ● Glonass(24)+ ● Galileo(30)+ ● BeiDou(35)+ ● QZSS(4)+ ● IRNSS(7)+ ● SBAS(13)



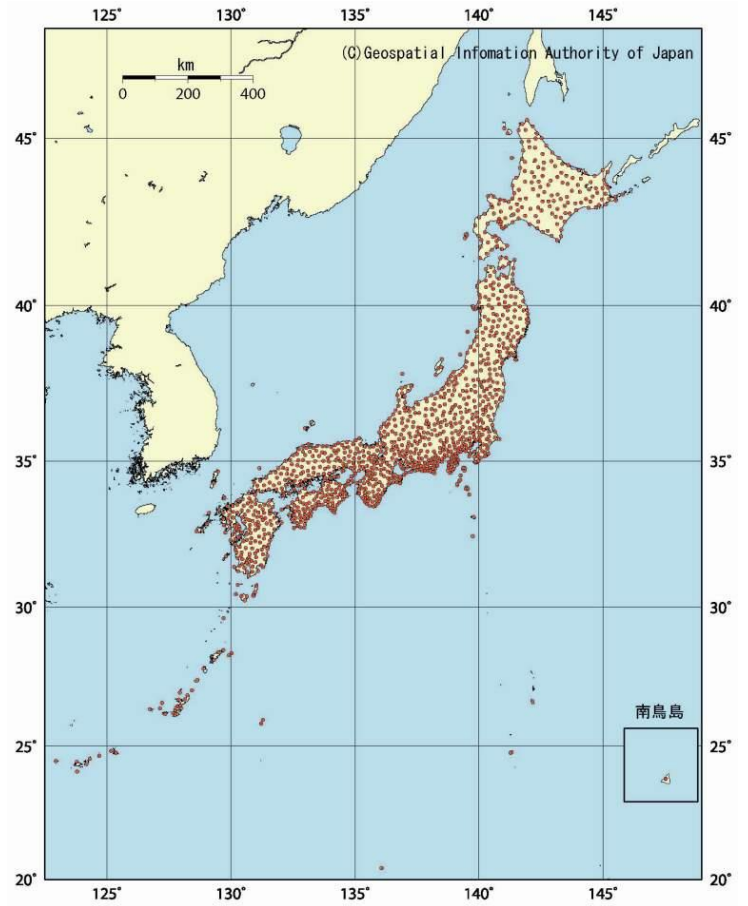
ENRI

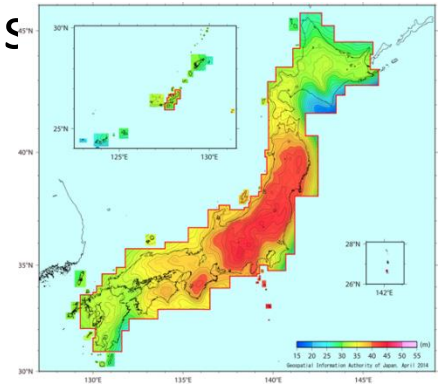
- ENRI is responsible for research and development in the field of electronic navigation in Japan.
- ENRI is the most important institute for the **development of MSAS** (NEC is a main operator).
- ENRI is the most important institute in terms of **wide area differential GNSS R&D**.
- 3 researchers in ENRI are visiting professor at TUMSAT.
- They hold international workshop as shown in the right figure.

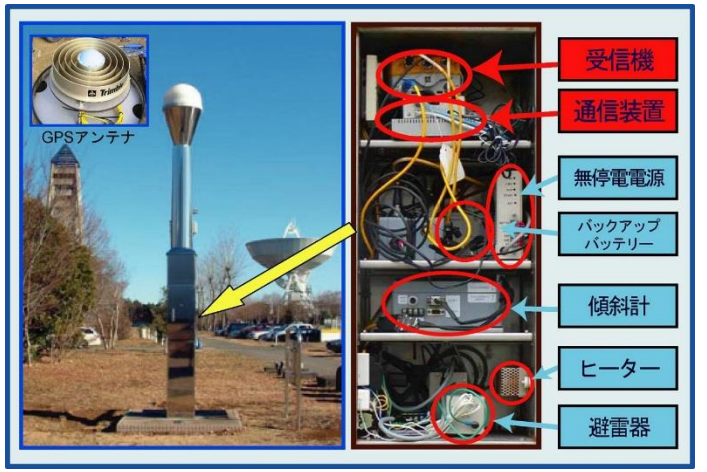


GSI (Geospatial Information Authority of Japan)

- GSI is the only national organization that conducts basic survey and mapping and instructs related organizations to clarify the conditions of land in Japan.
- **GEONET** has been operated for many years and it was quite useful for GNSS R&D.
- Recently, **REGMOS** (Remote GNSS Monitoring System) was launched for volcano monitor.
- **Precise GEOID model** has been updated.
- **Multi-GNSS R&D** related to precise positioning has been conducted since 2011 (TUMSAT joined).
- **GSILIB** (GNSS Surveying Implementation Library) was developed and now available.

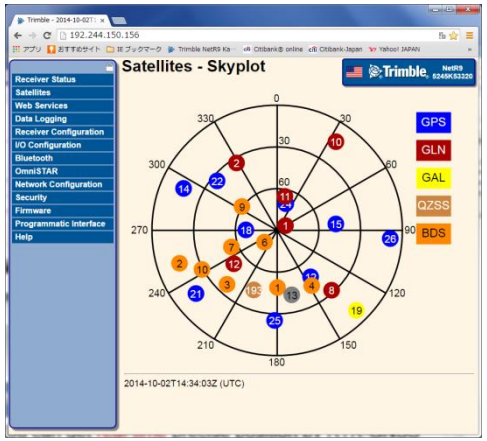






CORS Network (Universities)

CORS(Continuously Operating Reference Stations)



observation data via the Internet

Tokyo (Univ. of Tokyo, Keio Univ., TUMSAT)
Bangkok (Thailand), Manila (Philippine)

What you can do ?

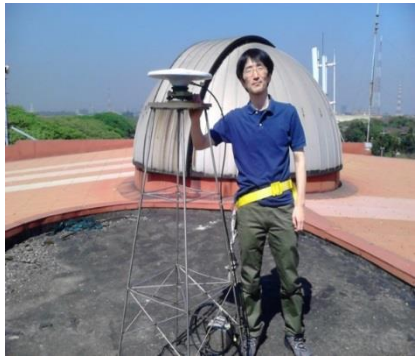
You can get real-time precise position by RTK-GNSS

Rover

Communication Link

NetR9

Reference



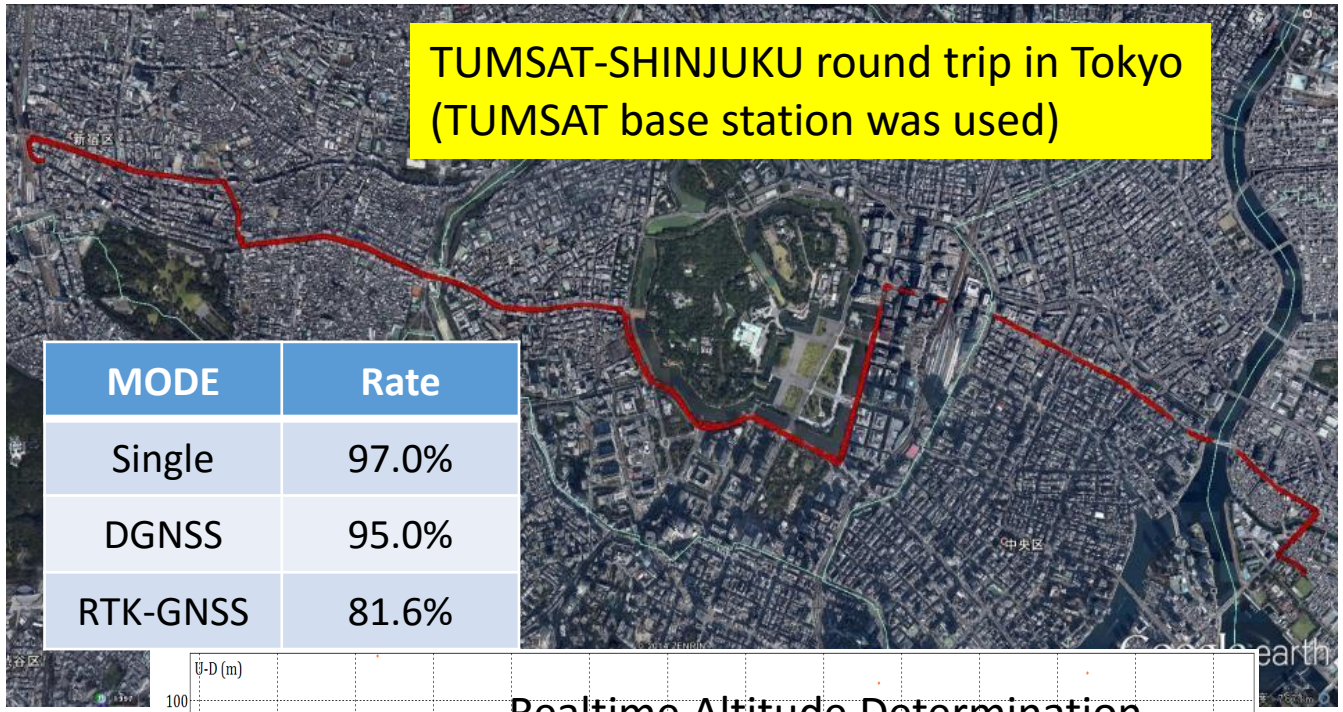
UOP

Chulalongkorn

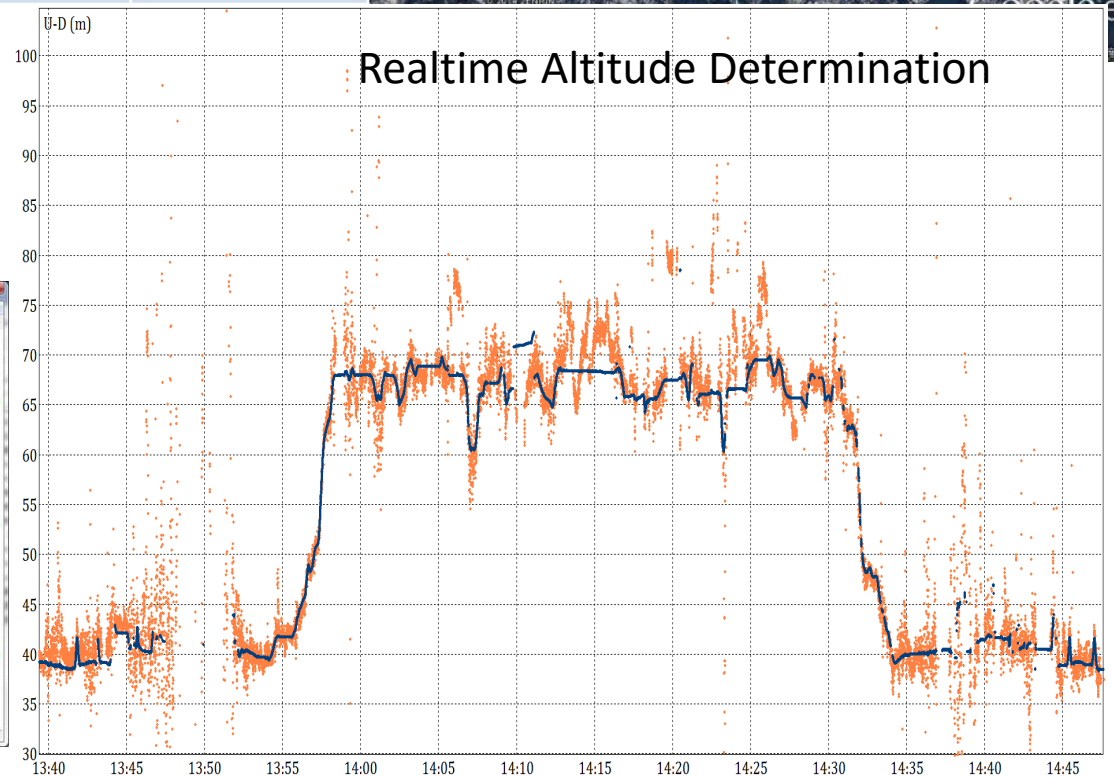
Our main objective for this work is to provide free multi-GNSS observation data to every users. Stimulating user is also important.

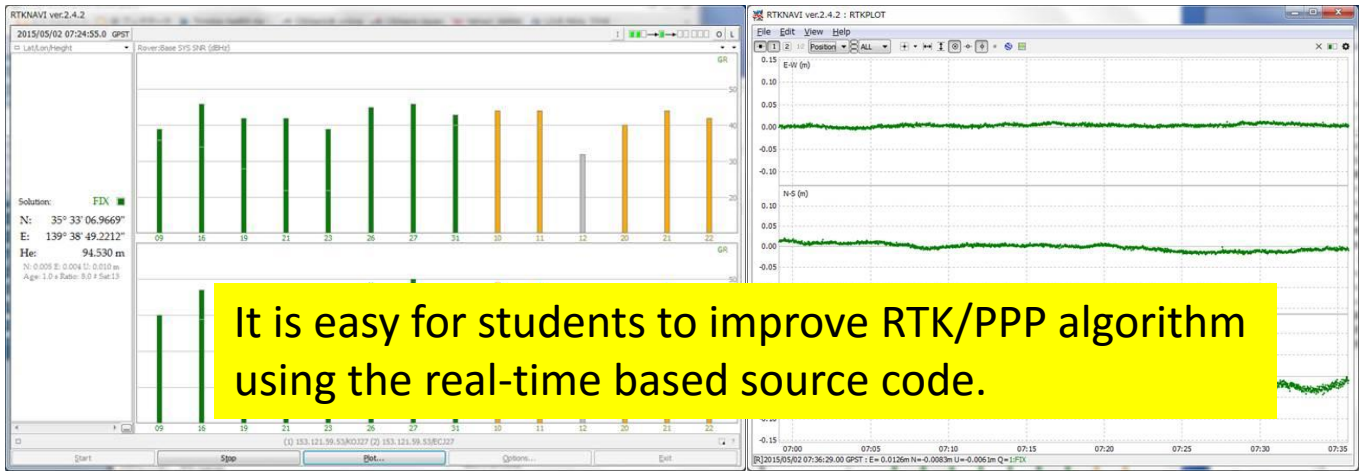
New service creation using RTK/PPP

- **Multi-GNSS RTK** improved the performance a lot even in the dense urban areas.
- However, we need to find the suitable applications to contribute society.
- **RTKLIB** is quite useful tool for research and education.



MODE	Rate
Single	97.0%
DGNSS	95.0%
RTK-GNSS	81.6%





It is easy for students to improve RTK/PPP algorithm using the real-time based source code.

BeiDou improves RTK (Car and Marine)

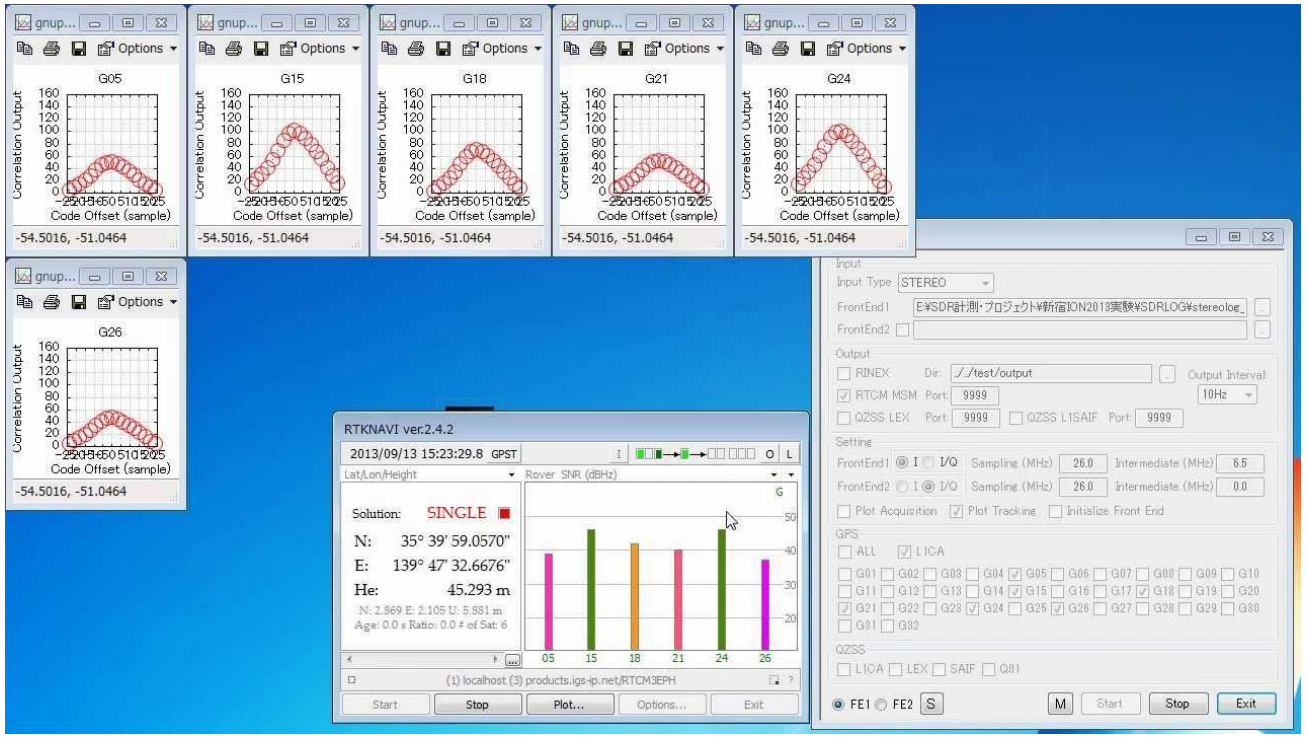
* Car test in dense urban areas with POS/LV (2014)
* Each 35-40 minutes data
* Dual frequency use
* Very few wrong fixes
* Elevation of QZS was high

		GPS	GPS/QZS	GPS/QZS/BeiDou
#1 (7:20)	FIX Rate	32.8%	43.6%	56.4%
	Distance Coverage	24.1%	31.9%	35.9%
#2 (9:41)	FIX Rate	18.8%	34.5%	50.1%
	Distance Coverage	8.9%	18.6%	28.0%
#3 (11:05)	FIX Rate	16.4%	30.4%	47.0%
	Distance Coverage	7.9%	12.9%	20.9%

TUMSAT's ship Test 24H

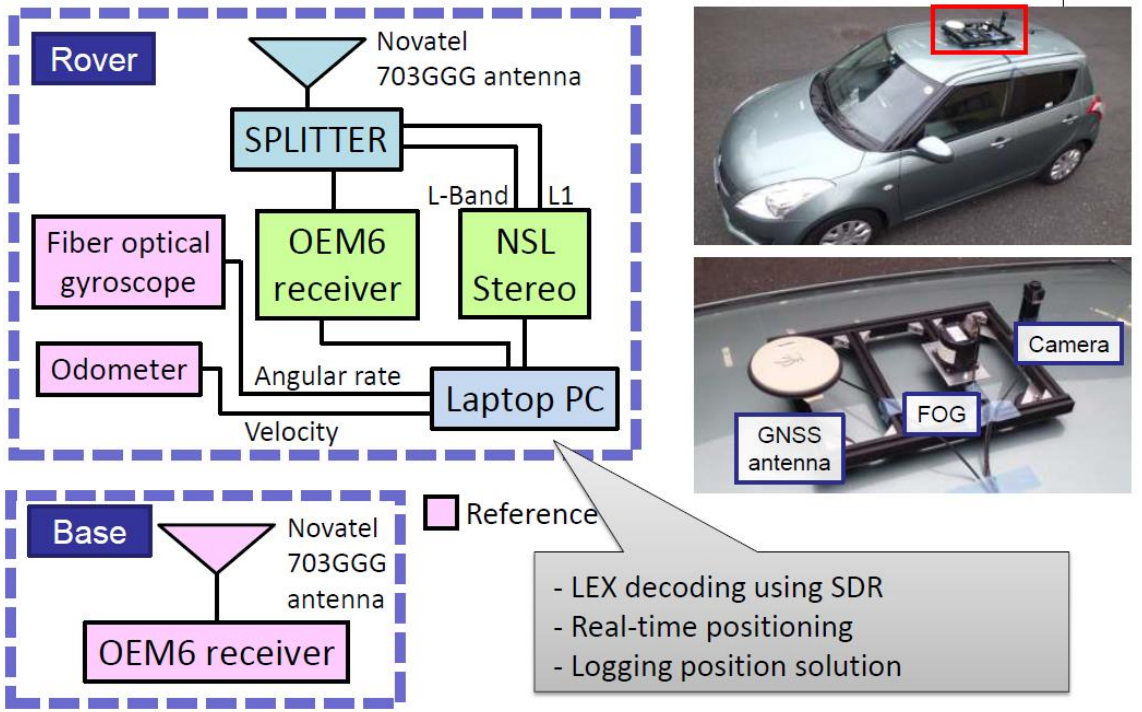
	24 hours RTK FIX Rate (%) (Instantaneous)		
	GPS	GPS/QZSS	GPS/QZSS+BeiDou
7/26/2013	40.9	49.1	90.3
7/27	50.3	60.8	87.6
7/28	62.2	68.5	91.7
7/29	64.7	70.3	92.5
7/30	55.7	60.7	82.7

SDRLIB (WASEDA Dr. Suzuki)

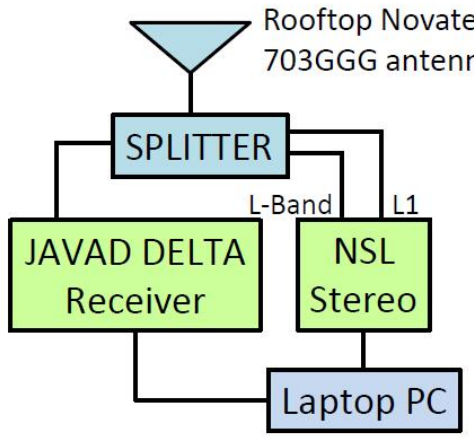


- SDR is very useful tool for R&D.
- TUMSAT has used post-processed SDR for many years, but Dr. Suzuki developed real-time version recently.
- With SDR, we can develop receiver even for LEX signal reception by ourselves.

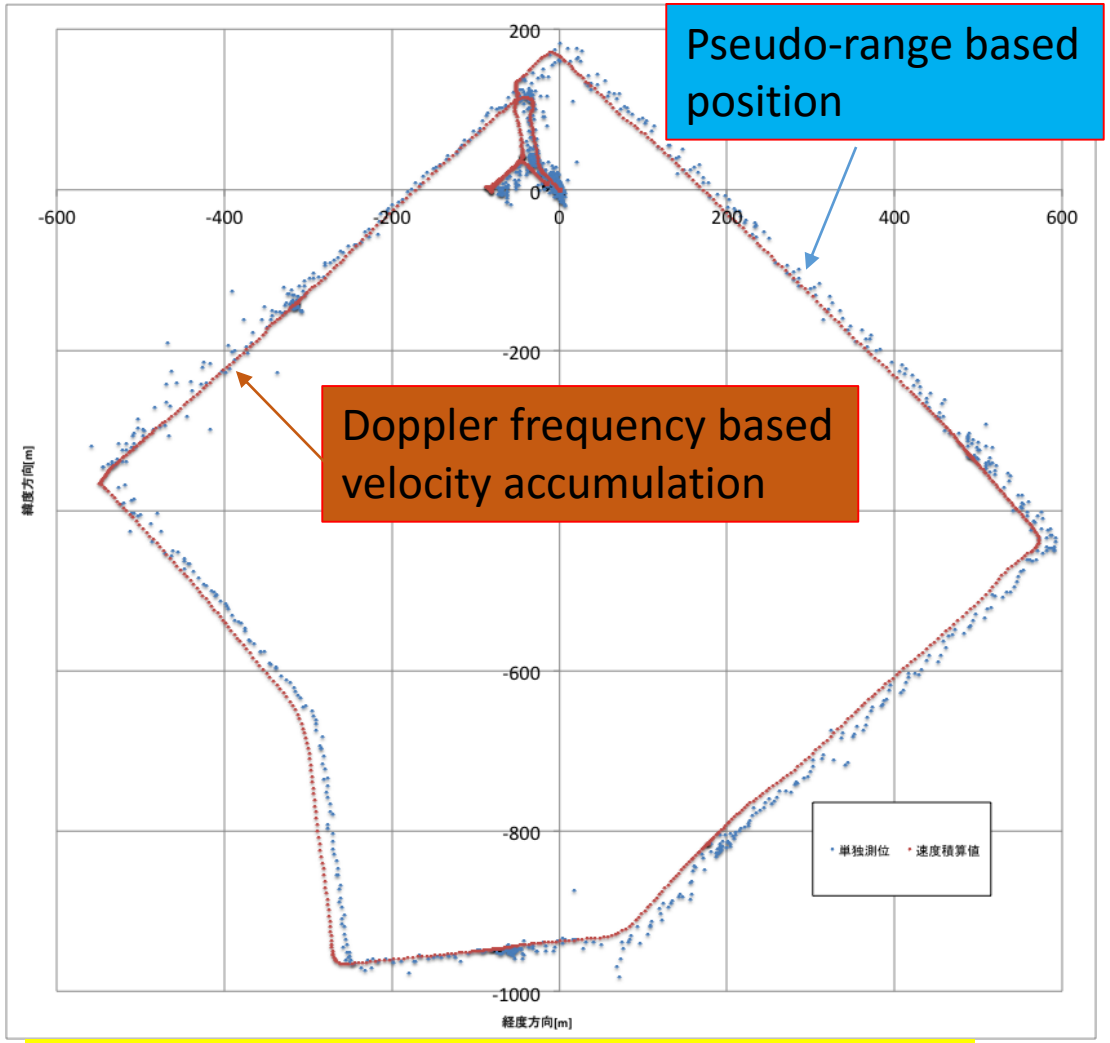
Realtime LEX PPP test (Kinematic)



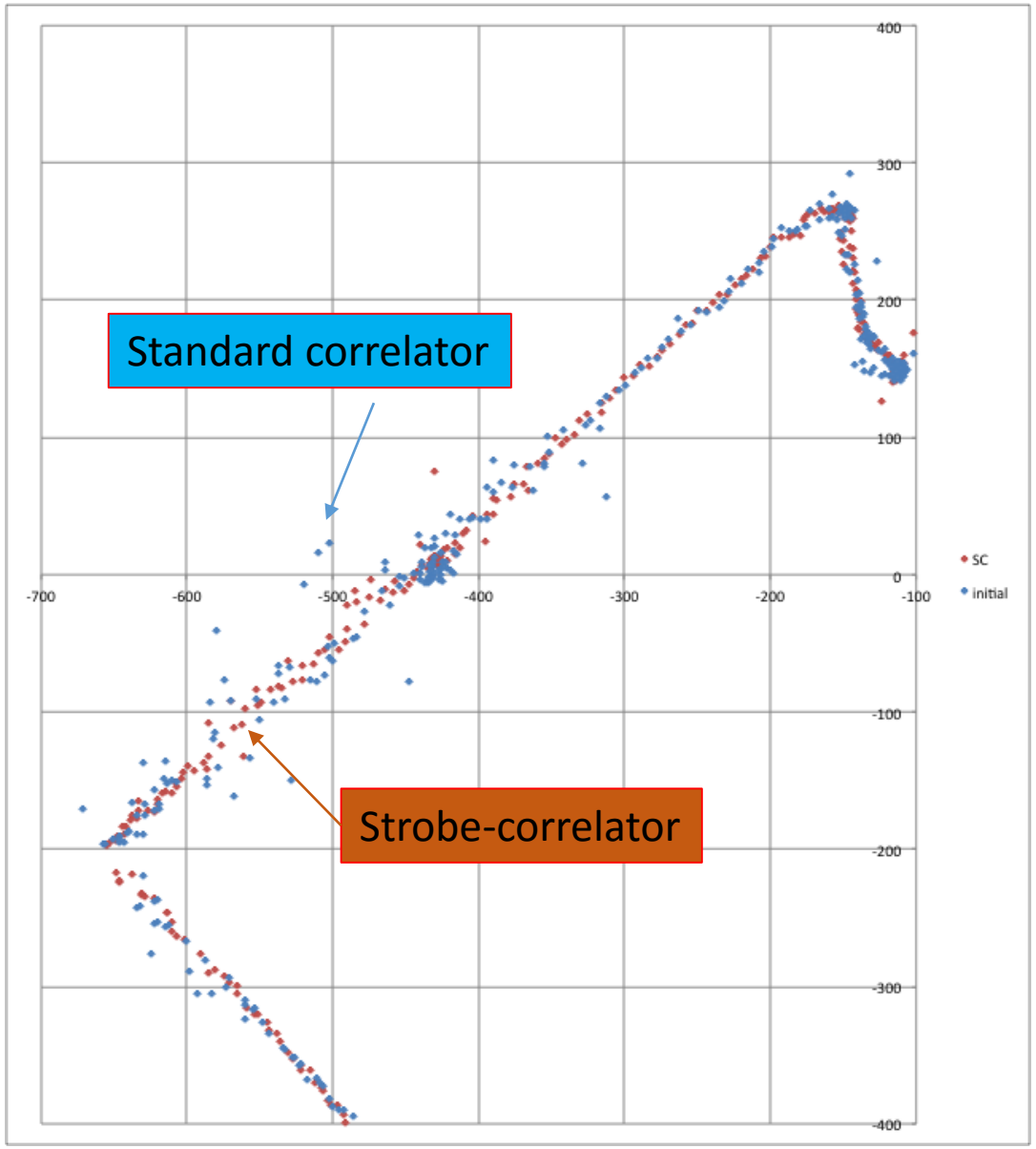
Reference path is estimated by RTK-GNSS/DR integration



The use of SDR



It is not difficult for even students (TUMSAT) to generate pseudo-range, Doppler frequency.

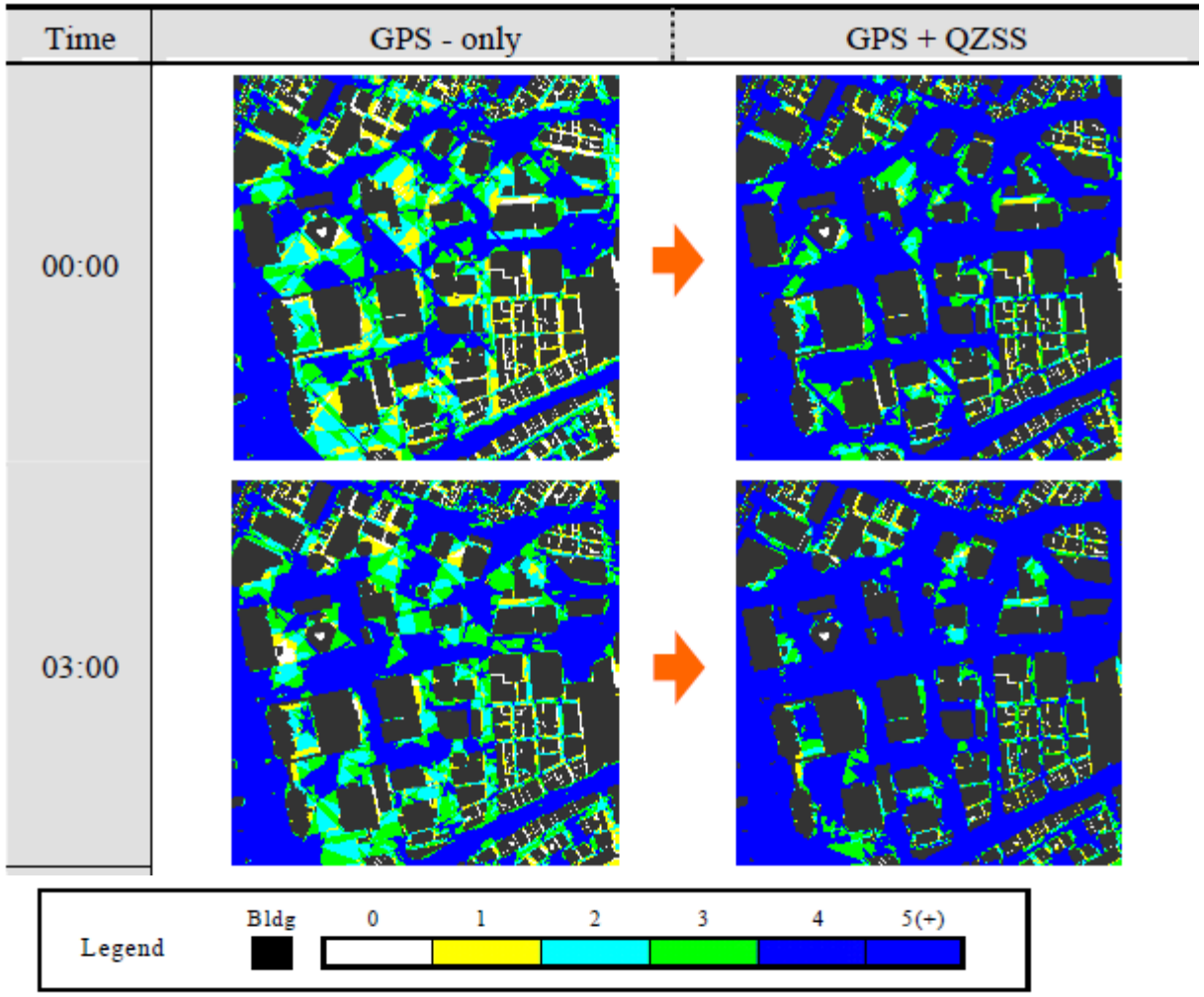


Comparison between strobe-correlator and standard correlator under high-rise buildings

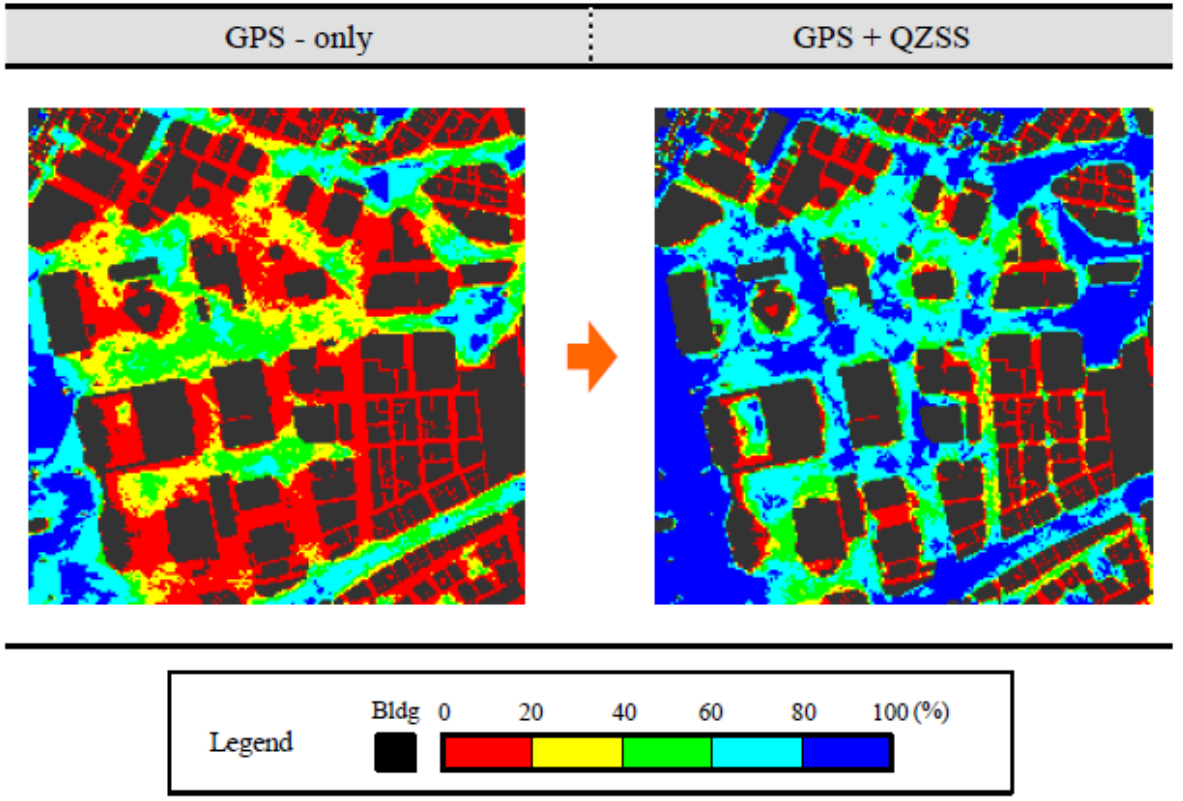
Satellite Visibility Prediction in Shinjuku (3 QZSs)

University of Tokyo 2004 Dr. Suh

Map of the Number of Visible Satellites



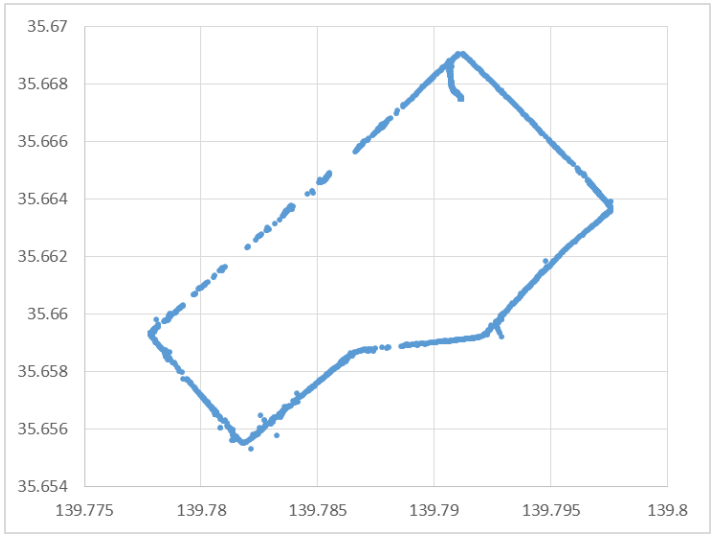
24 hours availability

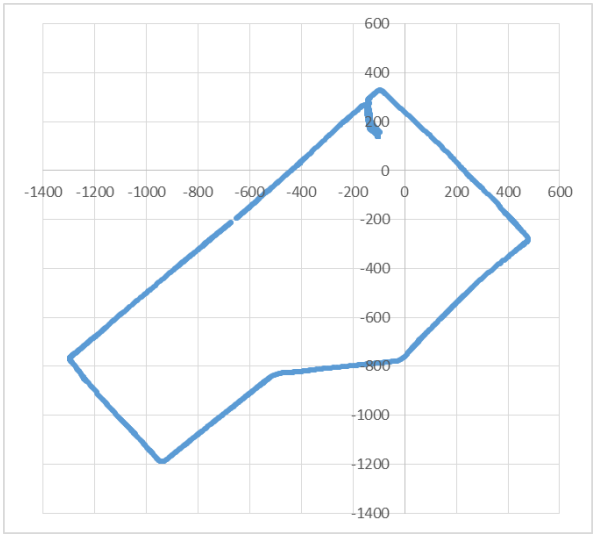


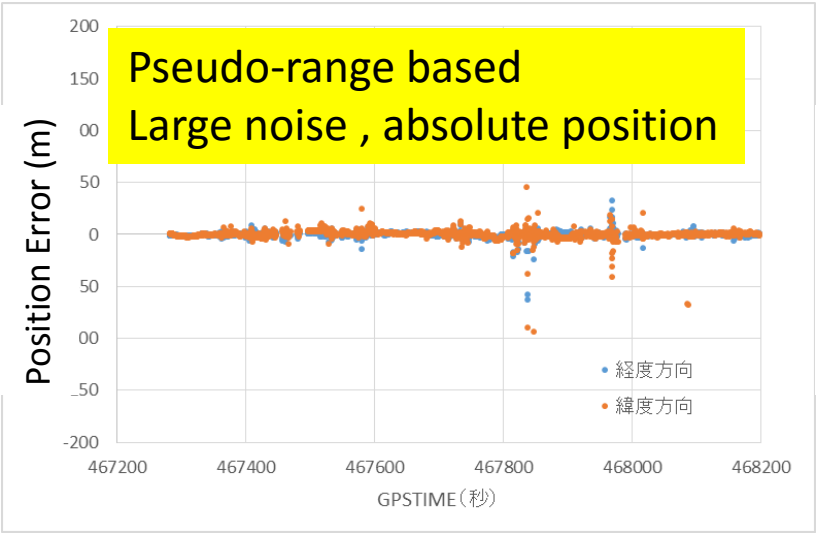
* Precise 3D model was used.
* Ray tracing method was used.
* We have developed **not only satellite visibility but positioning performance prediction**.

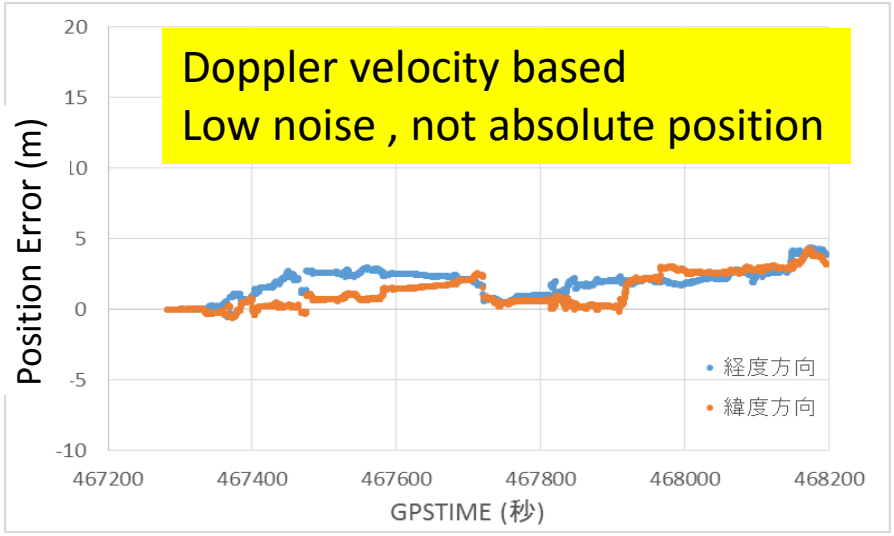
Low-cost GNSS (GPS/QZS/BEI) receiver evaluation

(KF loose-coupling using pseudo-range based position + Doppler based velocity)









$$x_{k+1} = Fx_k + Gw_k$$

$$y_k = Hx_k + v_k$$

$$\boldsymbol{x_k} = [x(k), y(k), v_x(k), v_y(k), a_x(k), a_y(k)]^{\mathrm{T}}$$

$$x(k+1) = x(k) + v_x(k)\Delta T + a_x(k)\Delta T^2/2.0$$

$$y(k+1) = y(k) + v_y(k)\Delta T + a_y(k)\Delta T^2/2.0$$

$$v_x(k+1) = v_x(k) + a_x(k)\Delta T$$

$$v_y(k+1) = v_y(k) + a_y(k)\Delta T$$

$$\boldsymbol{F} = \begin{bmatrix} 1 & 0 & \Delta T & 0 & \Delta T^2/2 & 0 \\ 0 & 1 & 0 & \Delta T & 0 & \Delta T^2/2 \\ 0 & 0 & 1 & 0 & \Delta T & 0 \\ 0 & 0 & 0 & 1 & 0 & \Delta T \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

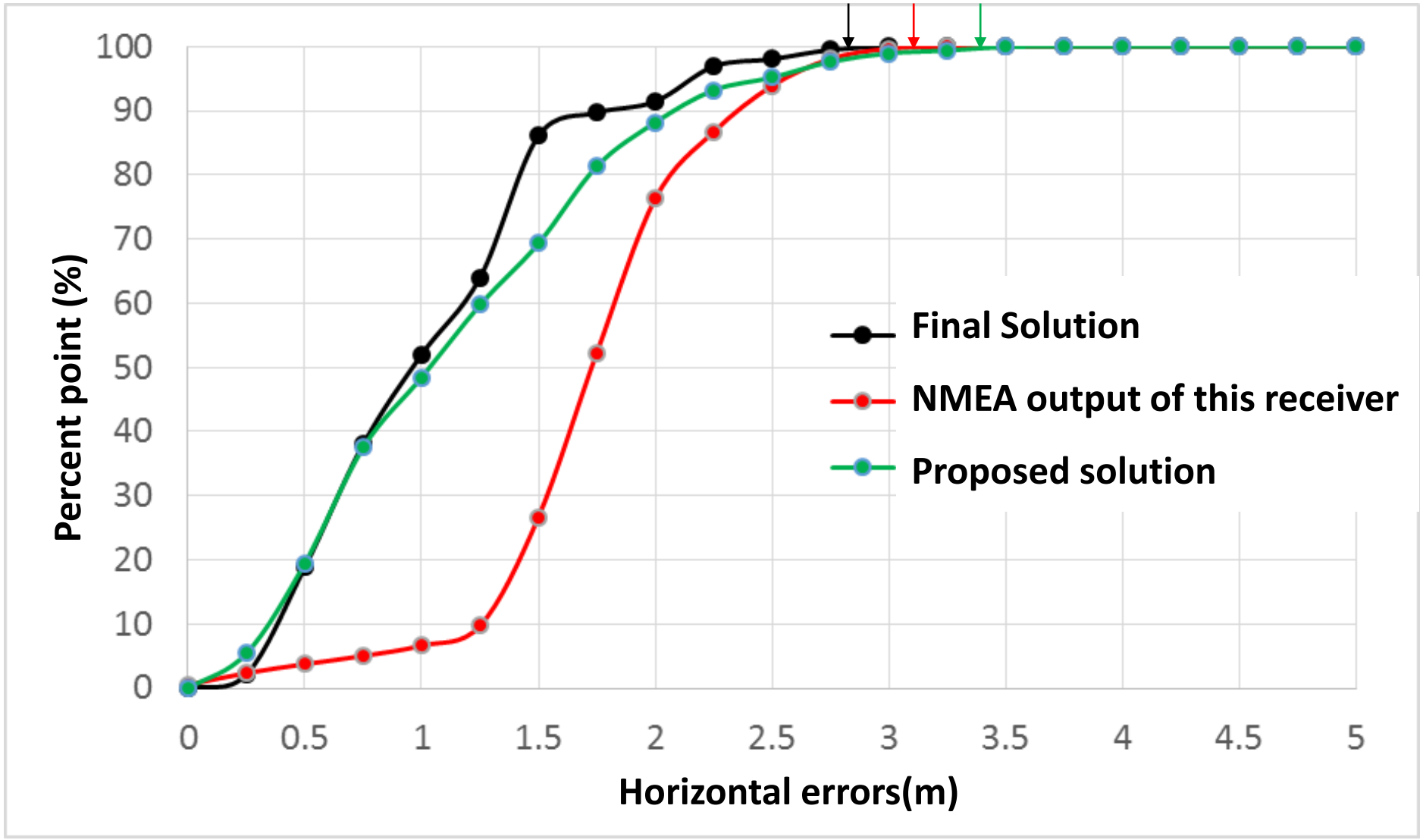
$$\boldsymbol{y_k} = [x(k), y(k), v_x(k), v_y(k)]^{\mathrm{T}}$$

$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

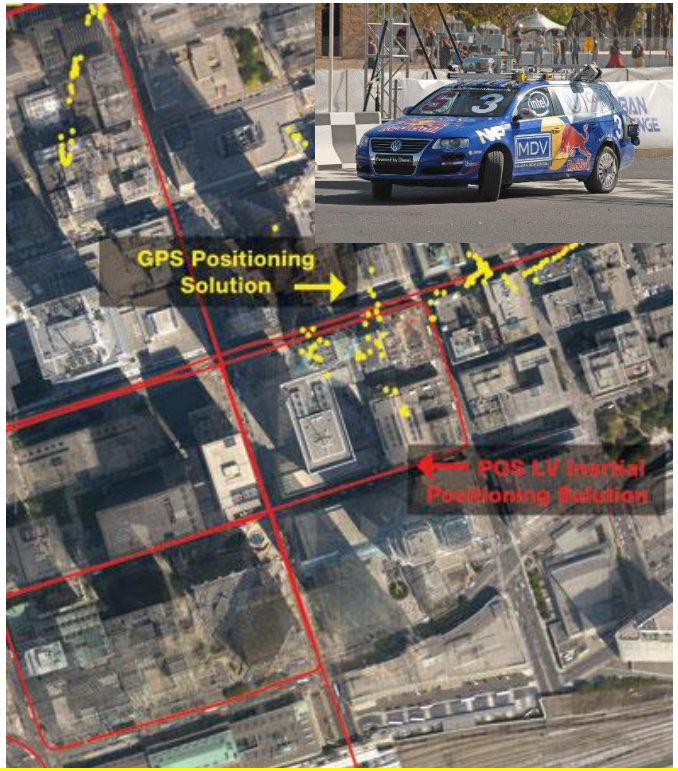
x_k : *state vector*
w_k : *system noise*
y_k : *measurement vector*
v_k : *measurement noise*

F : *state transition matrix*
G : *noise distribution matrix*
H : *observation matrix*

Absolute horizontal errors in normal urban areas using low-cost GNSS (GPS/QZS/BEI) receiver



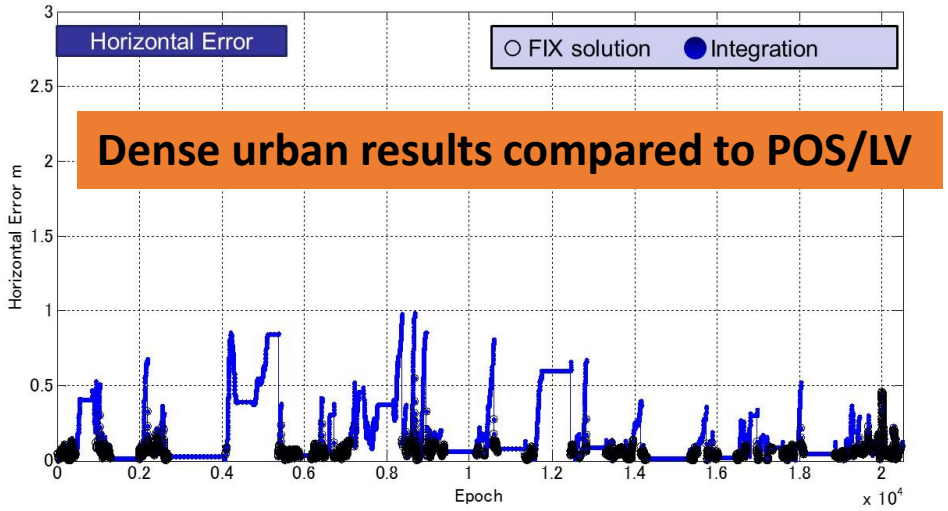
GNSS/IMU/Speed integration for reference platform car aiming to autonomous navigation



Over $300,000 for decimeter level reference car !

Our laboratory has developed integration algorithm and can provide hardware + software with $20,000.

Decimeter level
→normal urban areas
1 m level
→dense urban areas

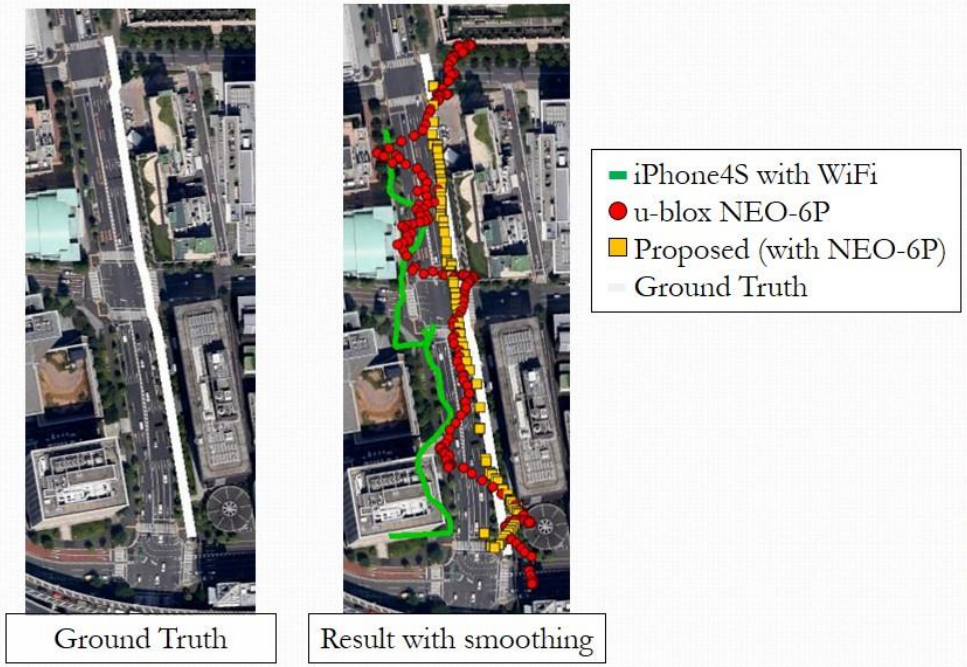


Dense urban results compared to POS/LV

University of Tokyo (Kamijo Lab.)

- He has been engaged in **ITS field** (recently several researchers in ITS are working with researchers in GNSS).
- GNSS accuracy improvement in urban areas
- Sensor integration for **pedestrian** as well as car

Experimental Results (1)



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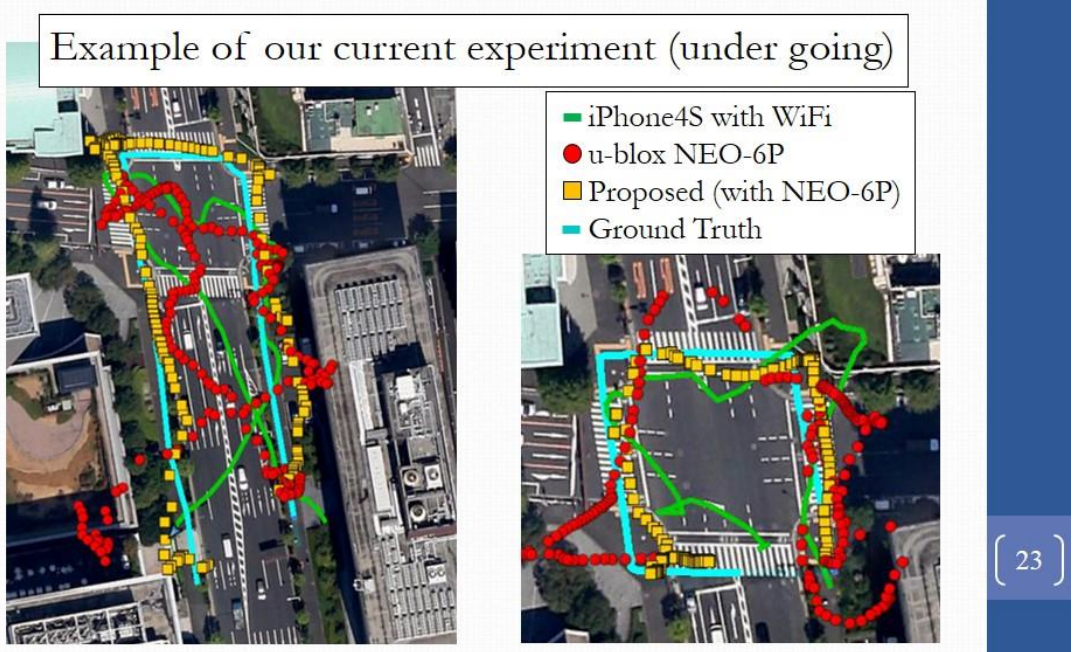
Precise Evaluation (1)



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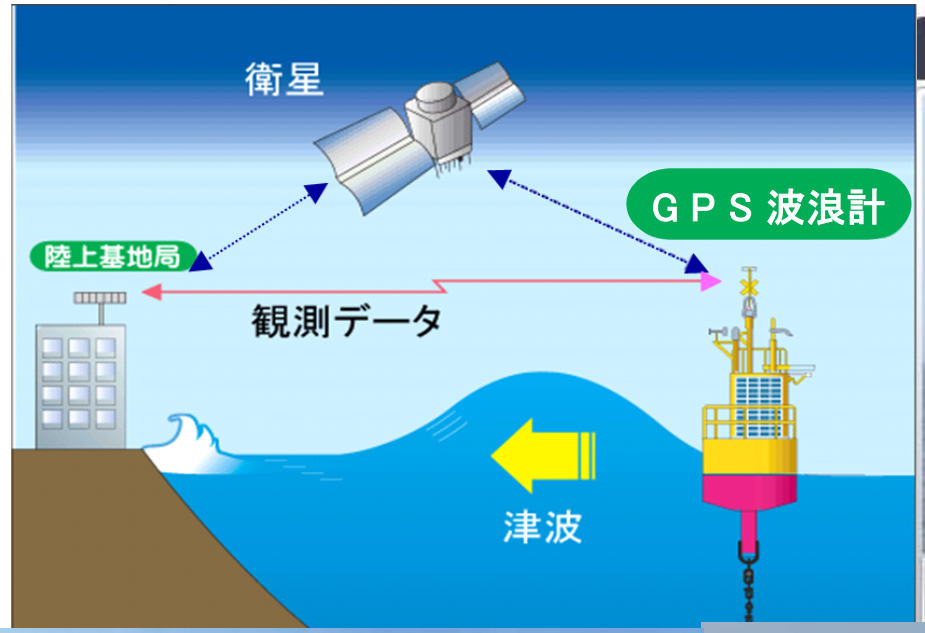
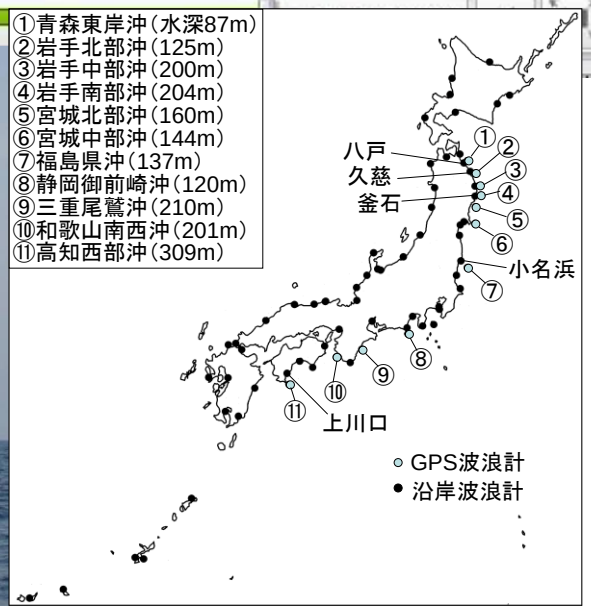
GNSS TSUNAMI BUOY



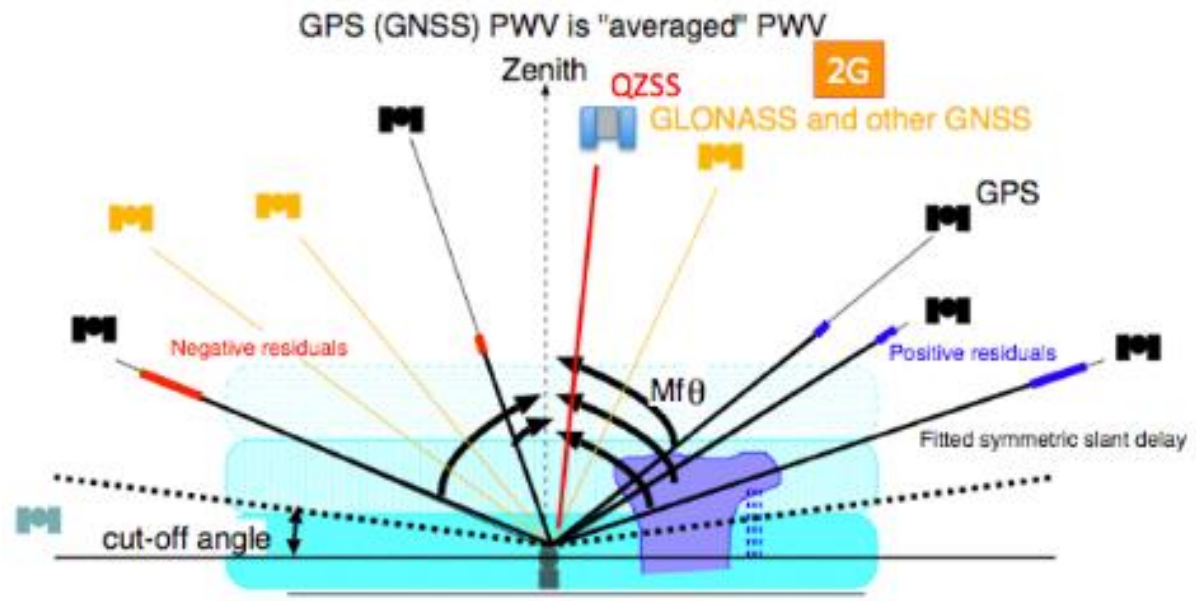


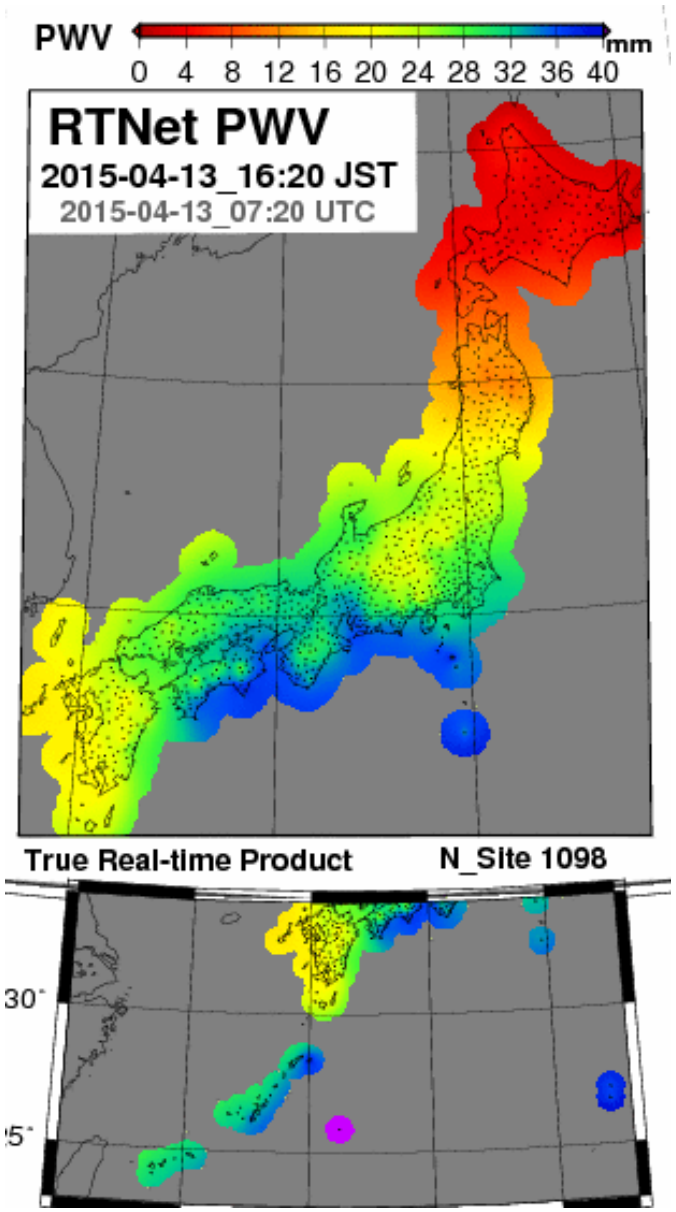
For now, 10-20km maximum baseline limitation due to RTK.

We are going to use PPP for this monitoring system in the near Future. One station has been already installed and tested.

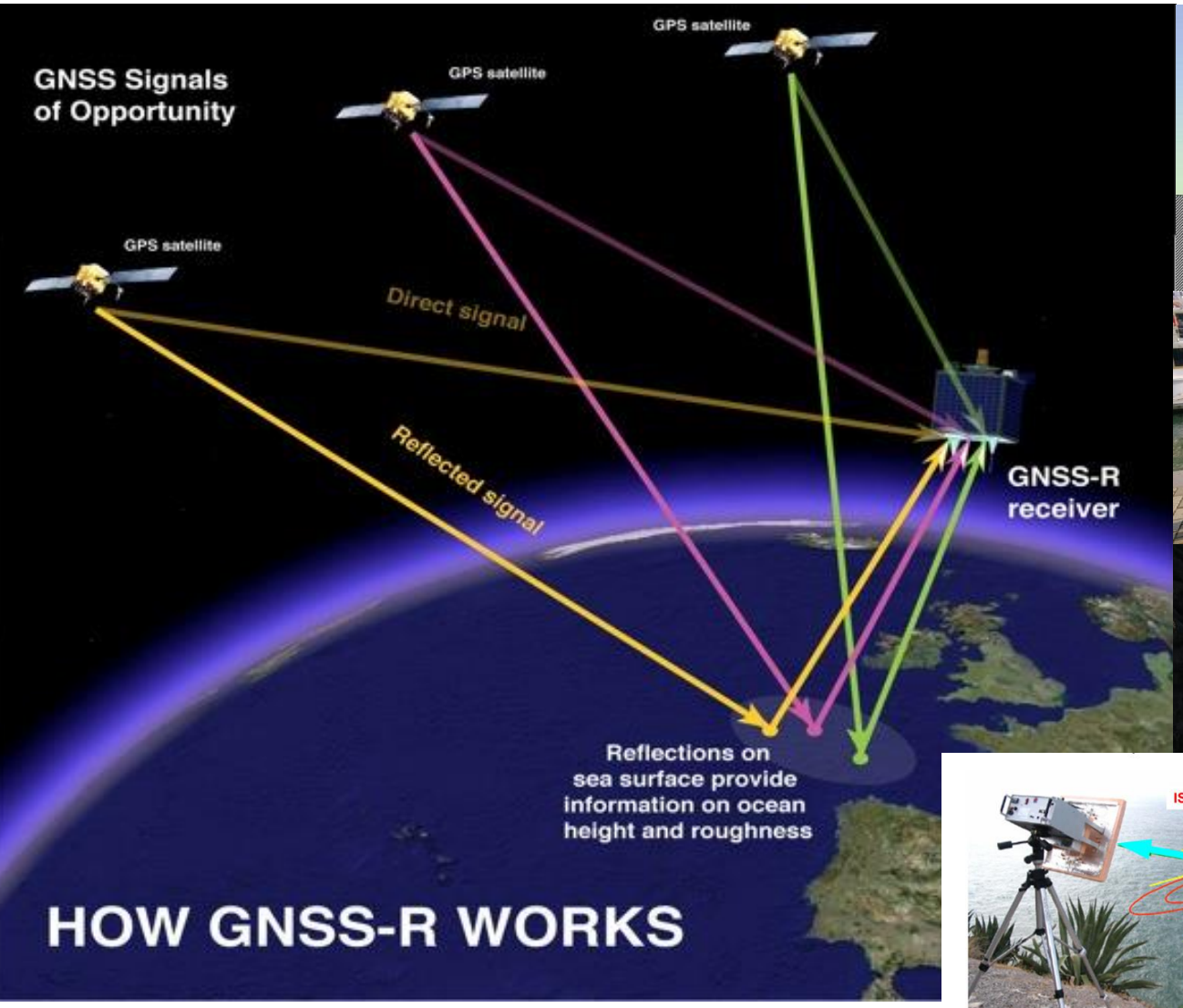
GNSS Meteorology（water vapor estimation）

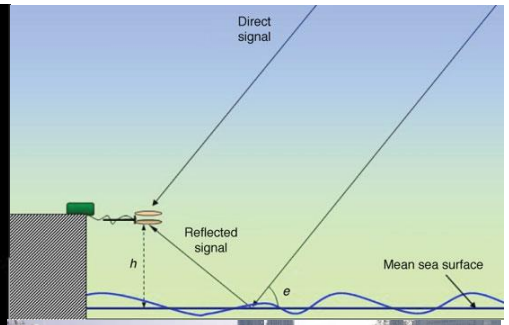
- In GNSS survey, if you can accurately estimate the atmosphere delay, it can use for meteorology.
- Currently, tropospheric delay estimated by the GNSS analysis is converted to "PWV" (precipitable water vapor)
- For Japan and major weather research institutions, it is used to create the initial field of numerical weather prediction and it contributes to the accuracy of weather forecast.

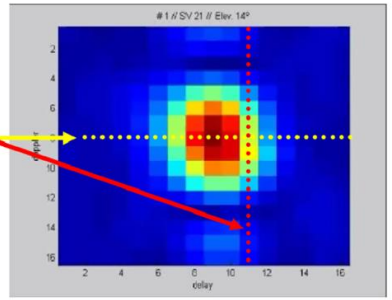




GNSS Reflectometry (GNSS R)



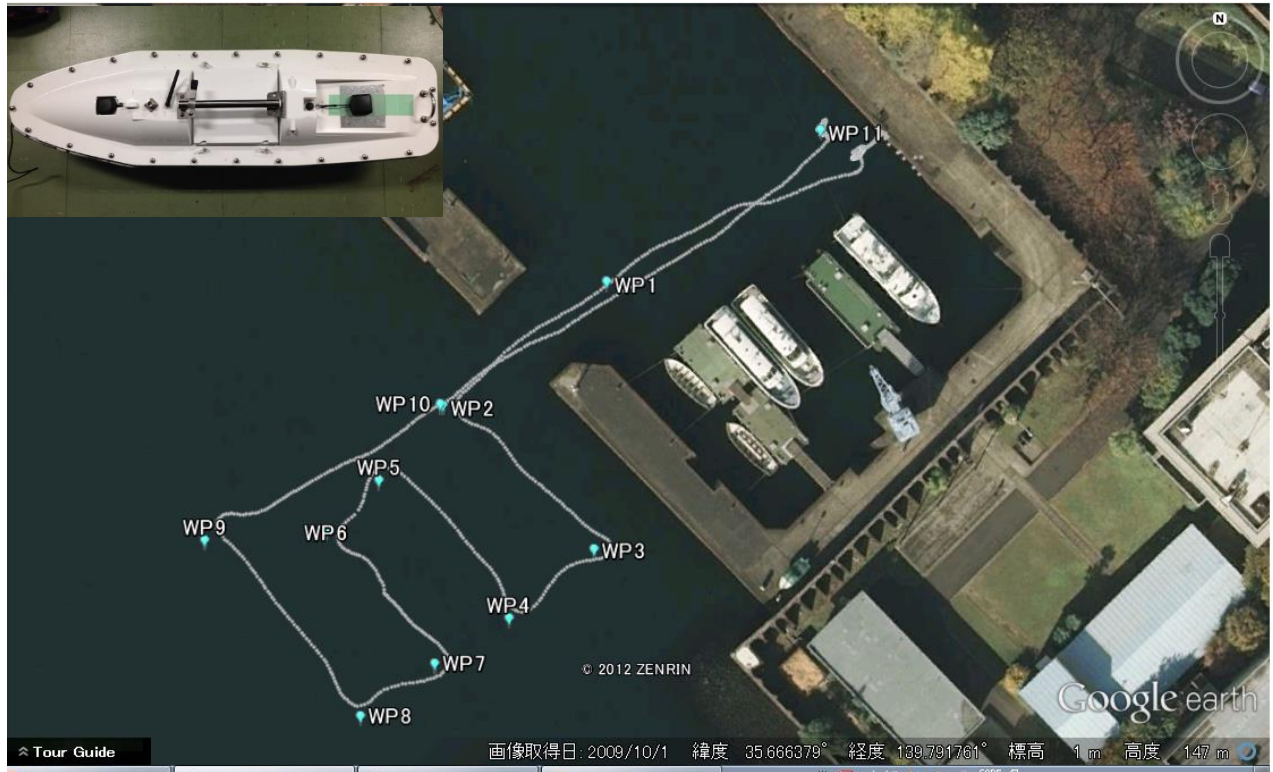


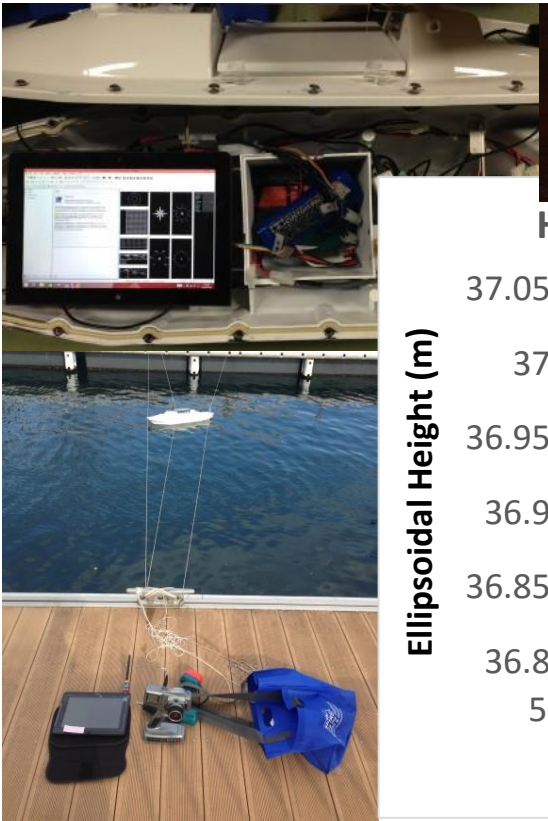


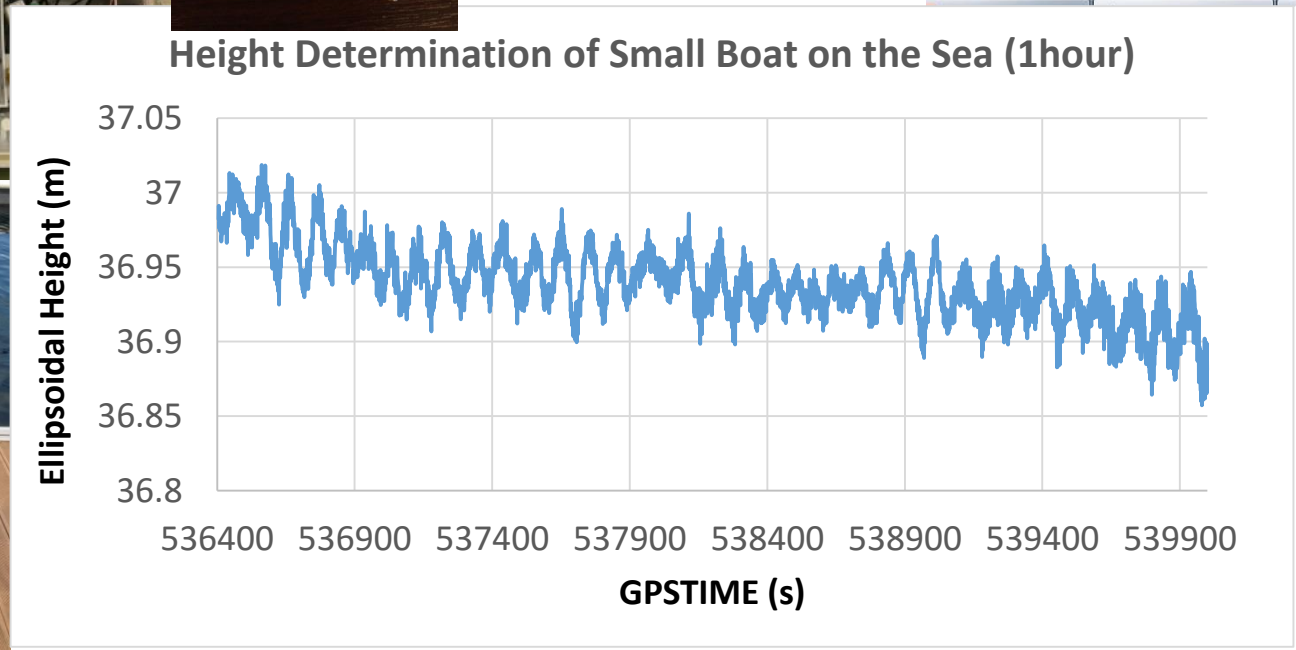
Recently it is popular in the world.
In Japan, Kyushu university and Chubu university (Dr. Ebinuma) are conducting test
(research fund : 2014-2017)

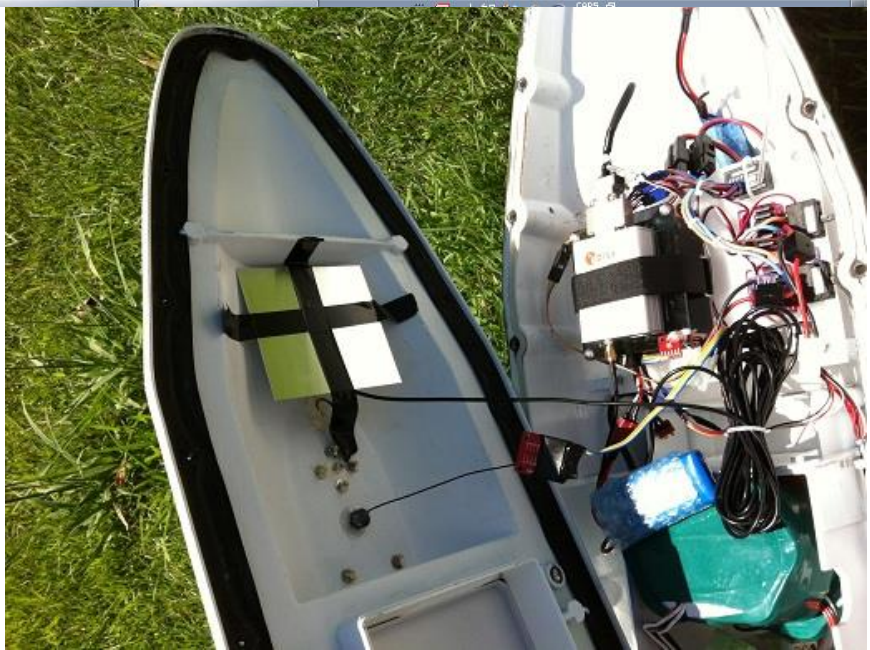
Autonomous navigation using small boat

- Waypoint navigation
- Monitoring (low-cost RTK)
- **<u>Waypoint navigation for “UAV” and “small robot car”</u>** has been done.









Companies

NAME	Main product/service related to GNSS
MITSUBISHI	Satellite maker, Precise positioning service, Mobile mapping system
NEC	MSAS/GBAS, Satellite station, QSS
TOPCON	Receiver manufacture (survey), Base station, Machinery
FURUNO	Receiver manufacture (low-cost), ITS
JRC	Receiver manufacture (low-cost), ITS
HITACHI ZOSEN	Base station, Buoy, PPP
EPSON	Watch, Wearable, Oscillator
SONY	Watch, Wearable, Pedestrian
CORE	SDR
Car Manufacture	Performance evaluation of GNSS

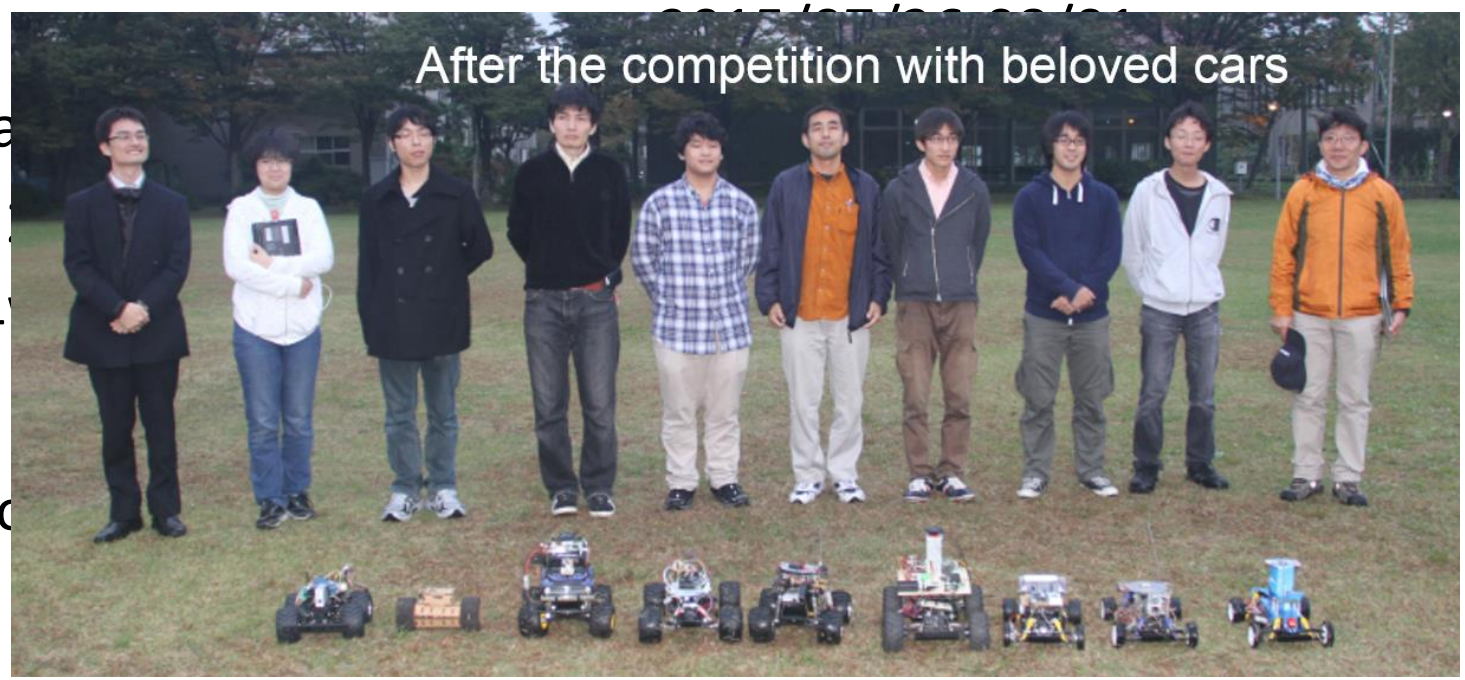
Project Overview and Up-Date of The Quasi-Zenith Satellite System

QZS System Services Inc.

This was partly presented in ION-PNT 2015

Activities of IPNTJ (The Institute of Positioning, Navigation and Timing of Japan)

- International Summer School on GNSS 2015 in Tokyo
- Robot Ca
- IS-GNSS
- 7th AOR-
- Internatio



Kyoto 2015/11/16-19

IS-GNSS 2015

■ Venue Miyakomesse

✧http://www.miyakomesse.jp/

■ Date November 16-19, 2015

Scholarship will be prepared for
Excellent Papers of Students.

http://www.isgnss2015.org

Tentative Schedule

Special Guest:

Prof. Parkinson

Day 1 Plenary Session

Key note speech

CGSIC-IISC Presentation

Prof. Changdon Kee and Prof. Sang Jeong Lee are invited.

GLONASS/Galileo/Bedou/IRNSS/QZSS

Ice Breaker

Day 2 AM/PM Parallel 4 Technical Session

Day 3 AM Parallel 4 Technical Session

PM Sightseeing Demo

Reception

Day 4 AM/PM Parallel 4 Technical Session

Closing

Important Dates

- Abstract Submission for Reviewed and Scholarship Application Papers : 2015/06/30

Extended to 07/07 for Korean Students

- Abstract Submission for Regular Papers : 2015/08/15
- Full Paper Submission for Reviewed and Scholarship Application Papers : 2015/07/31
- Acceptance Notification : 2015/09/15
- Full Paper Submission for Regular Paper : 2015/10/15
- **Conference Date : 16-19, November 2015**

http://www.isgnss2015.org

The 7th Asia Oceania Regional Workshop on GNSS

Multi-GNSS Demonstration Campaign

- Share and discuss the latest results and information of demonstrations in “Multi-GNSS Application Showcase”
- Get networking over Asia Oceania Region to find your GNSS solution in academic and industrial field
- Visit MGA website: http://www.multignss.asia

7-9 December 2015
Brunei Darussalam

BELS Building European Links toward South East Asia in the field of EGNSS
GNSS.asia
BEDB BRUNEI DARUSSALAM
JAXA Japan Aerospace Exploration Agency
SPAC
QZSS Services
ICG International Committee on Global Navigation Satellite Systems
IGS
Soartech Systems Sdn Bhd

Outline of International Summer School on GNSS 2016

- Date : 2016/07/26-07/31
- Organized by : Tok
  Technology (TUMS
- Co-Organized by :
  Timing of Japan
- Attendees : Japan
  level & young engi
  scholarship).
- Number of partici
- Language : English
- Fee : 60,000JPY, (2
- Call for applicatior
- Check the URL: htt

Time Table in 2014

	Jul 28	Jul 29	Jul.30	Jul 31	Aug. 01	Aug. 02
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
0830-0950	Introduction	Class B-1	Class B-4	Class C-1	Class C-5	Practice for System Design, to be continued to workshop -I
0950-1010	Break	Break	Break	Break	Break	
1010-1130	Class A-1	Class B-2	Class B-5	Class C-2	Class C-6	
1140-1230	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
1230-1350	Class A-2	Class B-3	RTK-LIB Practice	IMES-DEMO	SDR Practice	Workshop-1
1350-1410	Break	QZSS-Intro	Break	Break	Break	Workshop-2
1410-1530	Class A-3	Class B-4	RTK-Demo G-I	Class C-3	UAV Demo	
1530-1550	Break	Break	Break	Break	Break	
1550-1710	Self introduction	RTK-LIB Practice	RTK-Demo G-II	Class C-4	UAV-Appli.	Closing
1710-	Welcome Party	1 class=80 minutes			Farewell party	
	Instructors	Introduction	Dr. Akio Yasuda		System Design	Dr. Naohiko Kohtake
		Class-A	Dr. Nobuaki Kubo			Mr. Hiroaki Tateshita
		Class-B	Mr. Tomoji Takasu Dr. Harumasa Hojo			
		Class-C	Dr. Toshiaki Tsujii Dr. Taro Suzuki			