移動体における高精度測位技術に関する現在と未来

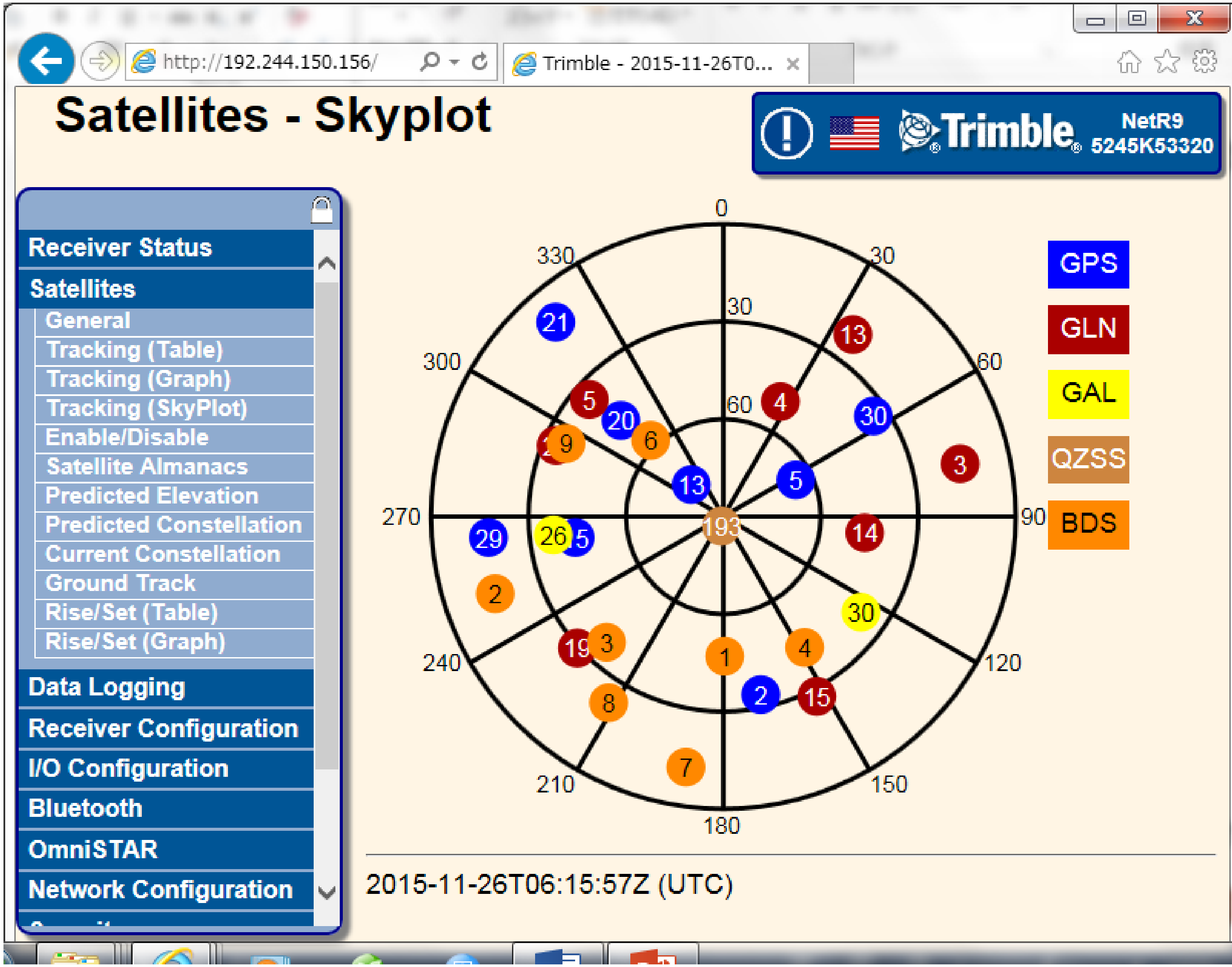
MWE2015　11月25-27日　横浜パシフィコ
位置情報サービス技術のフロンティア

久保信明（東京海洋大学）

発表概要

- 高精度測位の現状とこれから
  - コンシューマ及びサーベイ受信機
- 他センサとの統合
- 低コスト受信機の結果
- まとめ

Current GNSS Constellation



GPS : 32
GLO : 23
BEI : 14
GAL : 8
QZS : 1

TUMSAT reference station

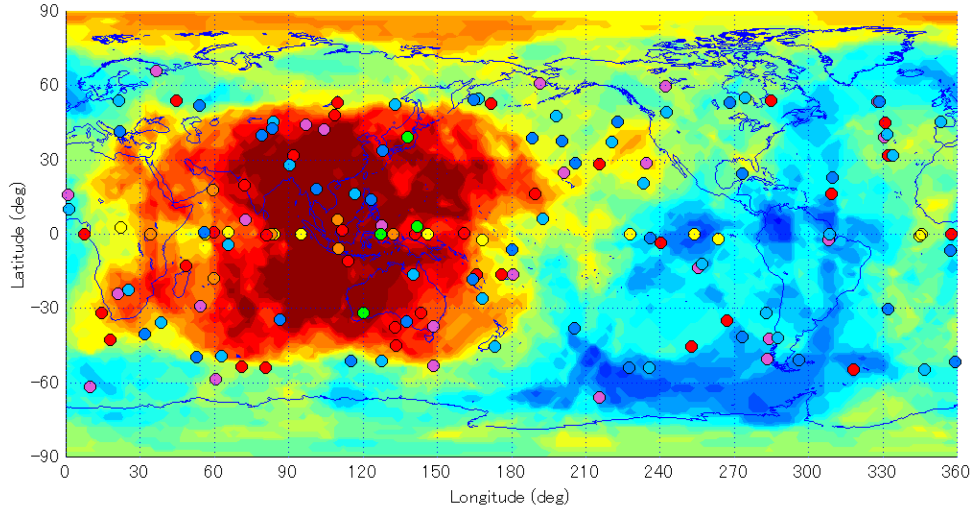
GPSの2周波は今も使いにくいか？

- これまでL2Pという軍用コードが使われてきた
- 原則、北米以外の受信機メーカの参入が妨げられていた→L2Cの出現
- 32機のうちすでにL2Cを放送している衛星数は18機
- 2周波は高精度測位に必要度が高い

ⅡF	ⅡR-M	ⅡR	ⅡA	合計
11	7	12	2	32

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)

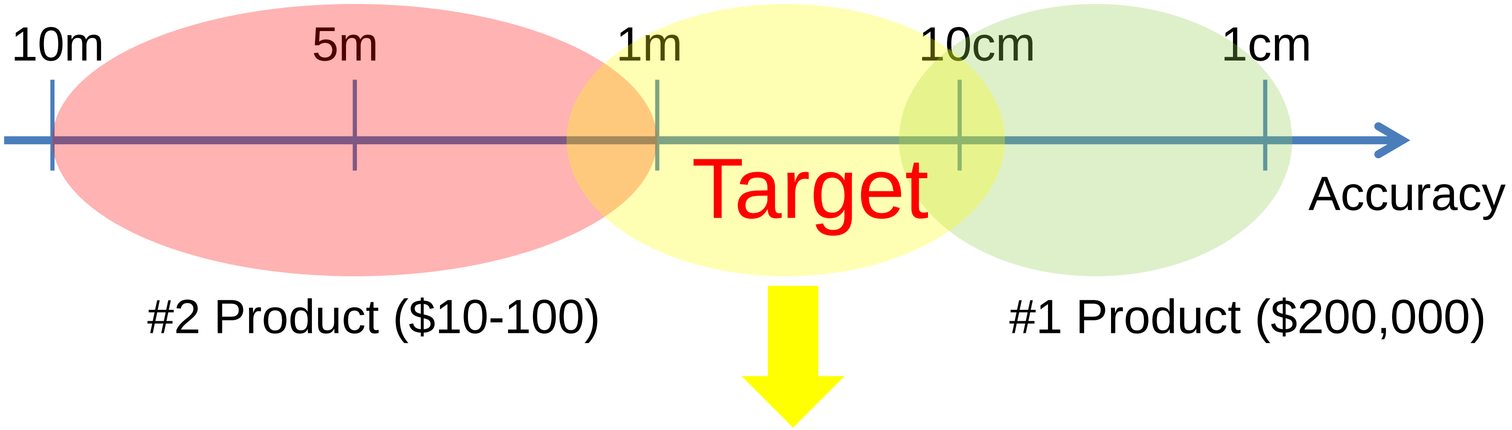
移動体測位現状

- Survey-grade GNSS+ Speed sensor + IMU

Reliable RTK still requires dual-frequency

Low cost

- Prospective accuracy in safety use for ITS like lane recognition is said decimeter level with continuous positions

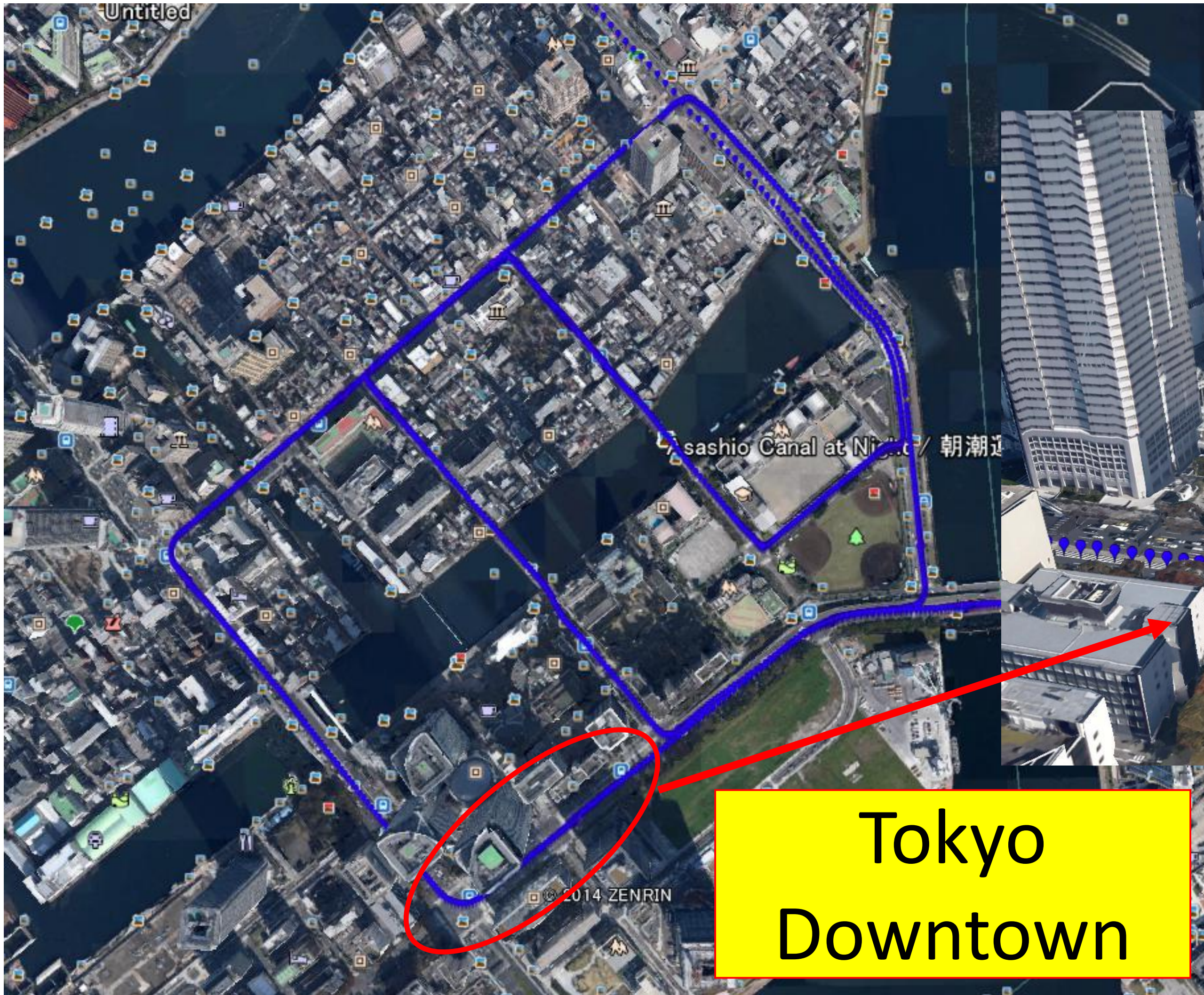


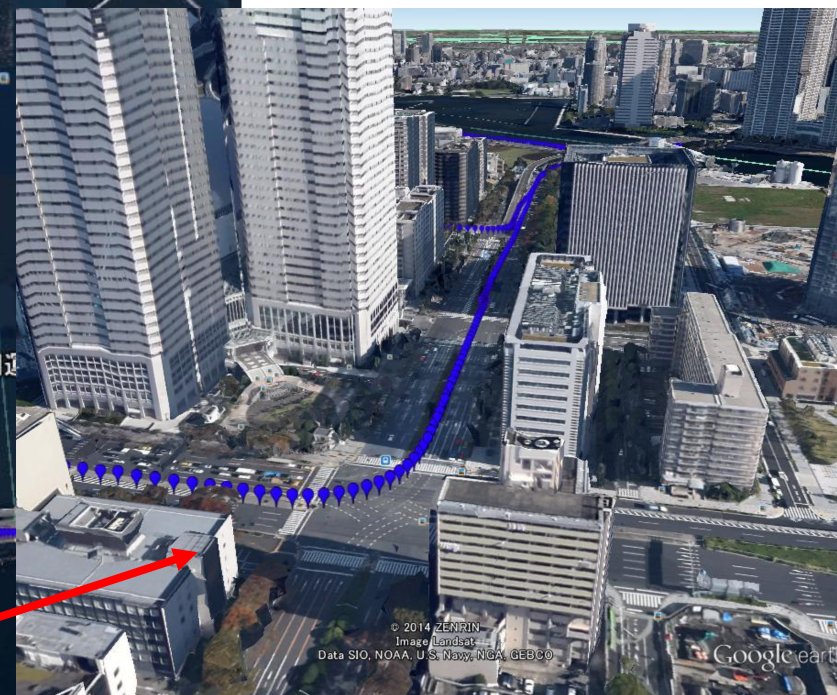
0.5m horizontal error and 100% availability

レーン検知とRTKの精度

- 実際のRTK中の動画

Performance of low-cost receiver with single-frequency GPS/QZS/BeiDou

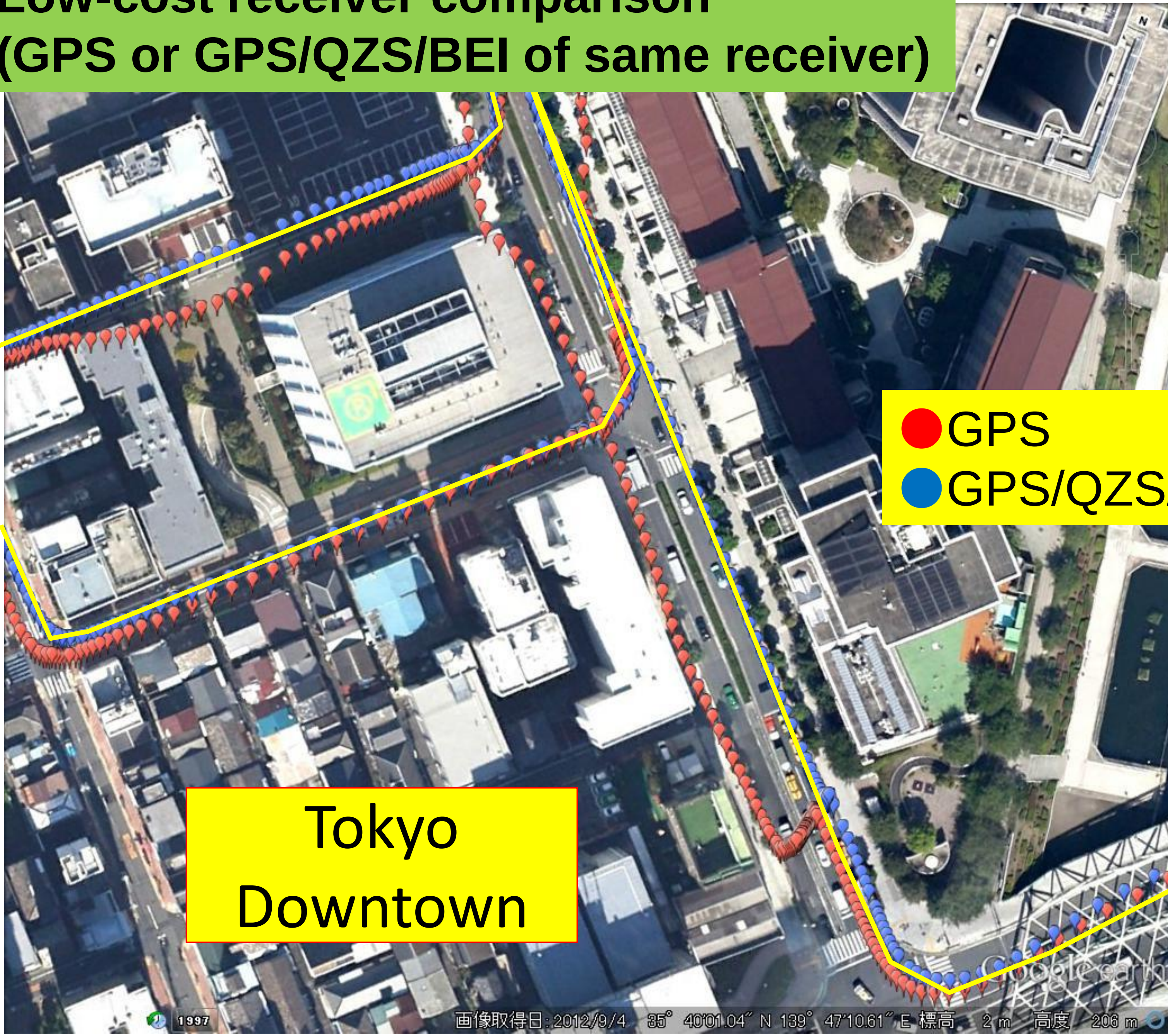


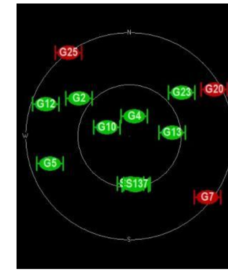


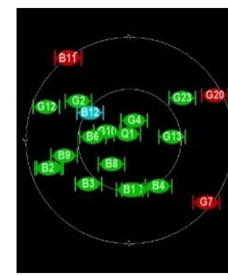
Many skyscrapers…

Google上ではあるが
自身の走行車線に一致

Low-cost receiver comparison
(GPS or GPS/QZS/BEI of same receiver)



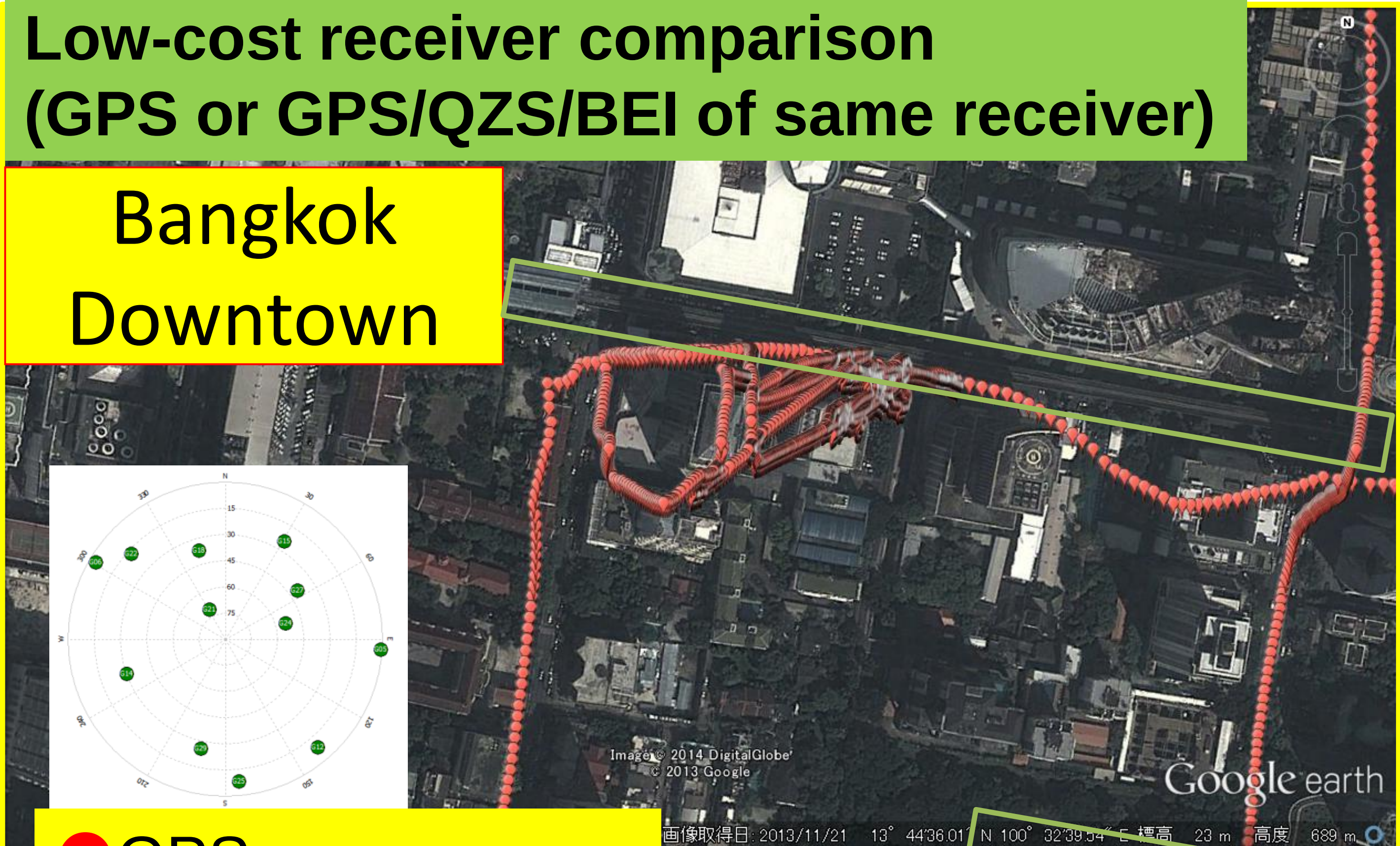




マルチGNSS
の効果は歴然

Low-cost receiver comparison
(GPS or GPS/QZS/BEI of same receiver)

Bangkok Downtown



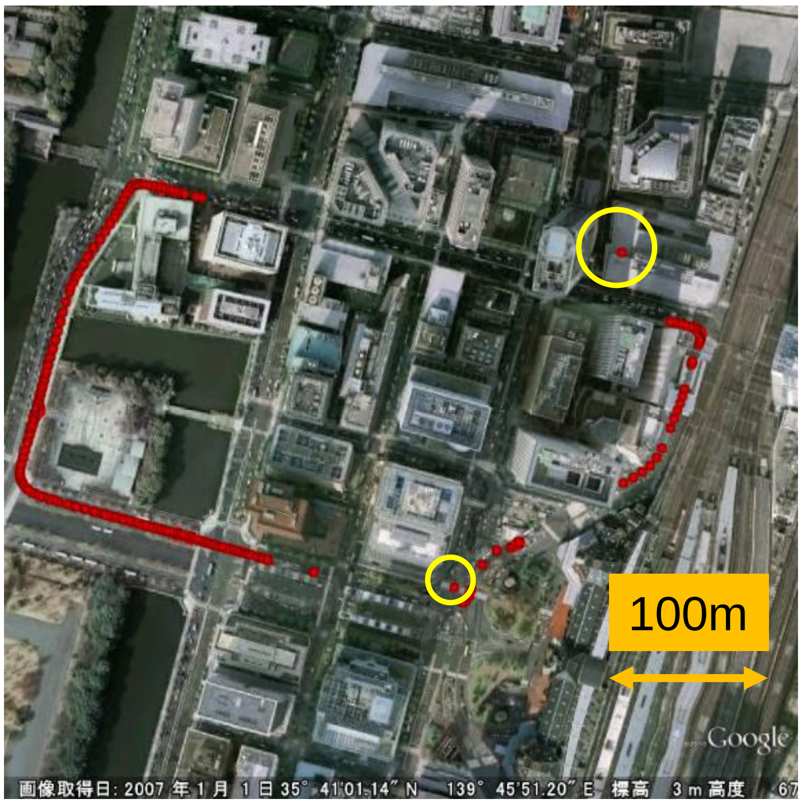
Under elevated train

● GPS
● GPS/QZS/BeiDou

マルチGNSSの効果は歴然.
さらにスピードセンサ＋IMUがあると？

Challenge in RTK

- Reliability as well as availability of RTK are quite important for future commercial users

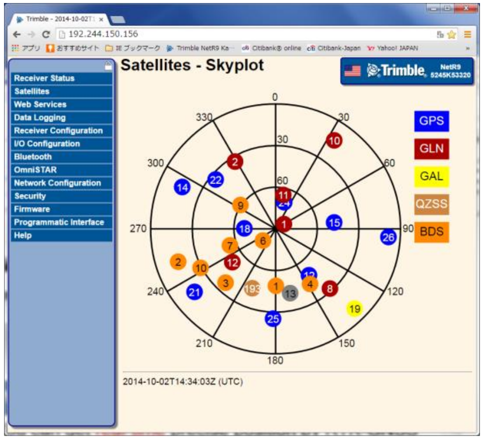


RTK-GPS example in dense urban areas (Marunouchi Tokyo)

Both reliability and availability were not enough…

We need to know the current power of RTK-GNSS exactly…

We provide local-area CORS network
(collaboration between universities)



CORS(Continuously Operating Reference Stations)

observation data via the Internet

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

What you can do ?

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

Rover

Communication Link

Reference

Mission of QZSS

QZSS provides positioning- related service and messaging service.

Positioning- related service

① Satellite Positioning Service

The service to provide the same as GPS satellites in spite of urban area or mountain area.

② Sub-meter Level Augmentation Service

The service to provide accurate positioning around 2-3 meters. (※)

③ Centimeter Level Augmentation Service

The service to provide highly accurate positioning around 10 centimeters.(※)

※ Ionosphere disturbance (fluctuations), multipath and others will affect the accuracy.

④ Positioning Technology Verification Service

The service to provide an application demonstration for new positioning technology.

Messaging Service

⑤ Satellite Report for Disaster and Crisis Management (DC Report)

The service to provide users in the field with disaster management and rescue .

②, ③, ⑤ :These services are under investigation for overseas users.

Multi-GNSS RTK Test using Car

Test	Schedule
1st	2014/8/13 13:07–13:32
2nd	2014/8/13 17:26–17:52
3rd	2014/8/13 22:26–22:50
4th	2014/8/14 8:36–9:02
5th	2014/8/14 12:07–12:35

* GPS/QZS/GLONASS/GALILEO/BeiDou are entirely used in this test
* Trimble SPS855 receiver was used
* RTK : Trimble and Laboratory engine

Summary of Test Results

Multi-GNSS RTK (Trimble engine)

	Average NUS	Fix rate
Test 1	12.3	58.7%
Test 2	12.3	75.4%
Test 3	13.6	65.5%
Test 4	12.4	60.0%
Test 5	14.2	70.5%

GPS VS. Multi-GNSS RTK (Trimble engine)

Test 5	Average NUS	Fix rate
GPS	5.8	26.8%
Multi-GNSS	14.2	70.5%

FIX rate comparison between GNSS combinations (Laboratory engine)

Test 3	G	GJ	GC	GR	GJC	GJCR
RTK FIX rate	48.2%	58.2%	55.5%	55.4%	64.7%	65.9%
Velocity output	67.0%	80.3%	86.5%	82.4%	91.5%	94.7%

G:GPS J:QZSS C:BeiDou R:GLONASS

The reason for small contribution of BeiDou/GLONASS to RTK was just due to the shortage of high elevation those satellites

Summary of Test Results

Multi-GNSS RTK (Trimble engine)

	#1	#2	#3	#4
Test1	12.3	58.7%	23 秒	231 秒
Test2	12.3	75.4%	29 秒	227 秒
Test3	13.6	65.5%	27 秒	252 秒
Test4	12.4	60.0%	22 秒	159 秒
Test5	14.2	70.5%	6 秒	95 秒
	平均衛星数	FIX率	データ遅延	時間間隔

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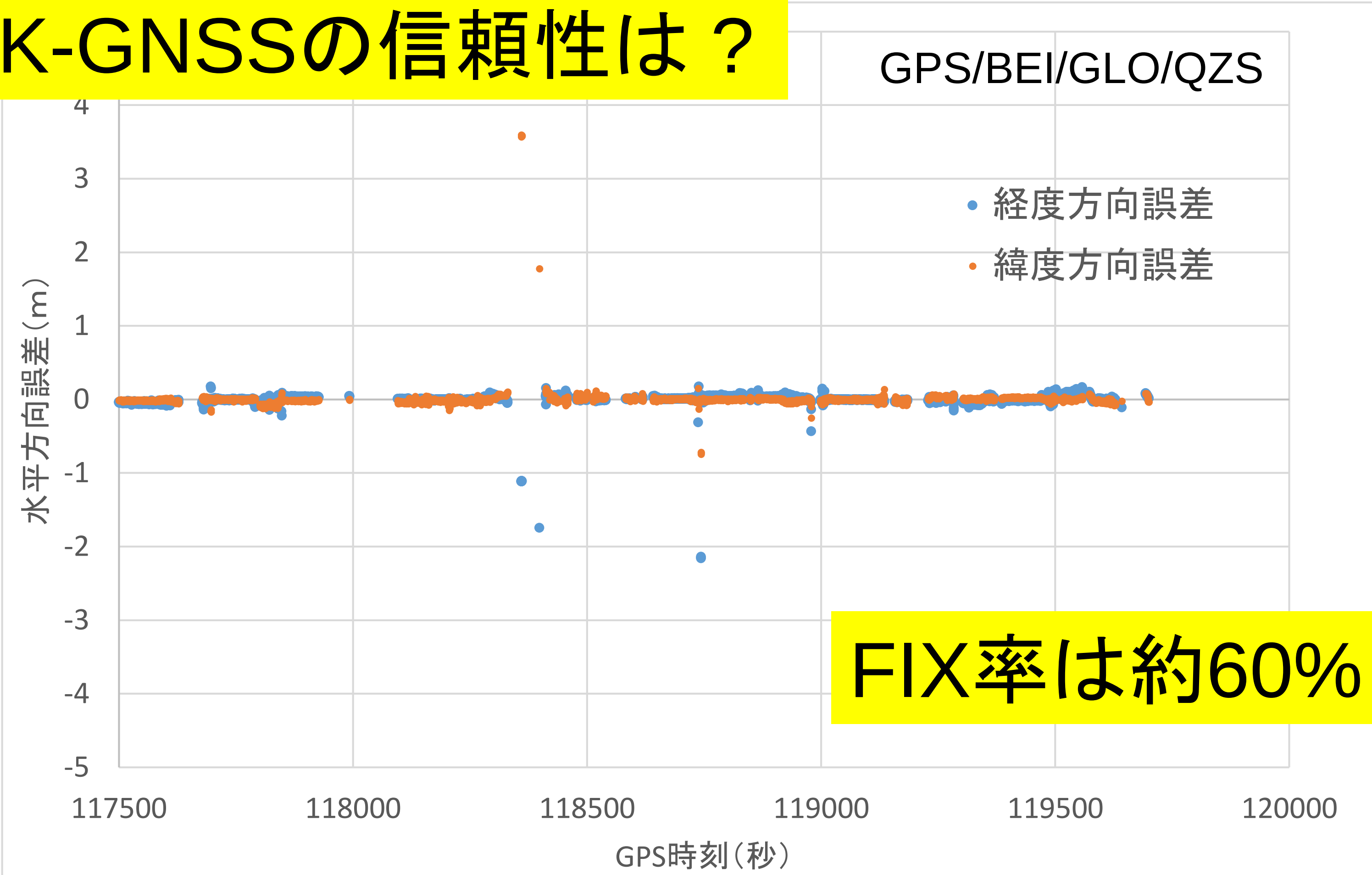
RTK-GNSSとレファレンス解の差

（Dense Urbanでの移動体）

RTK-GNSSの信頼性は？

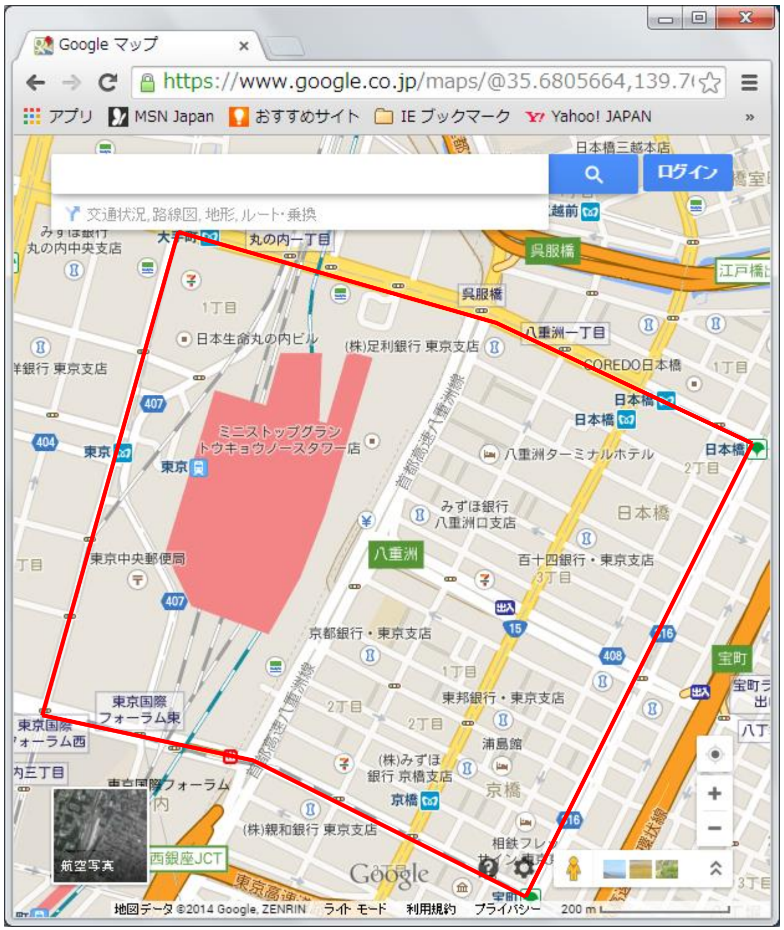


FIX率は約60%

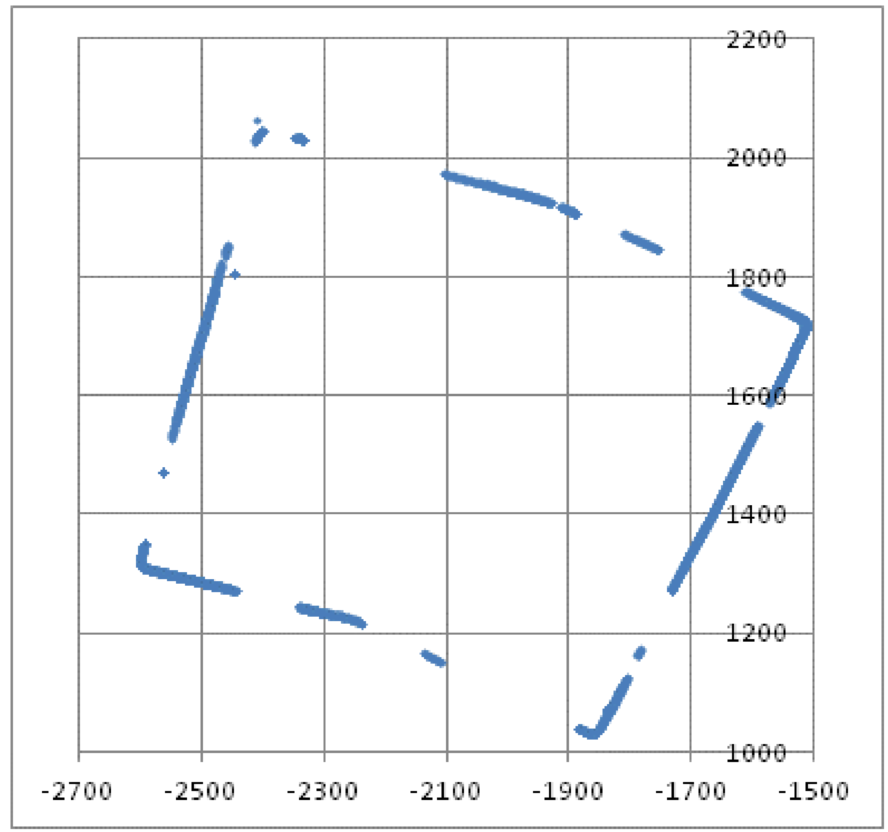
水平50cm以内は99.88%　水平20cm以内でも99.82%

丸の内周辺のみのRTK-GNSS

2014年10月26日13時10分-14時40分　5周回　昼食停止時間除く



FIX率は41.2%



5周回分の水平位置

RTK-GNSSとコンシューマレベルのIMU及び車速センサとの統合（プロテクションレベル）

●Trajectory ●Under pass

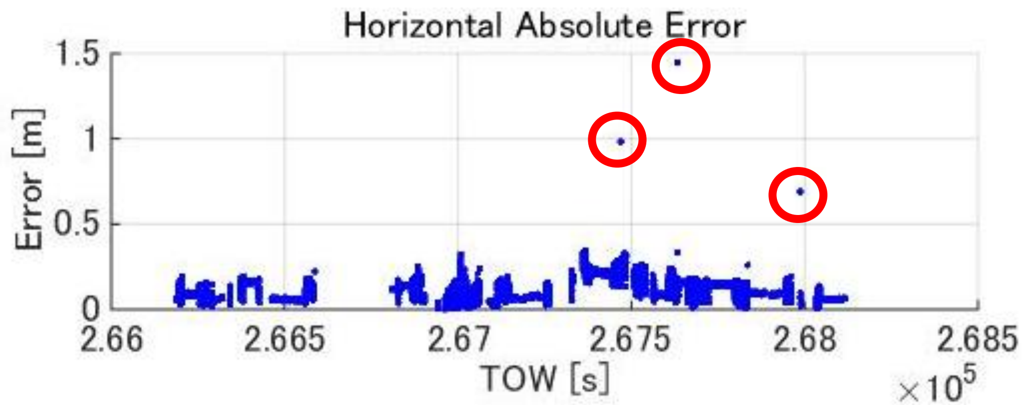
名古屋駅周辺都市部

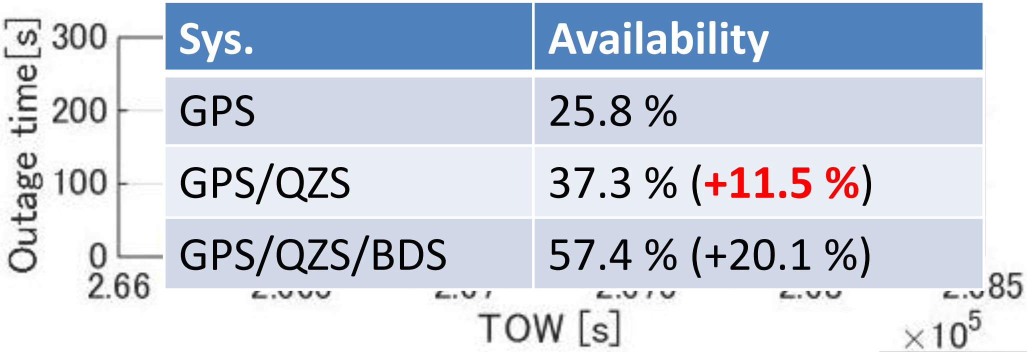
Total 3 tests
Period : about 30min
Data rate : 10Hz

Test	NUS (ave.)
1	9.2
2	9.7
3	9.3

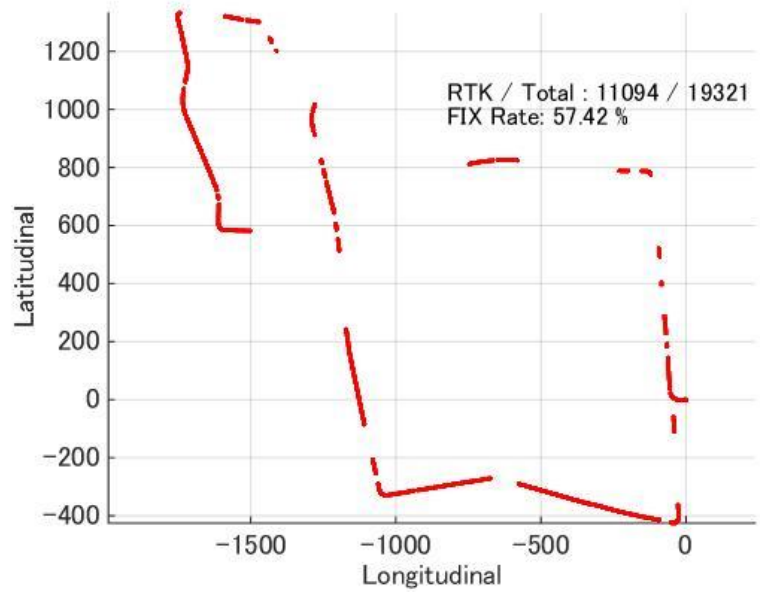
Number of used satellites.

RTK-GNSS Performance



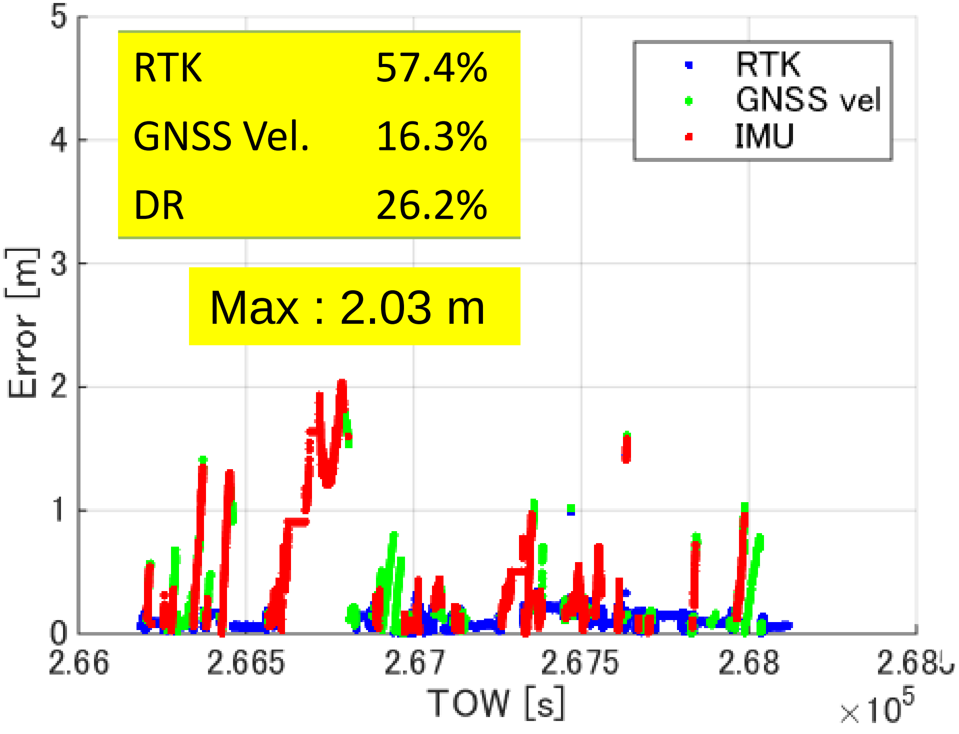


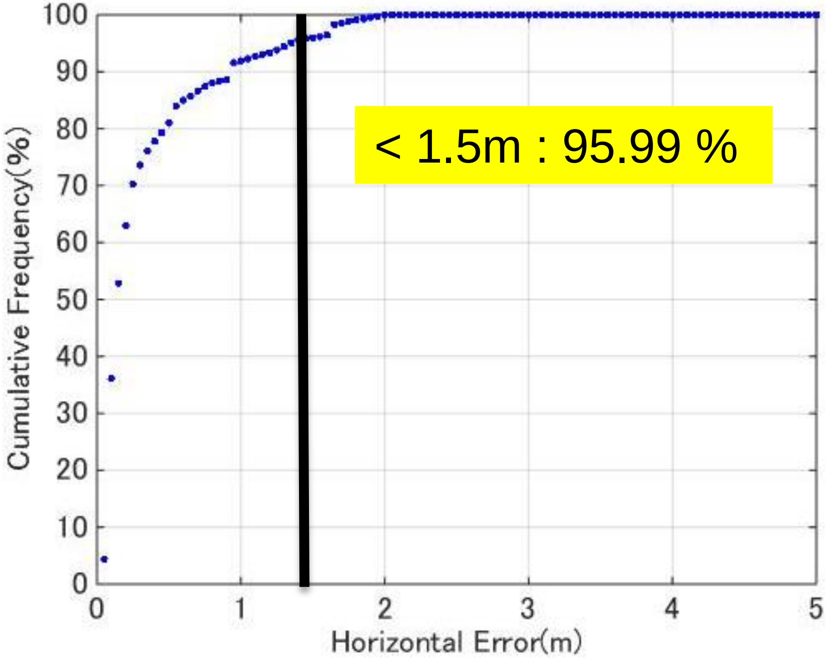
Sys.	Availability
GPS	25.8 %
GPS/QZS	37.3 % (**+11.5 %**)
GPS/QZS/BDS	57.4 % (+20.1 %)



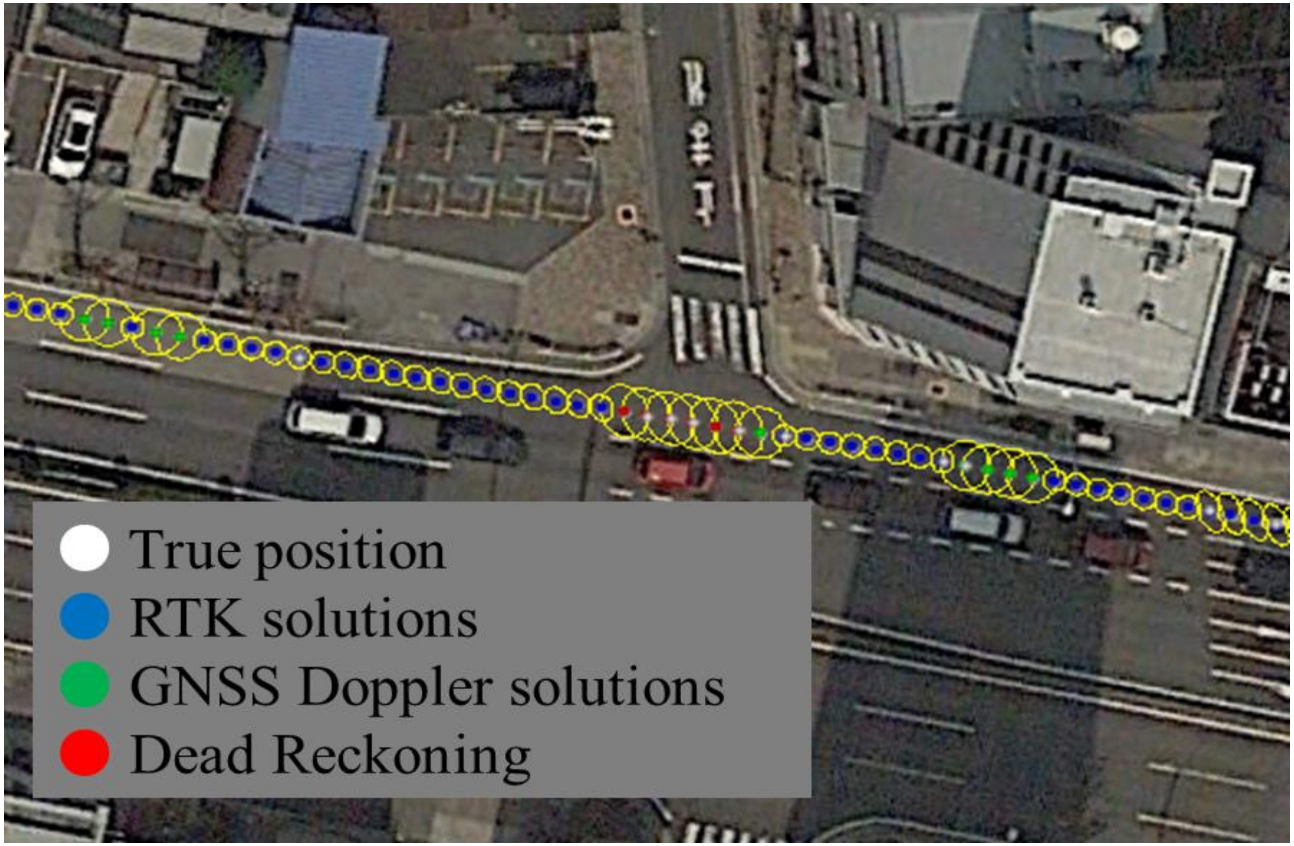
+QZS and BDS increased the availability a lot.
About 1.5-2 times compared with only GPS

Overall Results





Protection Level Estimation



- The covariance ellipse by satellite constellation

$$\frac{x^2}{\sigma_x^2} - 2\rho_{xy}\frac{xy}{\sigma_x\sigma_y} - \frac{y^2}{\sigma_y^2} = (1-\rho_{xy}^2)C$$

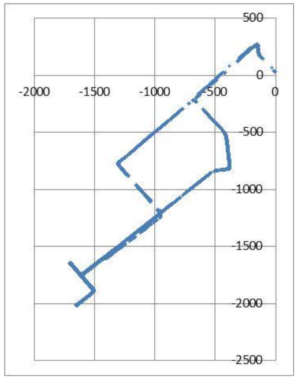
$$P = 1 - \exp\left(-\frac{C}{2}\right)$$

- Considered accumulating bias errors in GNSS-velocity and DR solutions.

Parameter	Value
RTK-GNSS error (m)	0.025
GNSS-velocity error (m/s)	0.02
IMU+Speed sensor error (m/s)	0.03

受信機による違いがあるのか？

- 2014年3月3日　15時台の30分
- 場所は晴海と月島周回で車両移動体で取得
- GPSの衛星配置は良くない
- アンテナはC社、分岐してA社とB社を接続

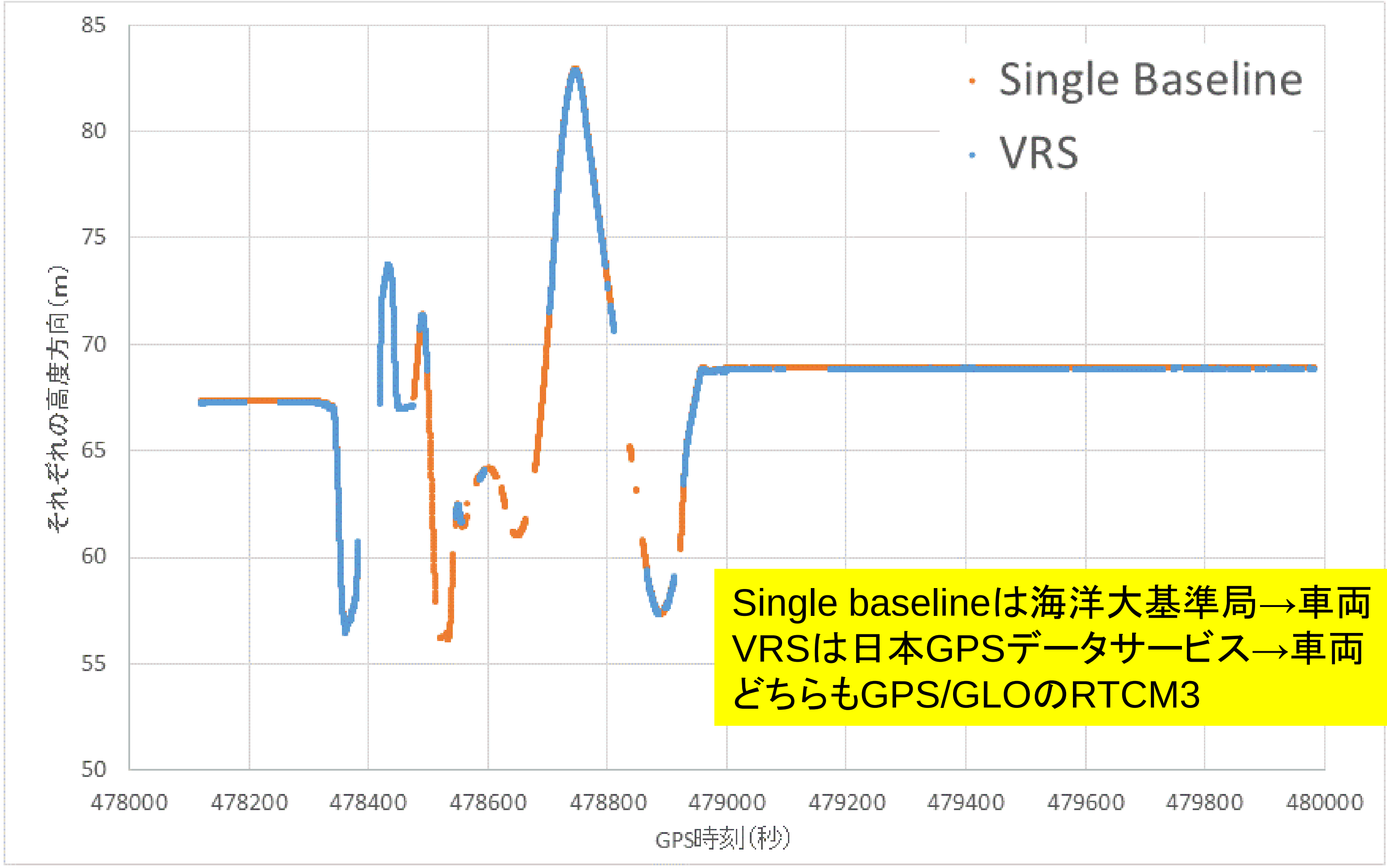


	平均可視衛星数	GPS/BeiDou/QZS 平均可視衛星数	GPS＋BeiDou FIX率
A社	9.04	4.96 / 3.83 / 0.25	73.3%
B社	10.62	5.36 / 4.79 / 0.47	63.8%

解析エンジンはLab.のもので、条件は全く同じ

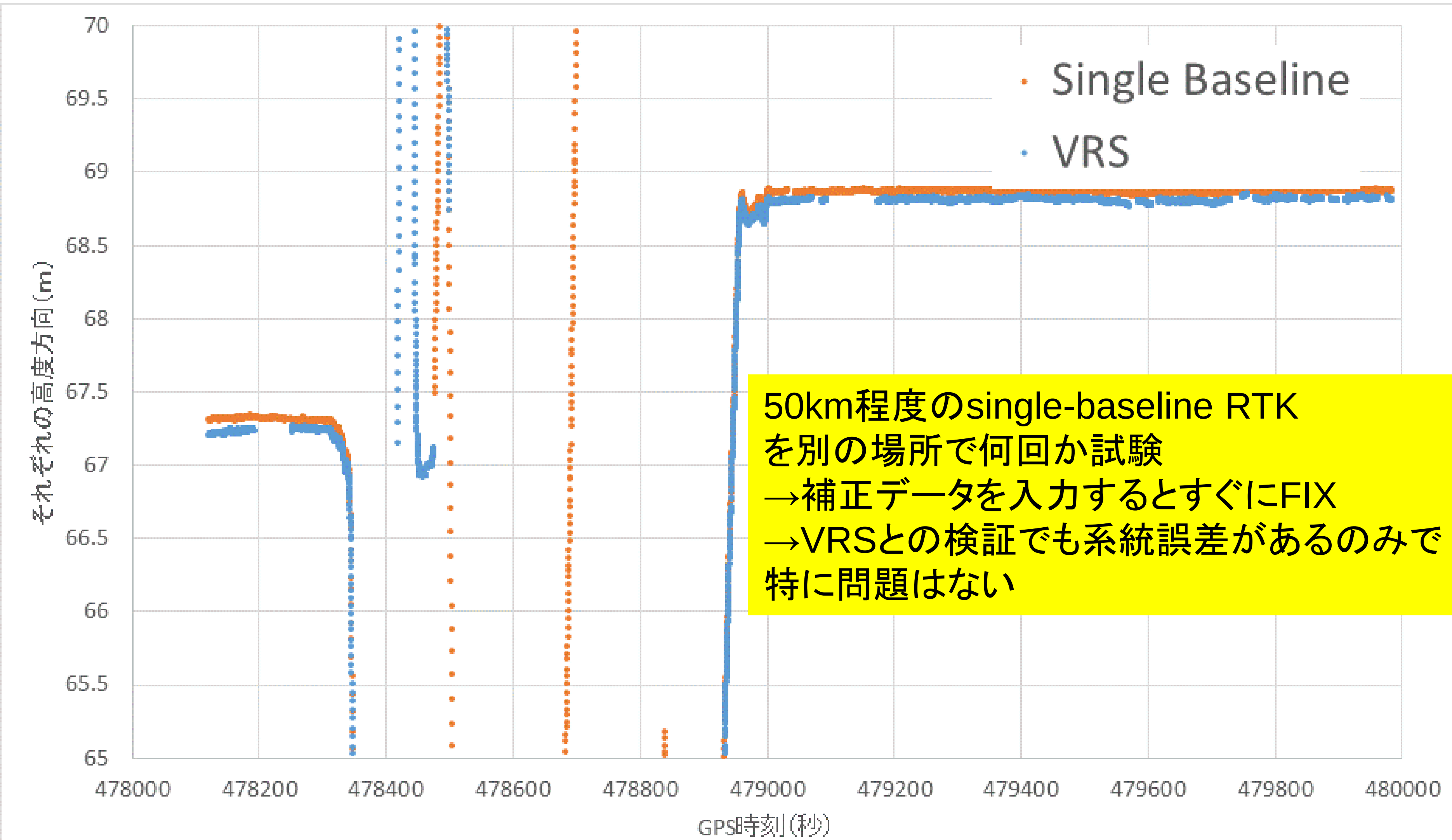
基線長の影響（VRSとSingle Baseline）

（2014/10/24 22時頃　成田空港から東関東自動車道を10km走行しPAへ　Single Baselineの基線長は51.5kmから44.8km）



Single baselineは海洋大基準局→車両　87.3%
VRSは日本GPSデータサービス→車両　65.4%
どちらもGPS/GLOのRTCM3

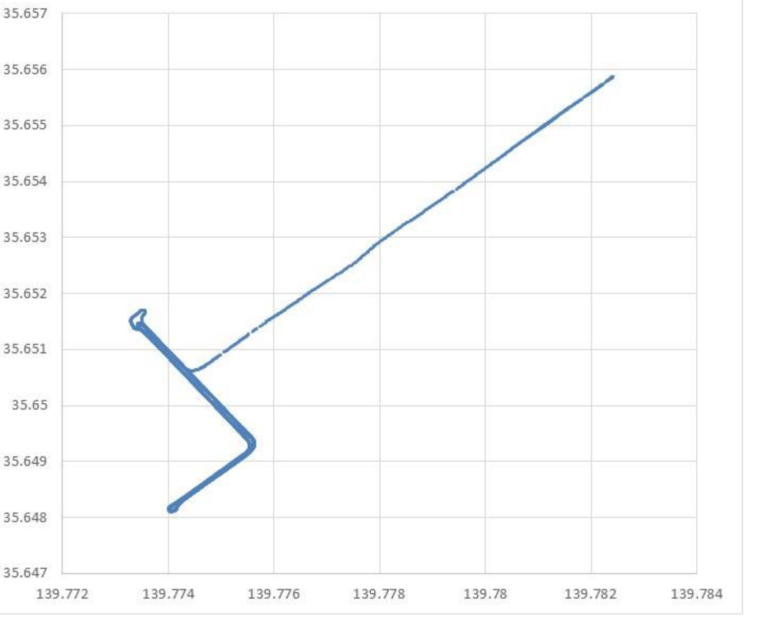
拡大



50km程度のsingle-baseline RTK
を別の場所で何回か試験
→補正データを入力するとすぐにFIX
→VRSとの検証でも系統誤差があるのみで
特に問題はない

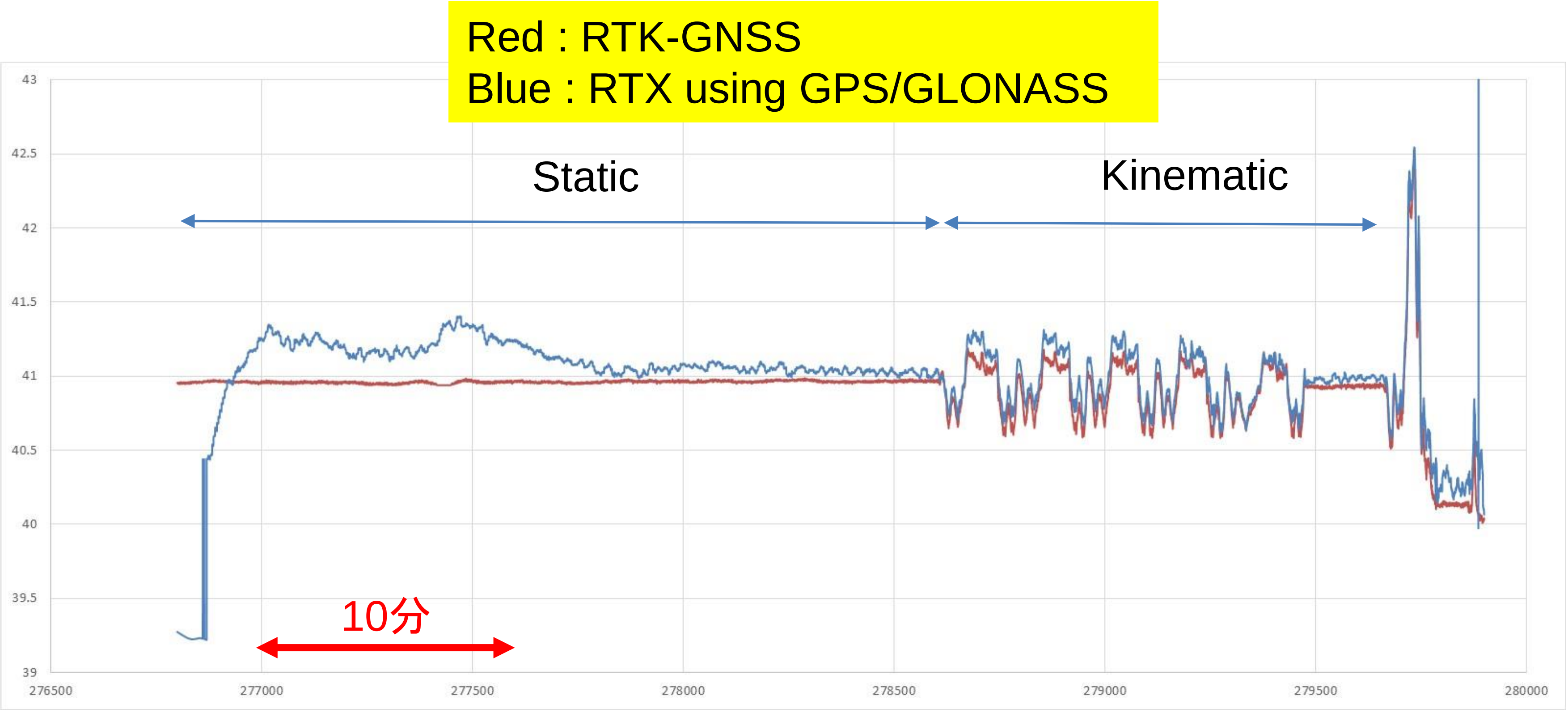
市販のPPPサービスはどれほどか？

- 30 minutes static and 15 minutes kinematic
- Trimble SPS855+**RTX** (PPP) option
- Comparison with RTK results
- Omni-star was used
- Open Sky



Horizontal plots at Harumi Area

Altitude Comparison between RTK and RTX (PPP)



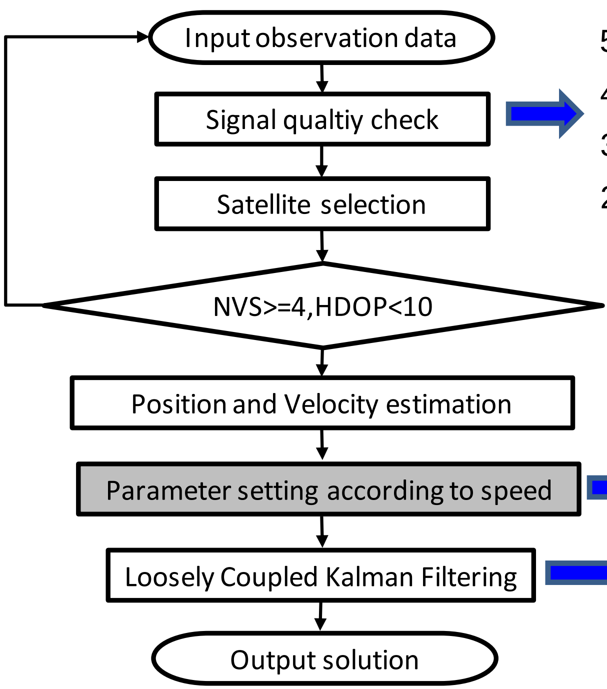
The accuracy was maintained within several centi-meters after 15 minutes of power on. Small bias (about 10cm) was deduced from other reason.

Proposed Multipath Mitigation Method Corresponding to Speed

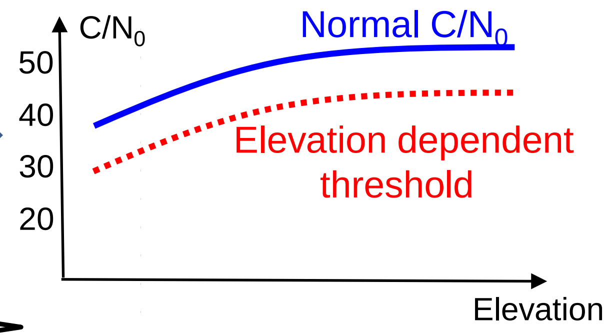
Proposed antenna motion method may not be practical…

Based on the amount of our test data,

* Doppler frequency derived **"velocity"** is quite tolerant to strong multipath condition
* Pseudo-range based **"position"** is not tolerant to strong multipath condition.
* We need to put them together efficiently **according to speed**.
* **NLOS** satellite has to be removed as much as possible.



Flowchart



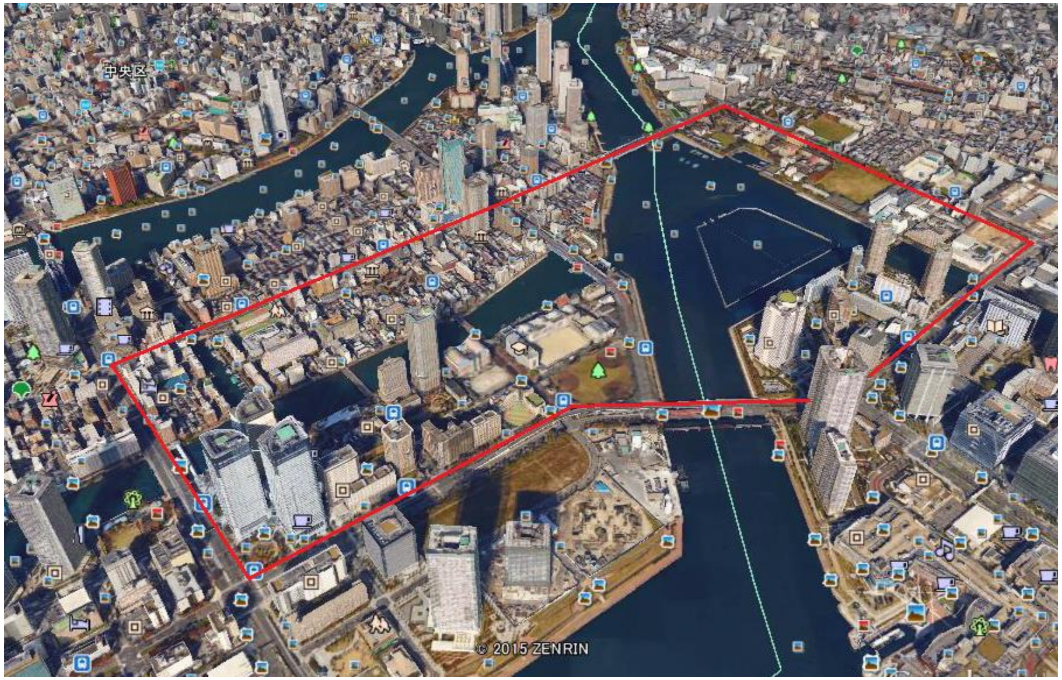
Speed	Weighting
Slow or zero	Position <<< Velocity
Normal	Position < Velocity

$$x_{k+1} = Fx_k + Gw_k$$
$$y_k = Hx_k + v_k$$
$$\boldsymbol{x_k} = [x(k), y(k), v_x(k), v_y(k), a_x(k), a_y(k)]^T$$
$$x(k+1) = x(k) + v_x(k)\Delta T + a_x(k)\Delta T^2/2.0$$
$$y(k+1) = y(k) + v_y(k)\Delta T + a_y(k)\Delta T^2/2.0$$
$$v_x(k+1) = v_x(k) + a_x(k)\Delta T$$
$$v_y(k+1) = v_y(k) + a_y(k)\Delta T$$
$$\boldsymbol{F} = \begin{bmatrix} 1 & 0 & \Delta T & 0 & \Delta T^2/2 & 0 \\ 0 & 1 & 0 & \Delta T & 0 & \Delta T^2/2 \\ 0 & 0 & 1 & 0 & \Delta T & 0 \\ 0 & 0 & 0 & 1 & 0 & \Delta T \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$
$$\boldsymbol{y_k} = [x(k), y(k), v_x(k), v_y(k)]^T$$
$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

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*

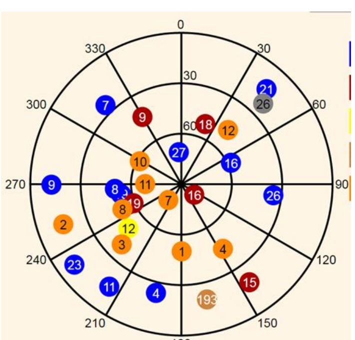
Loosely coupled KF

Kinematic Car Test

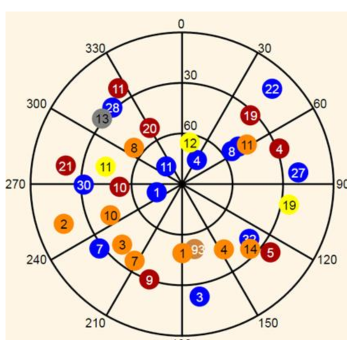


Test route

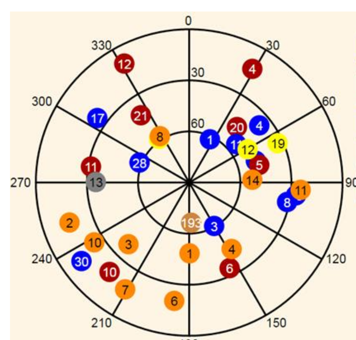
- August 2015
- Tsukishima, Tokyo
- Popular low-cost single frequency GNSS receiver
- GPS/BEI/QZS (DGNSS)
- 3 times for same route
- 20 minutes with 5Hz
- References : POS/LV
- Normal urban areas except for several high-rise buildings



1st



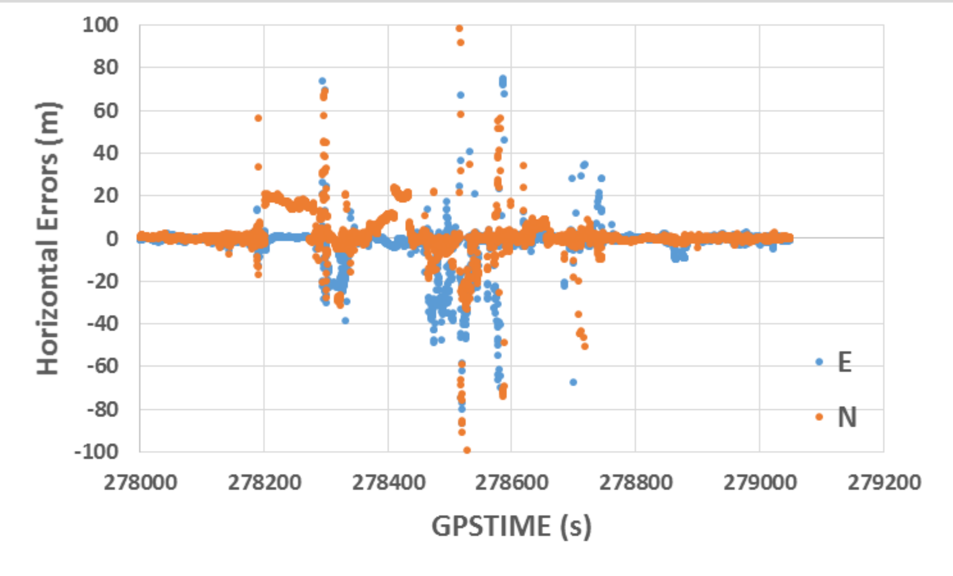
2nd



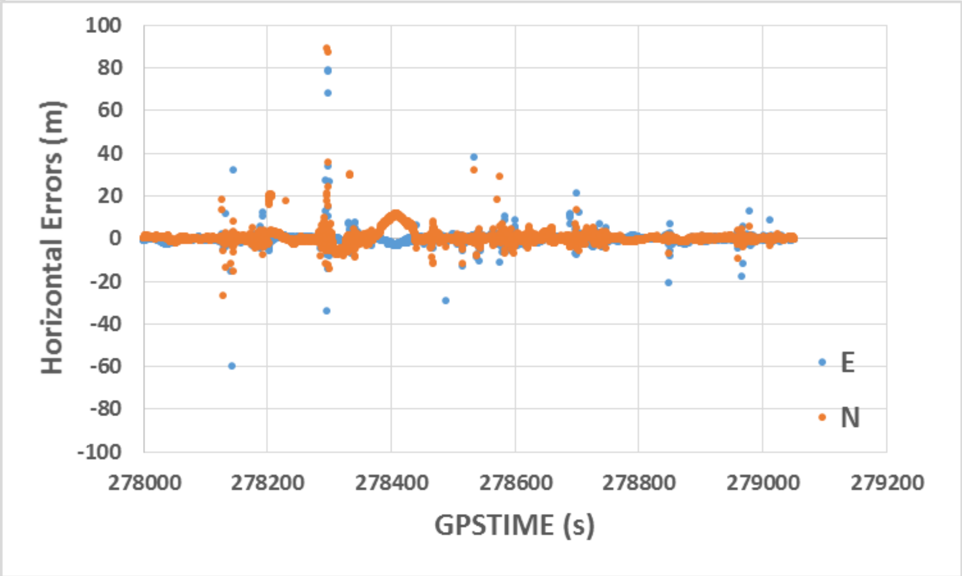
3rd

Detailed results are introduced using 3rd period raw-data (normal constellation) GLO/GAL were not used.

Code Based Positions with or without C/N_0 check



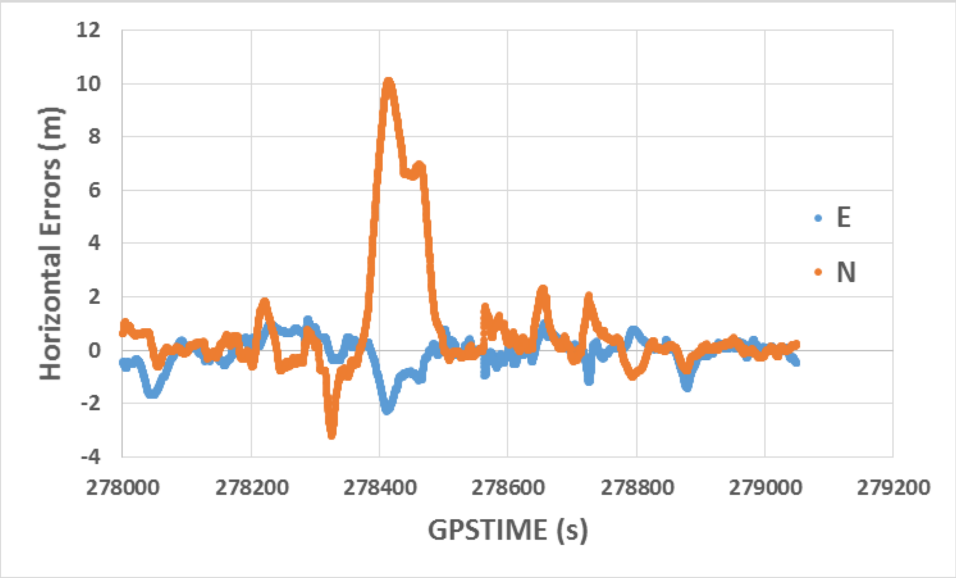
Without C/N_0 check



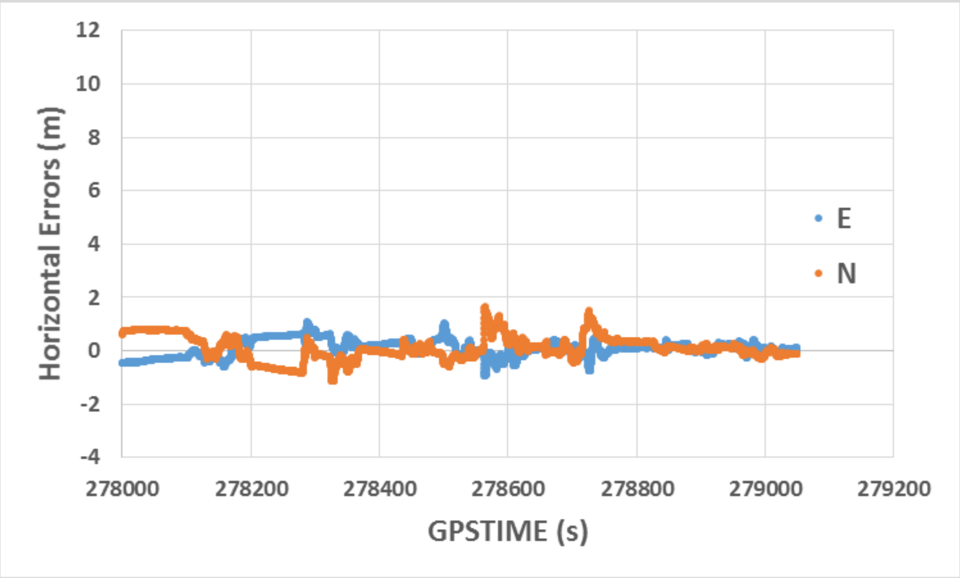
With C/N_0 check

- We need to reduce the large jumps probably due to NLOS satellite as much as possible before coupling.
- C/N_0 based satellite selection is effective to some degree.
- Usually, “7-8 dB” is set as a gap between normal and threshold.

Final Loosely Coupled Positions with or without Speed Consideration



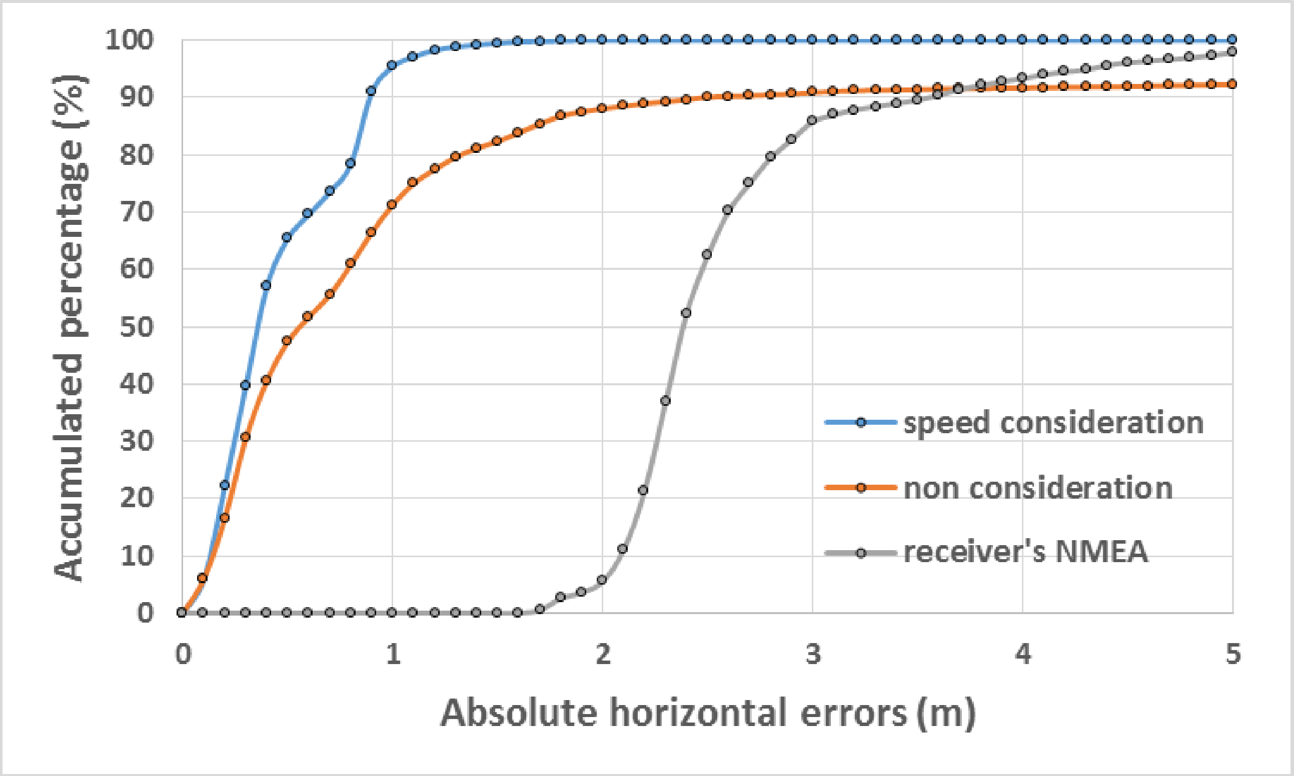
Without speed consideration



With speed consideration

- The normal weighting for "positioning / velocity" is "5m / 0.05m/s".
- "Speed consideration" means we heavily rely on velocity when the car speed is very slow or zero.

Relationship between Accumulated Percentage and Absolute Horizontal Errors

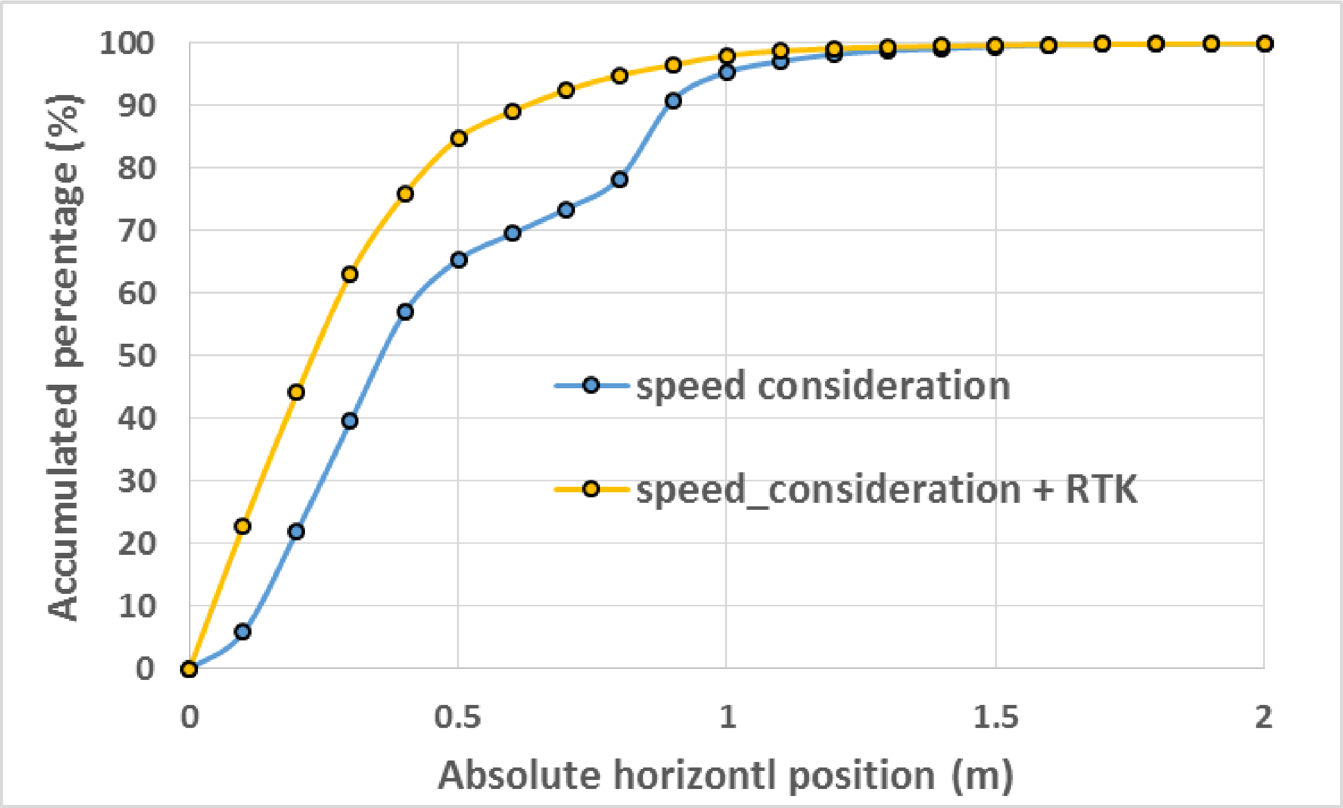


	Maximum error	% within 1.5 m
Speed consideration	1.86 m	99.5 %
Non consideration	10.36 m	82.4 %
Receiver's NMEA	5.31 m	0 %

(No correction

Results of other 2 tests were almost same tendency.

Accumulated Percentage and Absolute Horizontal Errors
+ low-cost single frequency RTK



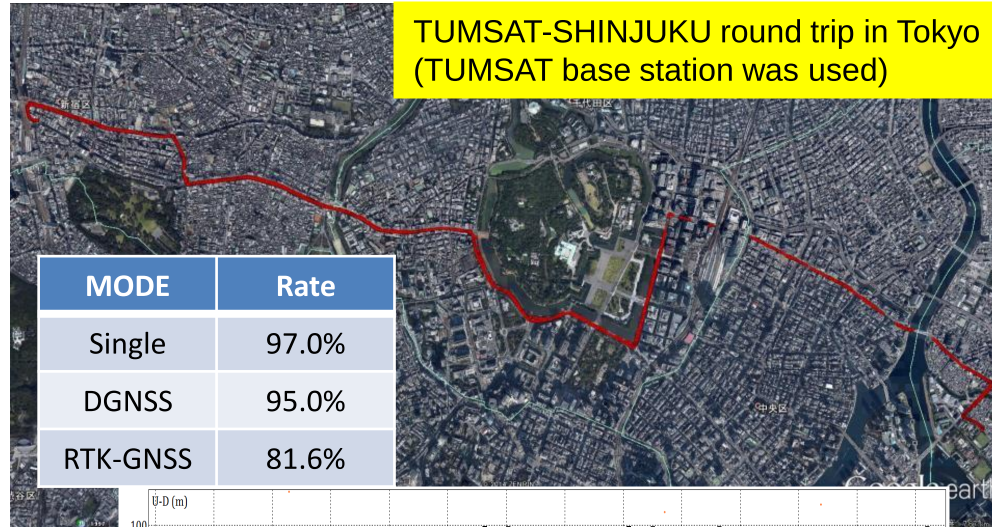
実験結果の現状（主に車両）GNSS単独での意味

	精度	収束	Open	Semi	Urban
PPP	-10cm	約15分	○	困難	困難
RTK	-1cm	瞬時	○	70-90%	-50%
1周波	1-3m	瞬時	○	○	精度が落ちる

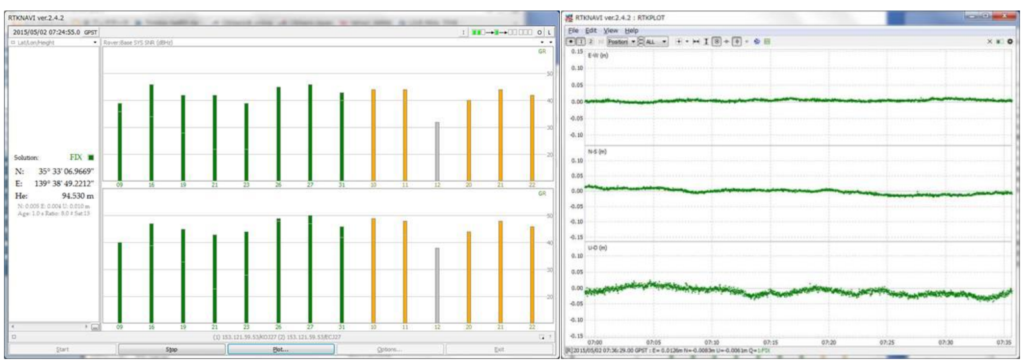
IMUやスピードセンサとの融合が前提

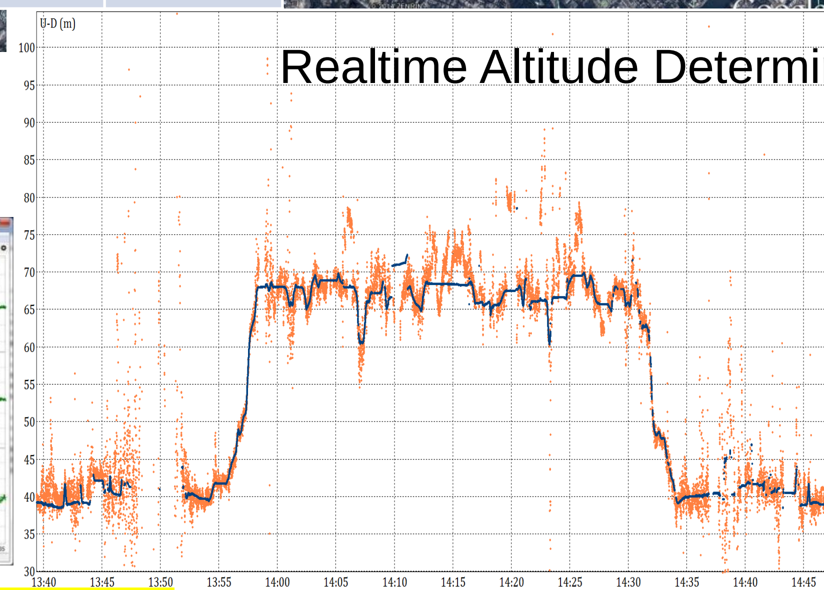
New Service Creation using RTK

- **<u>Multi-GNSS RTK</u>** improved the performance a lot even in the dense urban areas.
- However, we need to find the suitable applications to contribute society.
- **<u>RTKLIB</u>** 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.

Low-cost Receiver Instantaneous Static RTK

- Very short baseline analysis -1m
- Total period: 24 hours
- Different mask angles – 15 & 30 degrees
- Open sky condition
- Data rate: 1Hz
- Average number of satellites –

  GPS L1 – **8.3 & 6.1**

  GPS/QZS L1 and BeiDou B1 – **15.9 & 12**

Mask angle = 15 degrees

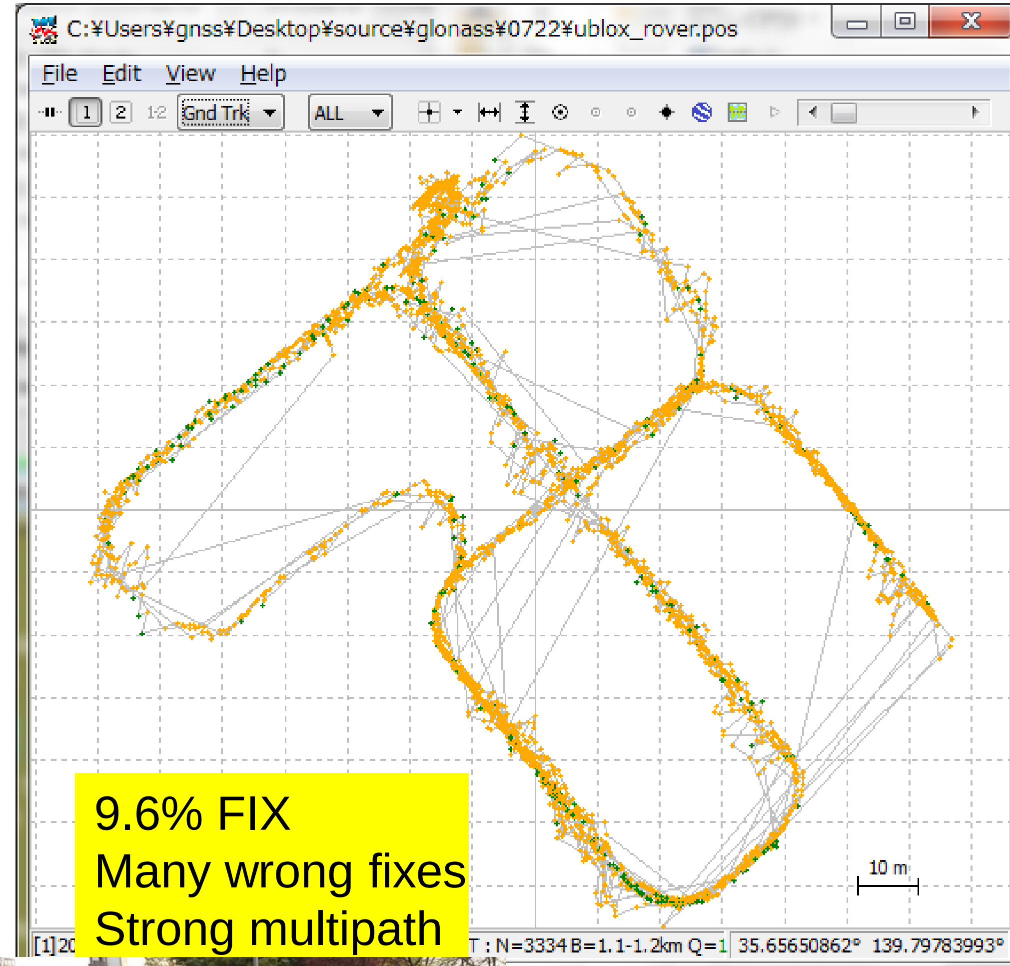
Combinations	Fix rate (%)	Reliability (%)
GPS	**52.53**	98.53
GPS+QZS	**65.78**	99.30
GPS+BDS	**99.82**	100
GPS/QZS/BDS	**99.85**	100
GPS (L1+L2)	**97.88**	100

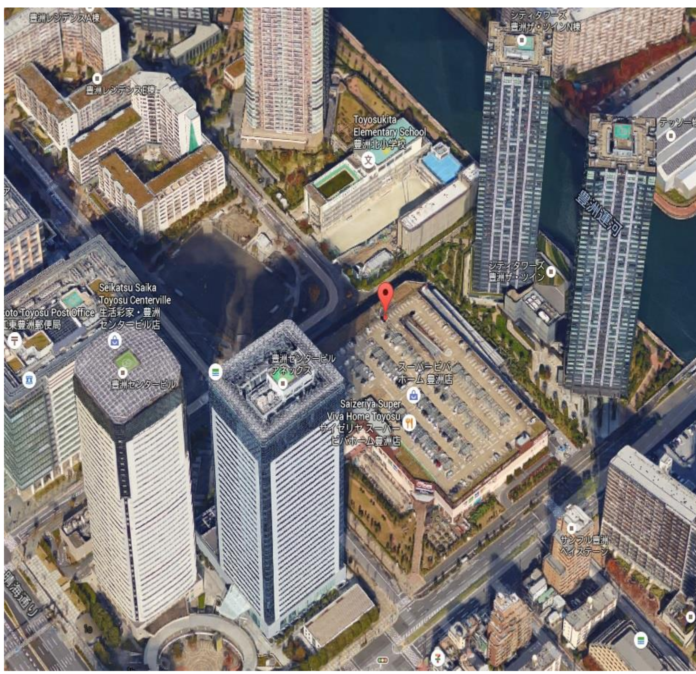
Mask angle = 30 degrees

Combinations	Fix rate (%)	Reliability (%)
GPS	**18.59**	91.72
GPS+QZS	**28.46**	95.35
GPS+BDS	**90.85**	99.87
GPS/QZS/BDS	**92.30**	99.90
GPS (L1+L2)	**70.76**	100

Low-cost Receiver Car RTK

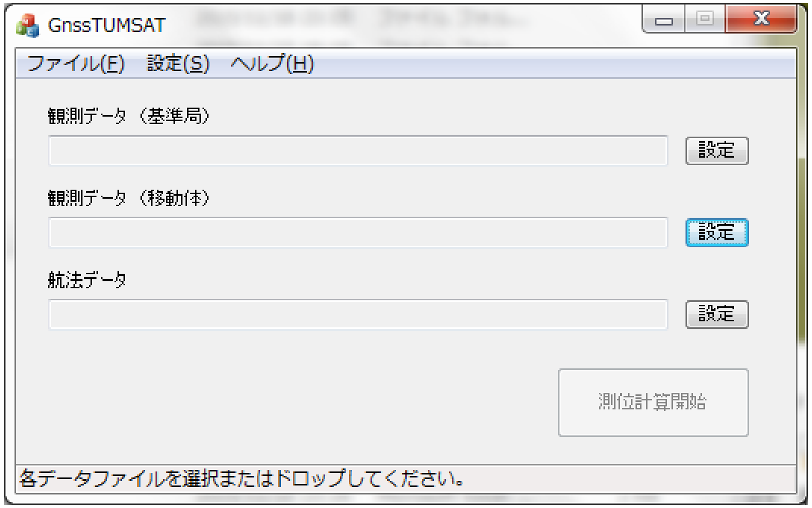
- Multipath rich urban environment in a parking lot
- Total period : ~25 min
- Mask angles – 15 degrees
- Frequency: 5Hz
- Reference station on the rooftop of our building at Etchujima
- GPS/QZS L1 and BeiDou B1 – ~12
- Instantaneous fix rate around 9.6% despite good availability (many wrong fixes)
- Cycle-slips for most of available satellites

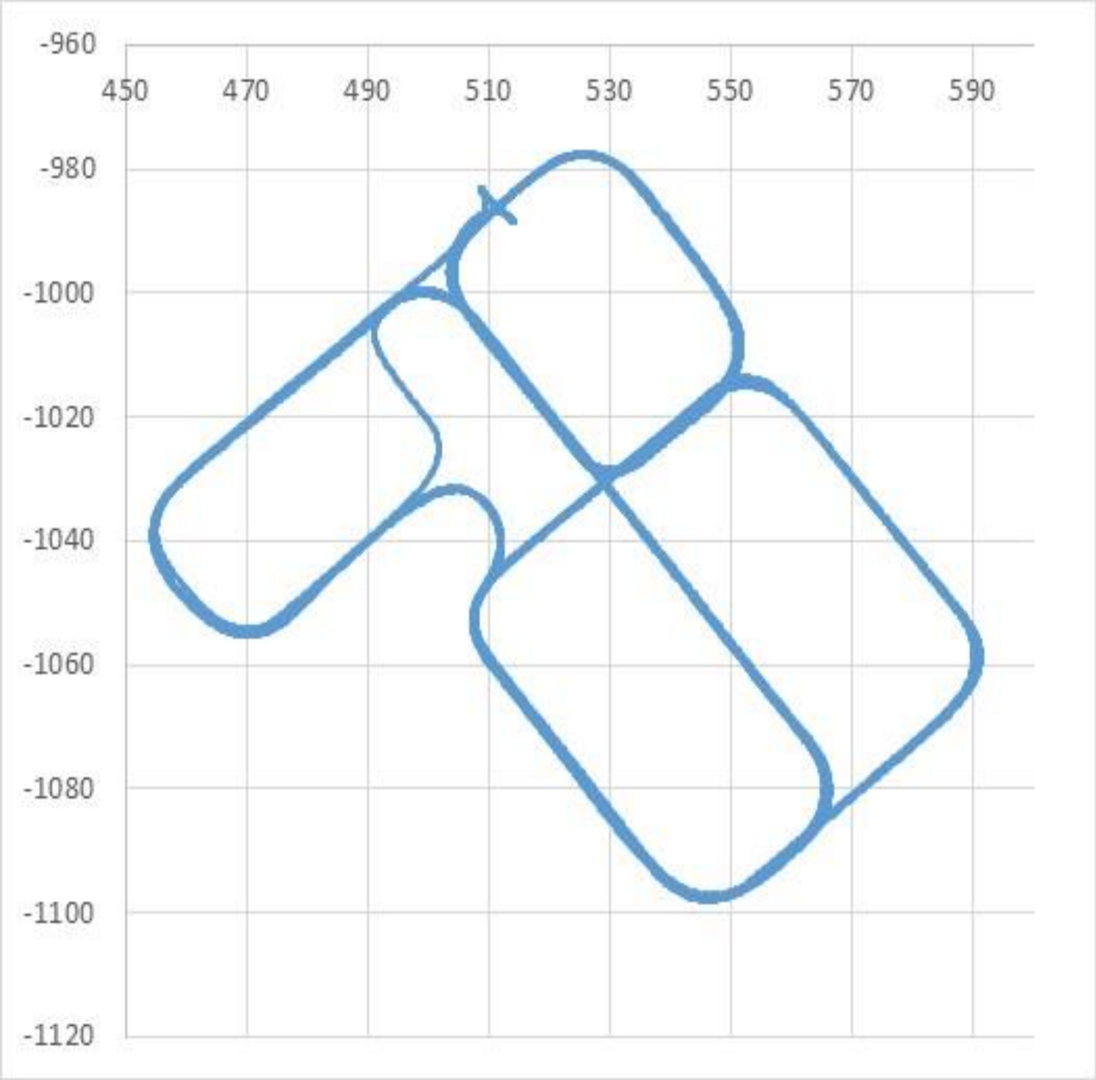




Nearly 100 % results using our software

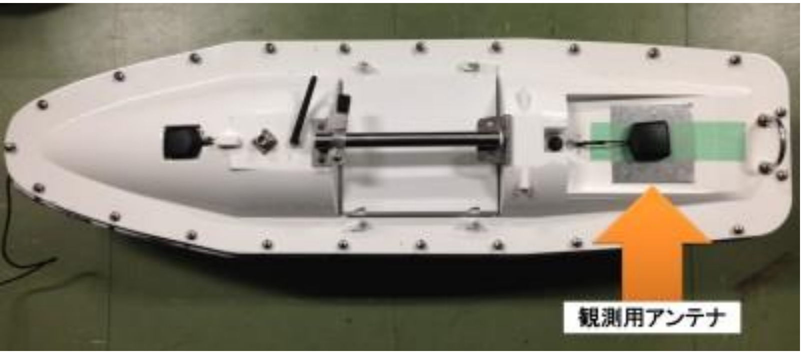
RTKLIB is great software but it still has a room to improve. We have developed the post-processed RTK software because some of applications requires nearly 100% availability even in post-processing.

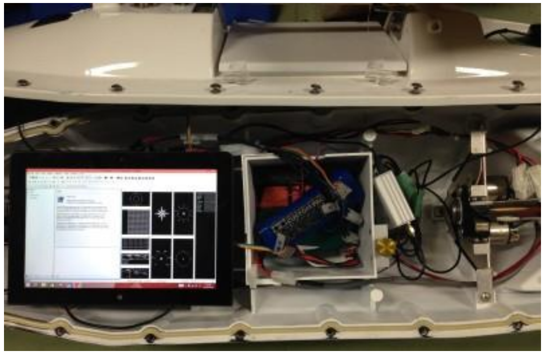


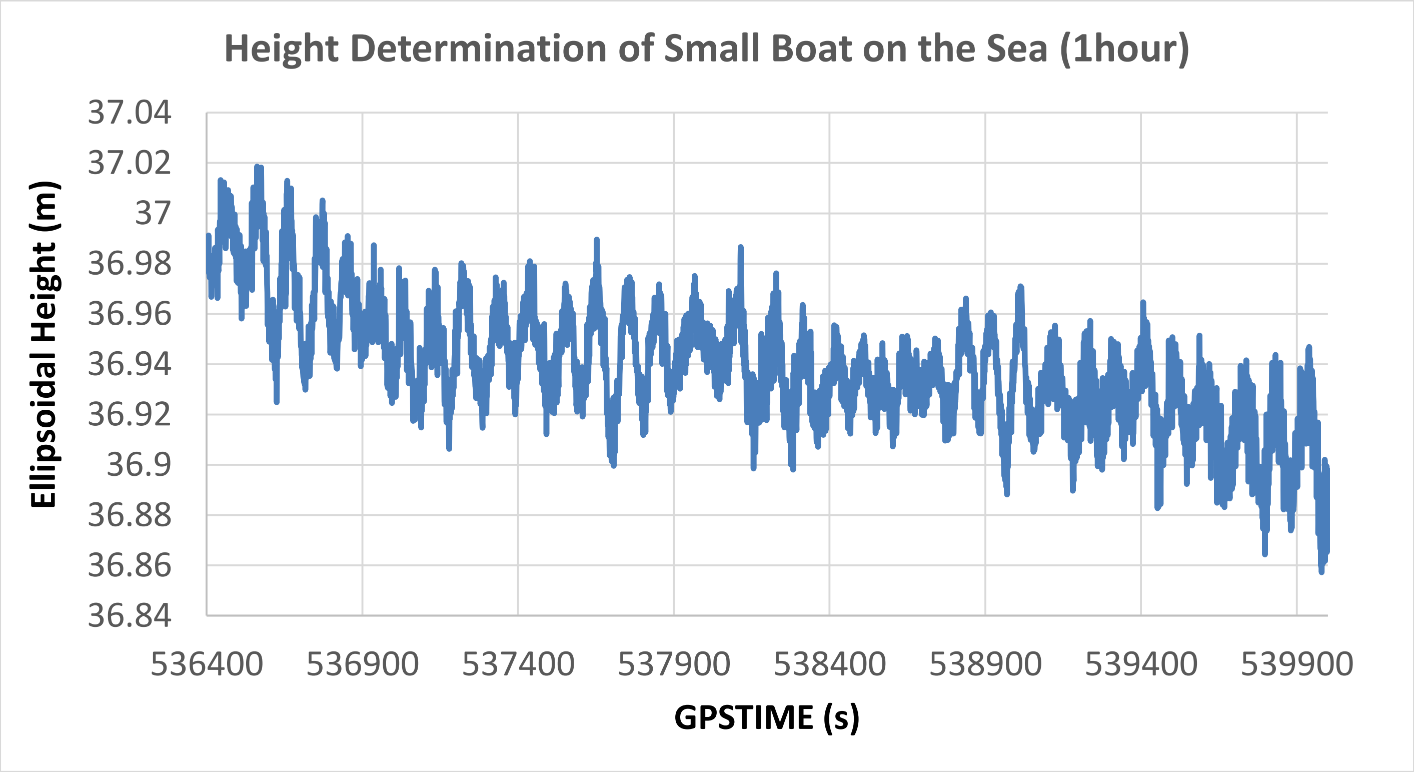


The new post-processed RTK software will be available within this year.

Precise Position for Small Boat







Precise Position for Drone