Tokyo University of Marine Science and Technology

Laboratory of Satellite Navigation Engineering

Achievement of Continuous Decimeter-Level Accuracy Using Low-Cost Single-Frequency Receivers in Urban Environments

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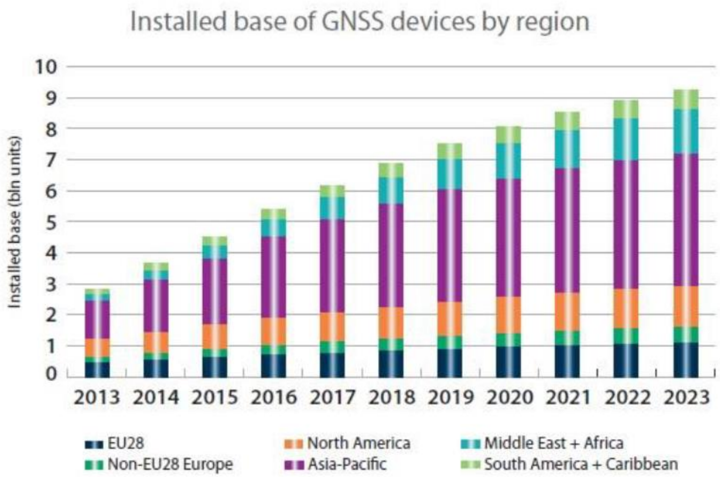
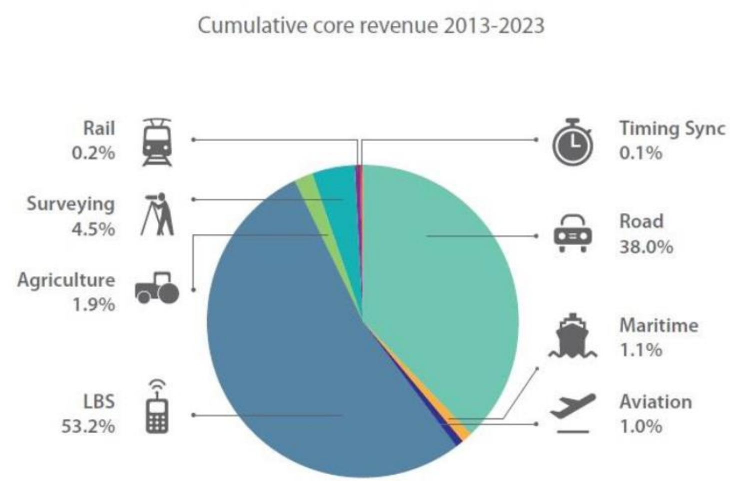
Outline

- Background and objective
- Past work
  - DGNSS + Doppler Velocity
  - Loosely-coupled KF
- RTK-GNSS using single-frequency receiver
  - Improved ambiguity resolution
- Integration of Past work and RTK-GNSS
- Further improvement of RTK-GNSS
- Conclusion

Background

- Background
  - Advanced driver assistance systems (ADAS) with features such as lane change assist and automatic braking in automotive applications are becoming popular.
  - Precise farming, UAV and entertainment etc. also need the precise position at low cost
  - GNSS is one of the candidates for these services.
  - The growth of consumer GNSS receiver is amazing. Multi-GNSS is no wonder.

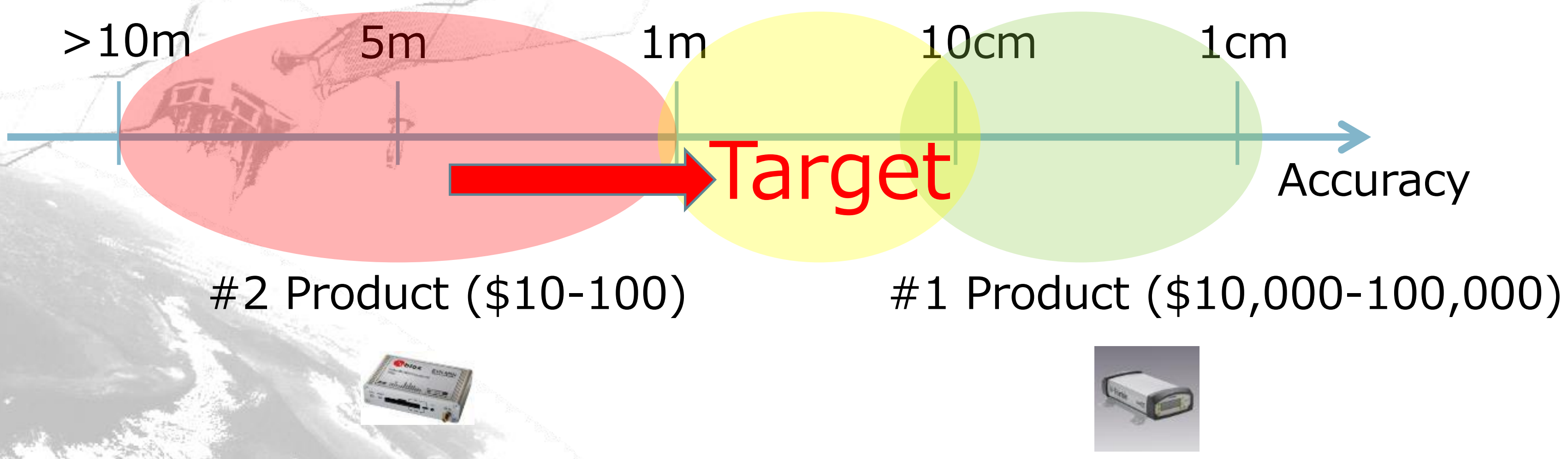




2015,Patent application technical trends surveys navigation satellite systems ,Japan Patent Office

Objective and Target

- Decimeter-level accuracy is expected.
  - It's time to use correction data even with consumer GNSS receiver.
  - Multi-GNSS improves accuracy and availability, but there are something to consider when using multi-GNSS (inter-system biases etc.).



Objective and Target

- We do not use Inertial Measurement Unit (IMU)
  - IMU/Speed are significantly important in automotive navigation. Here we want to find out the limitation of GNSS. It helps a lot in GNSS/IMU/Speed integration.
- Target is "normal urban area"(several short gaps).
- Maximum horizontal error

  < 1.5-2.0 m
  - Based on past work (ION2015)

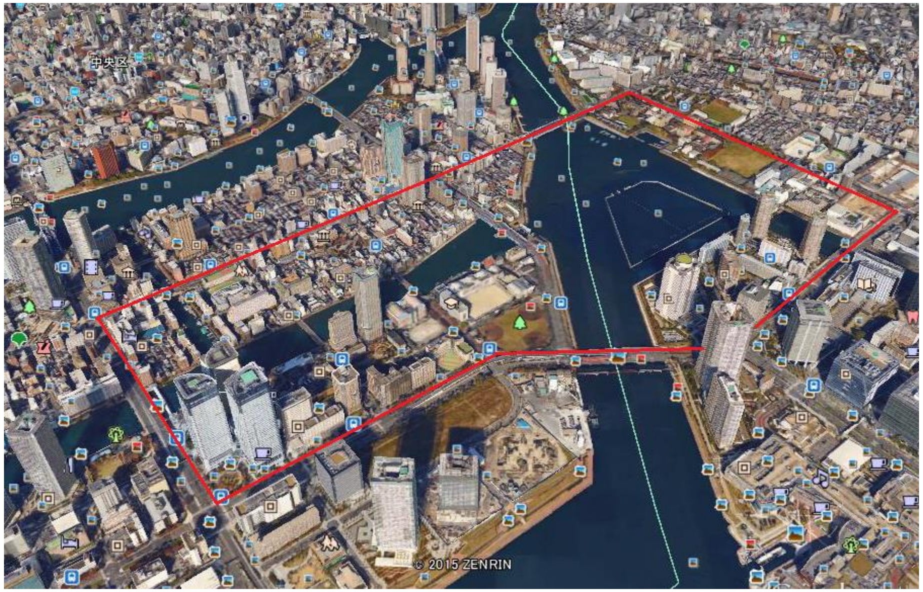
< 1.0 m

by adding RTK solutions.

Ex. Target area at test route

PAST WORK

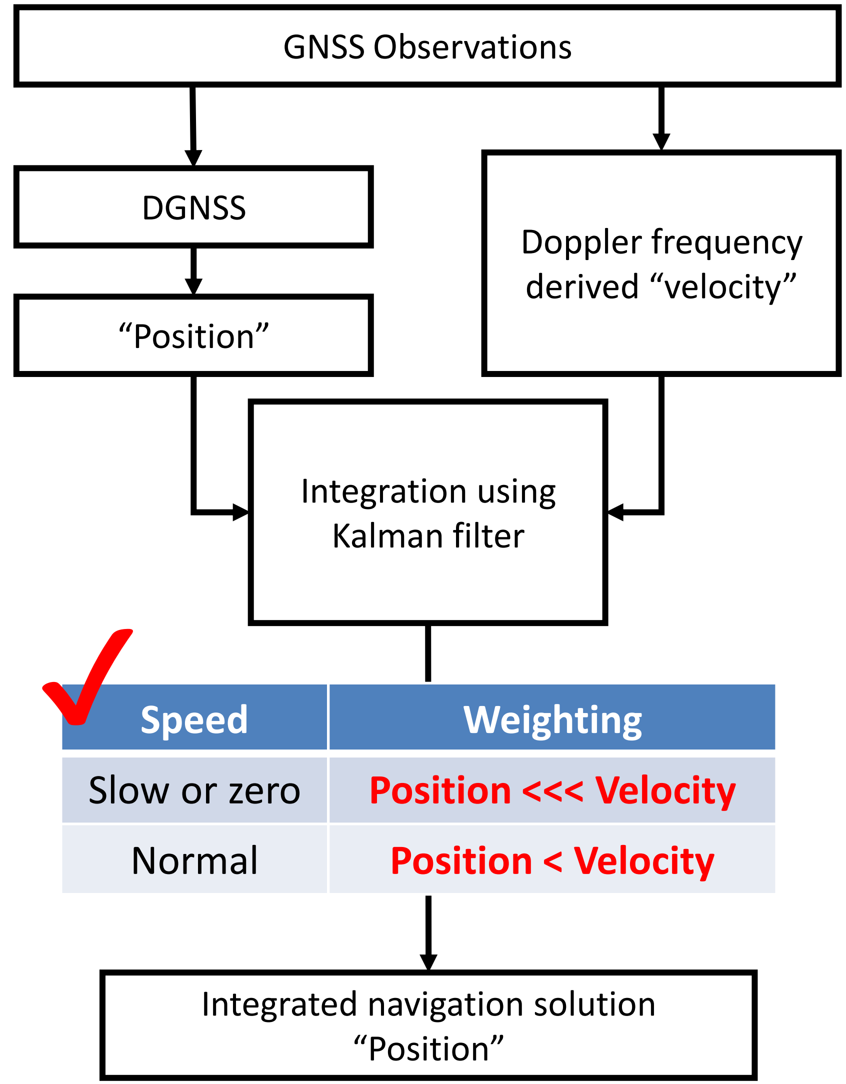
[ION2015]   Kinematic Car Test



Test route

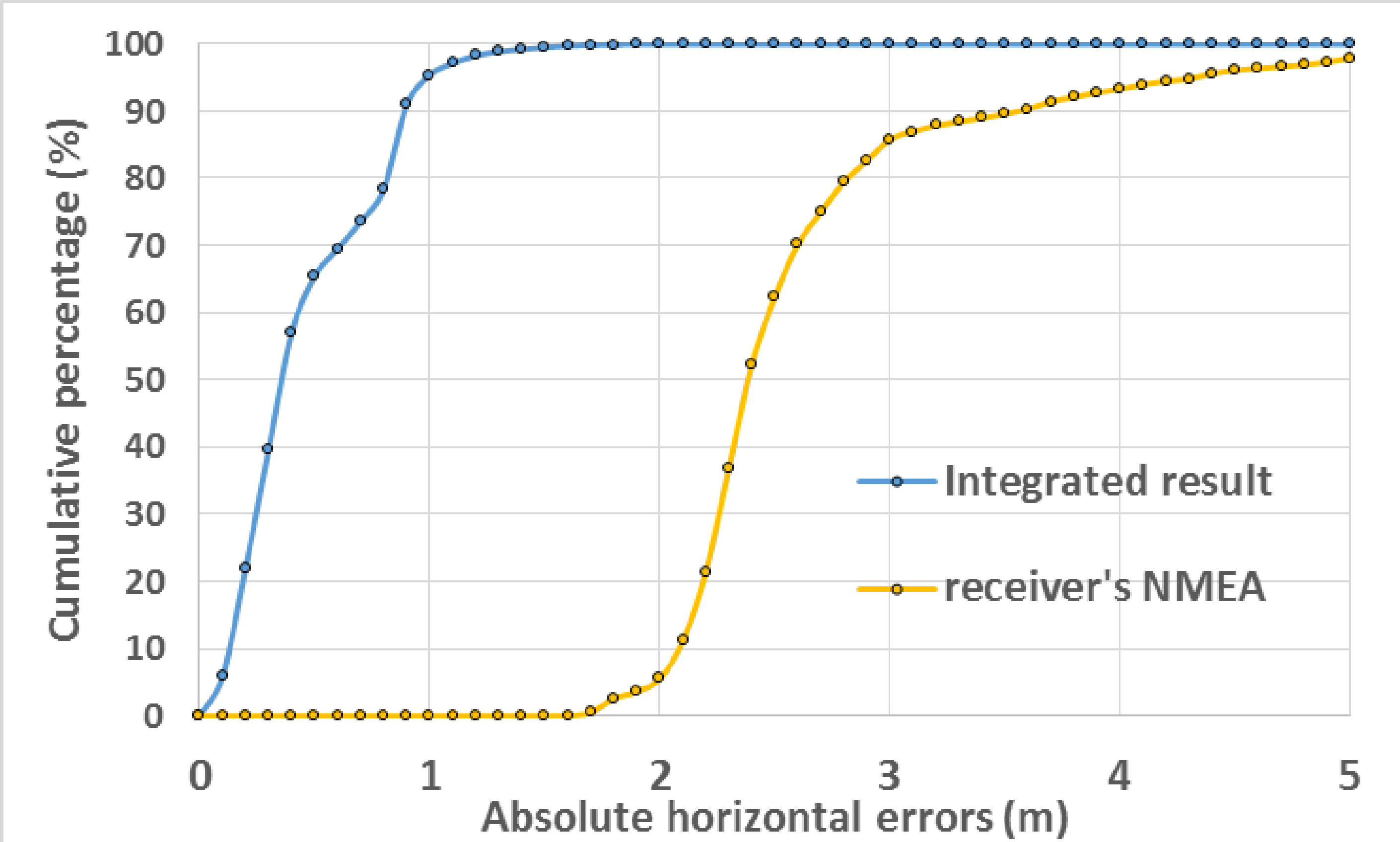
Test configuration

- Tokyo, August 2015
- Single frequency GNSS receiver (ublox M8T)
- GPS/BEI/QZS (DGNSS)
- 20 minutes with 5Hz (3 times for same route)
- Reference positions : POSLV
- Normal urban areas except for several high-rise buildings



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

[ION2015] Kinematic Car Test



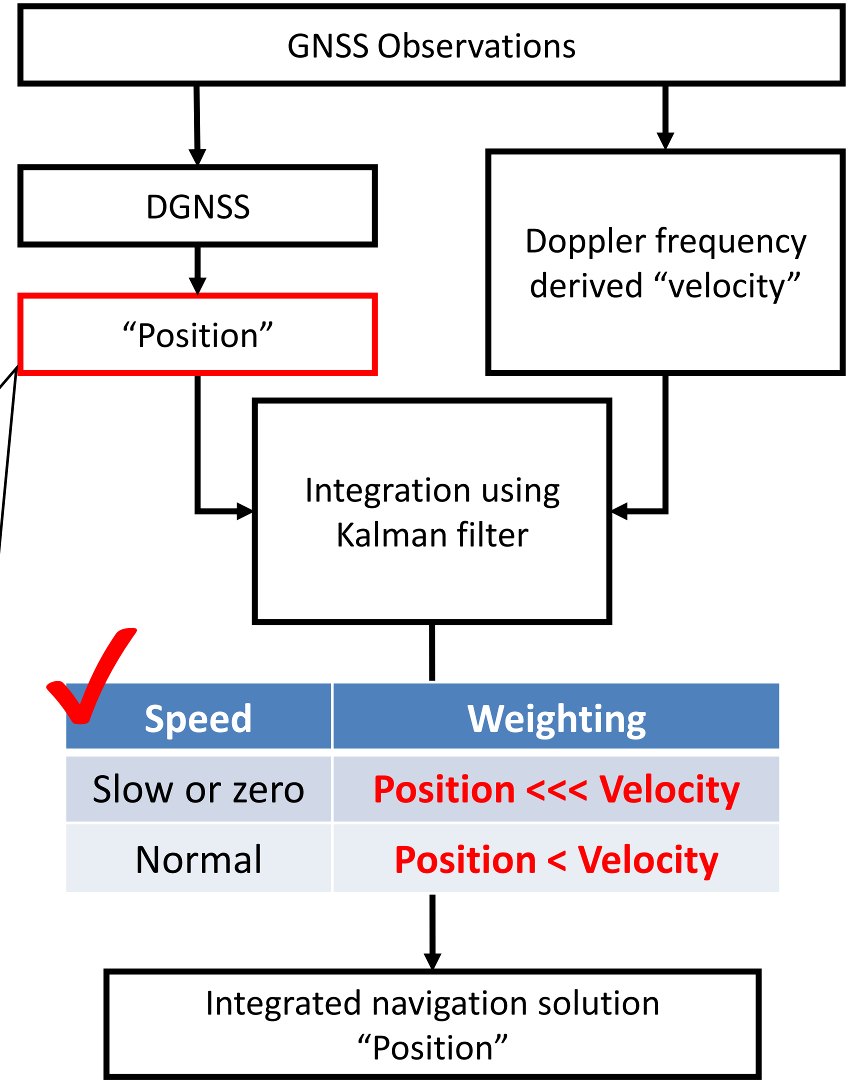
	Maximum error	% less than 1.5 m
Speed consideration	1.86 m	99.5 %
Receiver's NMEA	5.31 m	0 %

(No differential correction)

Results of other 2 tests were almost same.

Multi-GNSS Code-Differential Method

1. The receiver supports multi satellite systems increased.
2. It is advantageous that the number of the visible satellites increases in urban areas.
3. Therefore, single-difference method is used in code-differential because a few satellites for each satellite system are decreased using double-difference method.



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

Maker	GPS	GLONASS	Galileo	BeiDou	QZSS	SBAS	
Qualcomm	v	v		v	v	v	Izat
Broadcom	v	v			v	v	bcm4752
MediaTek	v	v	v	v	v	v	MT3333
U-blox	v	v	(✓)	v	v	v	u-blox m8
CSR	v	v	v	v			SiRV-starVea
ST-Microelectronics	v	v	v	v	v		TESEO III
SkyTraq	v	v			v	v	S1216F8-GL
Telit	v	v	v	v	v	v	SE868 V3
FURUNO	v	v	v		v	v	GN-87
JRC	v		v		v	v	CCA705

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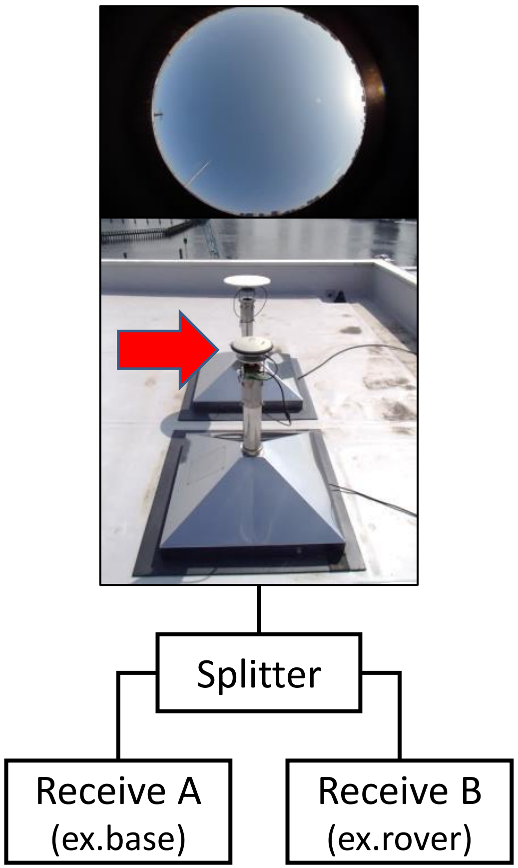
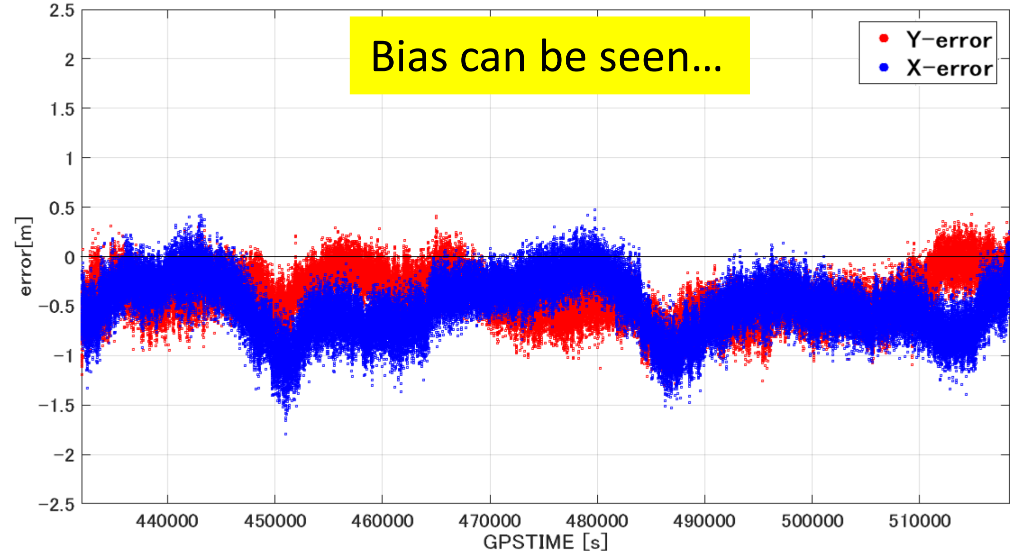
Receiver bias investigation



Interval Total	1Hz:24 hours
Receiver	Ublox-NEOM8T FW3.01　×2
	GPS/QZSS/Galileo/BeiDou//Glonass
Antenna	NovAtel GPS-703-GGG

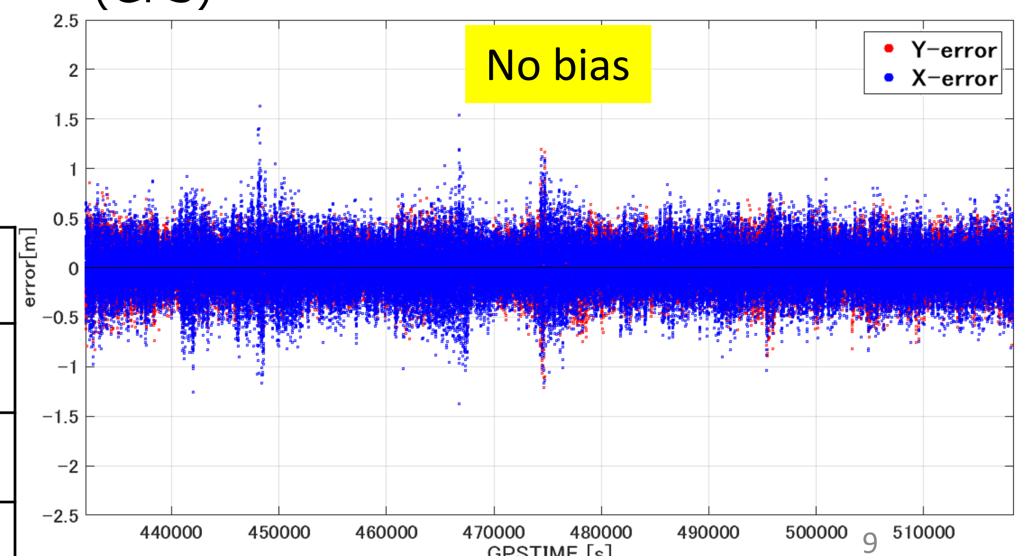
◆ DGNSS

(GPS/QZSS/Galileo/BeiDou)



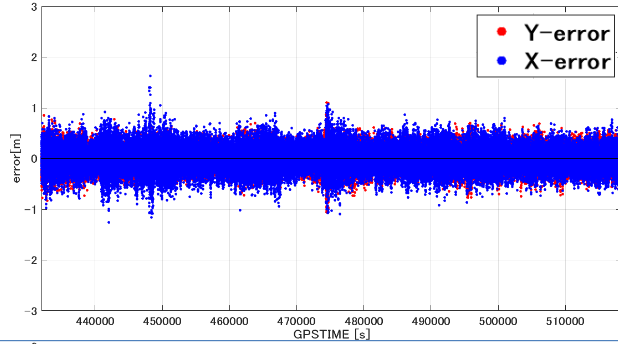
◆ DGPS

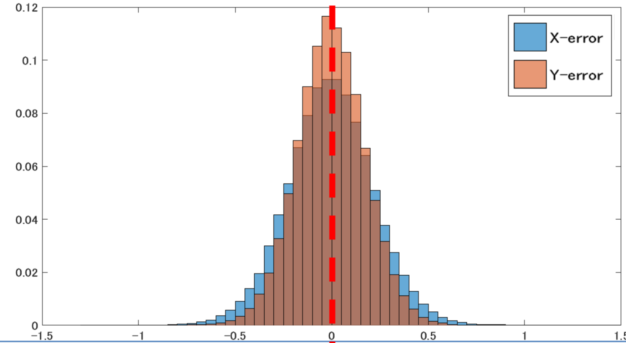
(GPS)



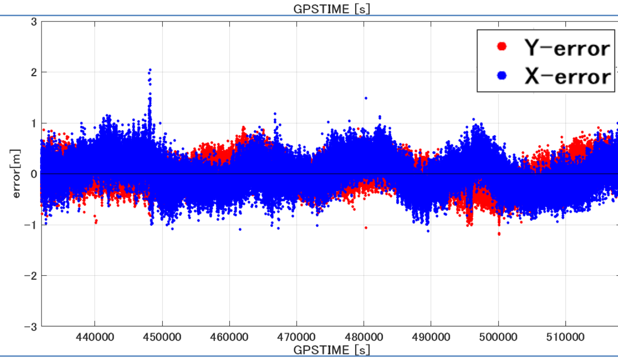
◆ Horizontal error ◆ Histogram

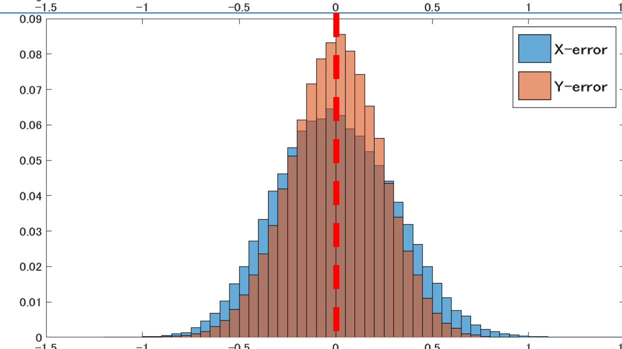
- GPS
- QZSS



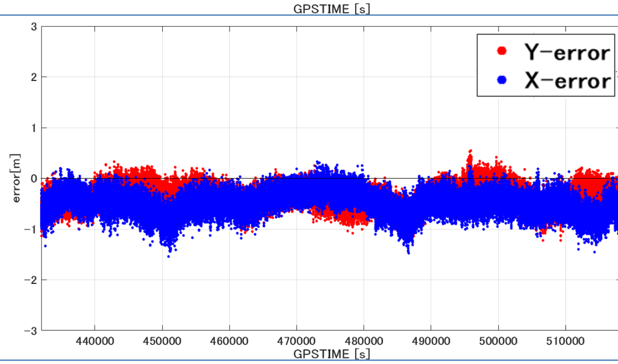


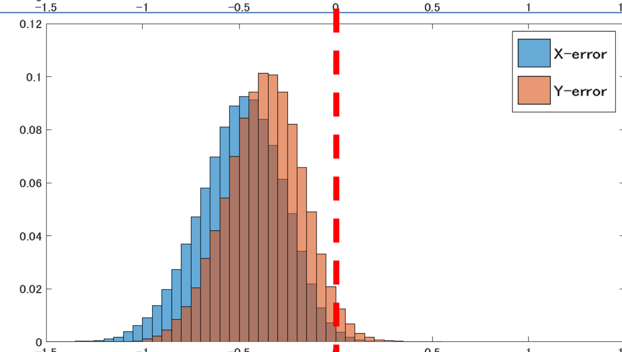
- GPS
- Galileo



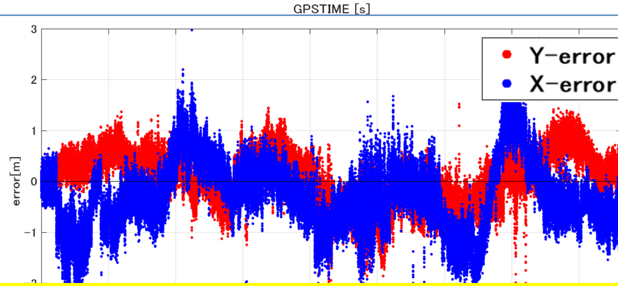


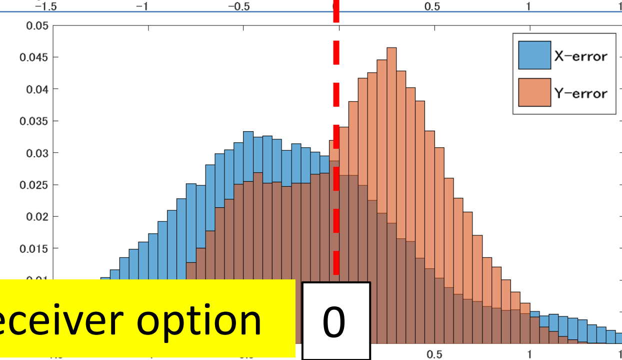
- GPS
- BeiDou





- GPS
- GLONASS





GLONASS is not used because of the limitation of receiver option

0

DGNSS [single difference method]

◆GPS pseudorange

Base : $P^{ref} = \rho^{ref} + c \cdot (dt^{ref} - dT) + ion + tropo + noise^{ref}$

Rover : $P^{rov} = \rho^{rov} + c \cdot (dt^{rov} - dT) + ion + tropo + noise^{rov}$

Corrections

◆Beidou pseudorange on the basis of GPS

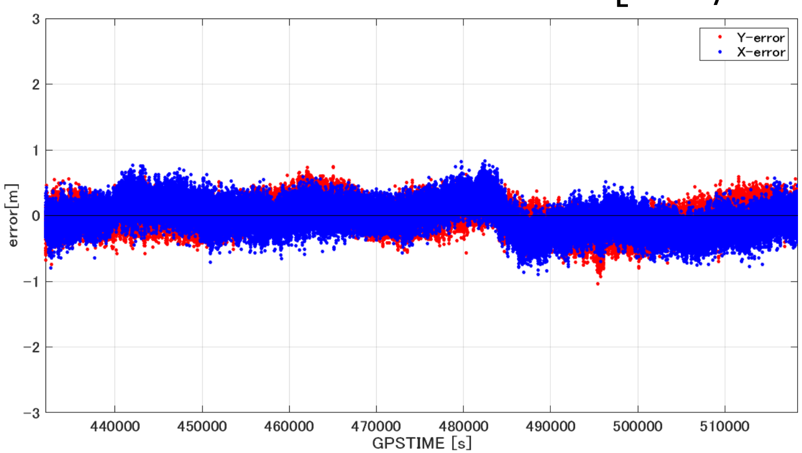
Base : $P^{ref}_{BeiDou} = \rho^{ref} + c \cdot (dt^{ref} - dT - GBTO^{ref}) + ion + tropo + noise^{ref}$

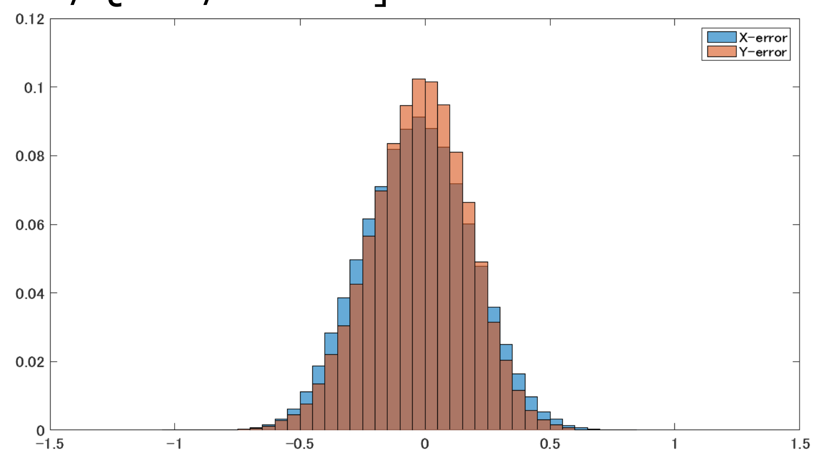
Rover : $P^{rov}_{BeiDou} = \rho^{rov} + c \cdot (dt^{rov} - dT - GBTO^{rov}) + ion + tropo + noise^{rov}$

$GBTO^{rov} = GBTO^{ref} + \boldsymbol{Bias}$

Corrections

◆ As a result of consideration [GPS/Galileo/QZSS/BeiDou]



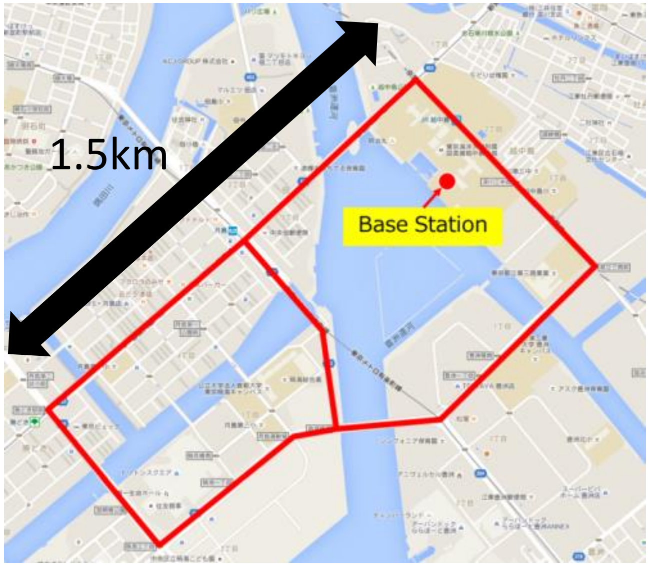


Data Acquisition

- Automobile testing near university campus
- Reference station on the rooftop of our building at campus
- Normal urban environment surrounded by several buildings and overpasses

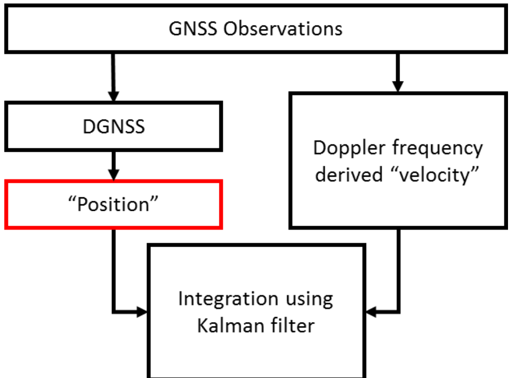
- HONDA Fit

Interval	5 Hz
Receiver	Rover/Ublox-NEOM8T FW3.01 Base/Ublox-NEOM8T FW3.01
	GPS/BeiDou/QZSS/Galileo
Antenna	Rover/NovAtel GPS-703-GGG Base/Trimble Zephyr Geodetic
Reference system	Applanix POSLVX (10-20cm)

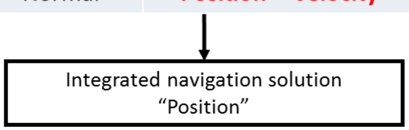


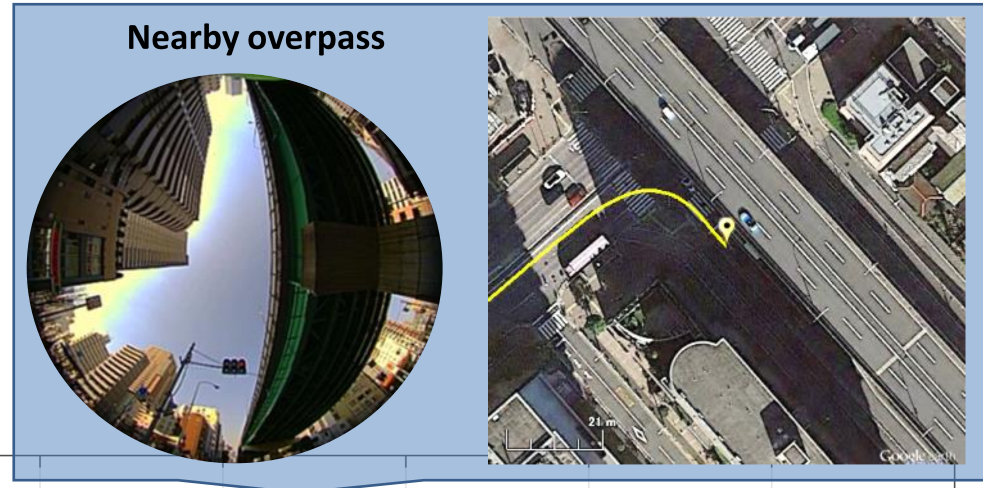
- Test route

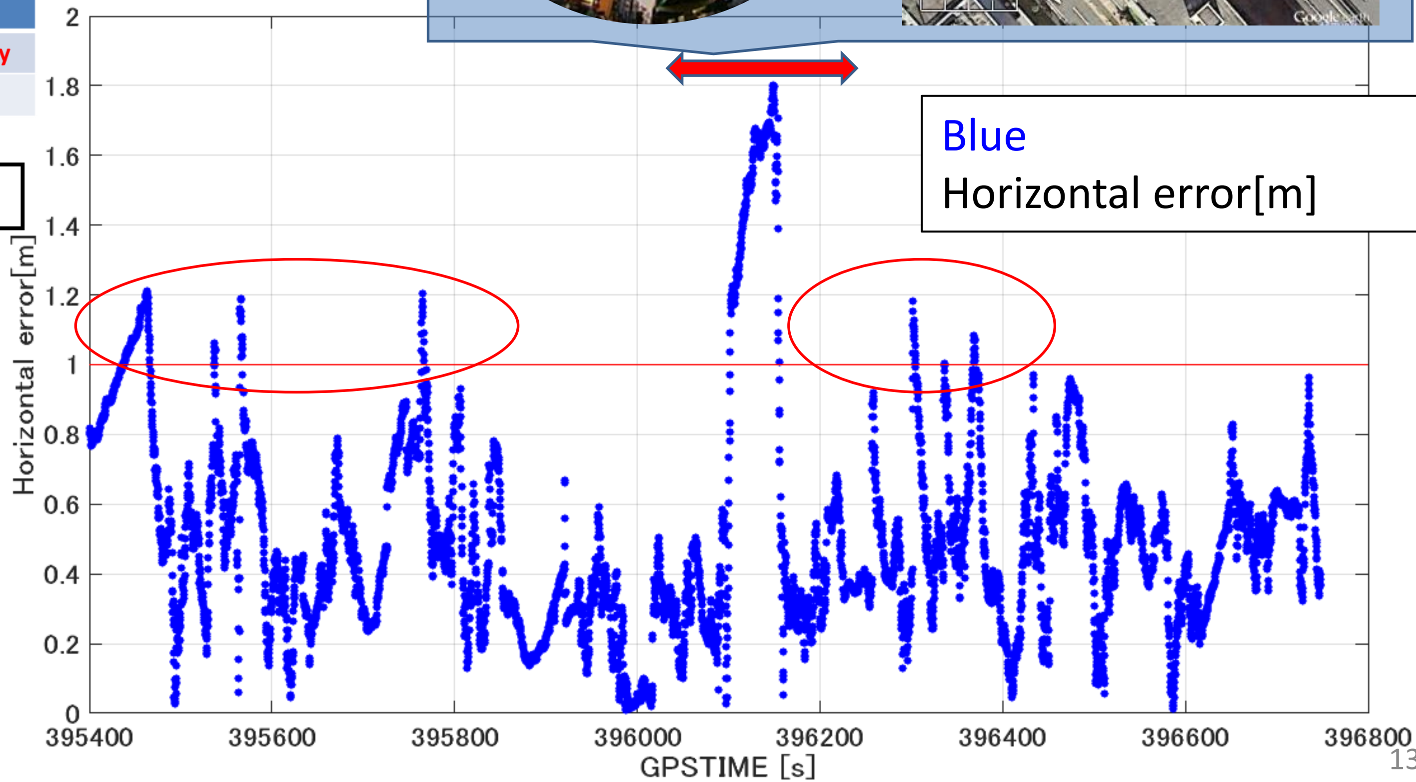
Previous method (Code and Doppler)



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







RTK-GNSS

- RTK method

  1.Signal quality check

  check LLI (Lose of Lock Indicator)

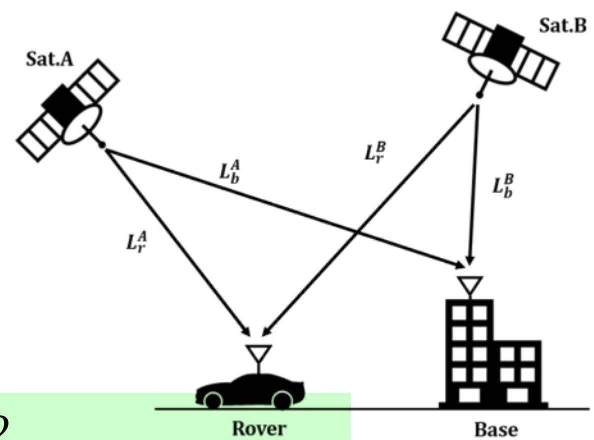
  2.Double-differenced

  in each satellite system

  [GPS/QZSS/Galileo] 1575.42

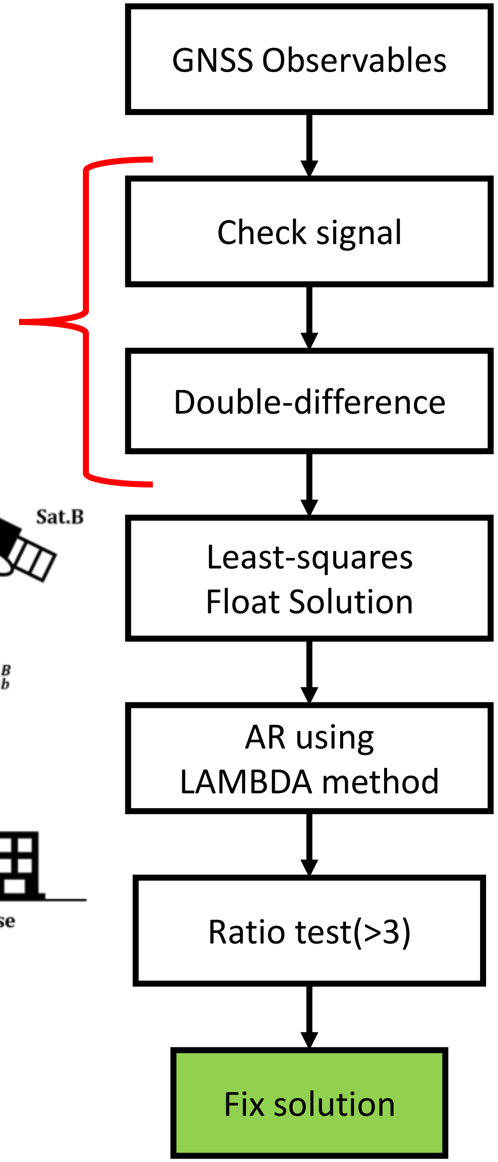
  ~~[Glonass]~~ [BeiDou] 1561.08

We did select BeiDou option in u-blox because of the performance



$$P_{rov\_ref}^{sv1\_sv2} = r_{rov\_ref}^{sv1\_sv2} + \varepsilon_{p,rov\_ref}^{sv1\_sv2}$$

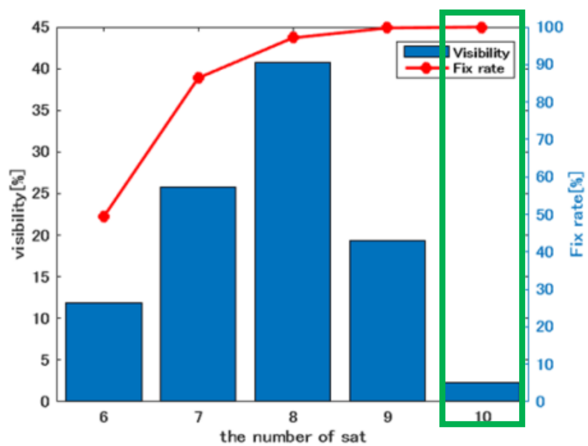
$$\phi_{rov\_ref}^{sv1\_sv2} = r_{rov\_ref}^{sv1\_sv2} + N_{rov\_ref}^{sv1\_sv2} + \varepsilon_{\phi,rov\_ref}^{sv1\_sv2}$$



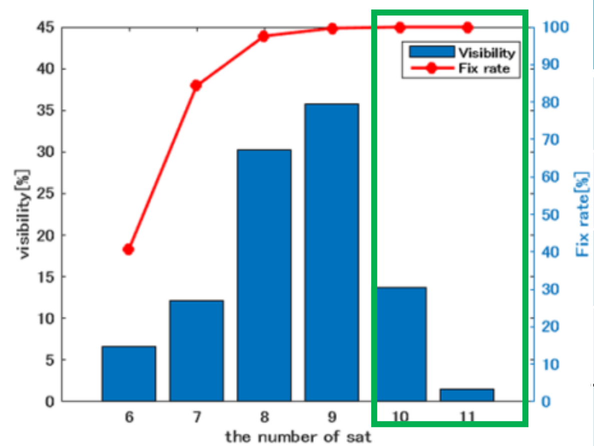
RTK-GNSS [Validation in advance]

- We checked the number of visible satellites and fix rate in SF-RTK.
- We tested RTK using 24-hour static data (same as DGNSS).

[GPS]

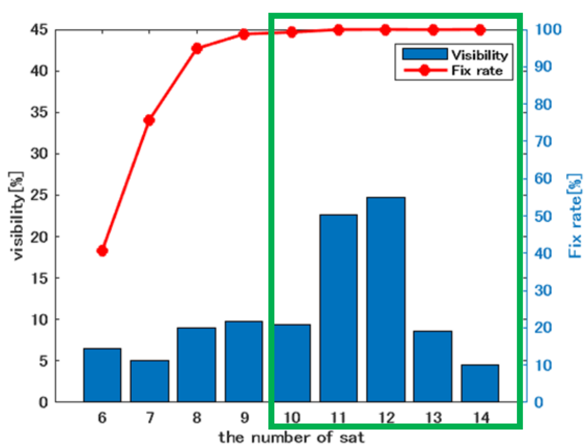


[GPS/QZSS]

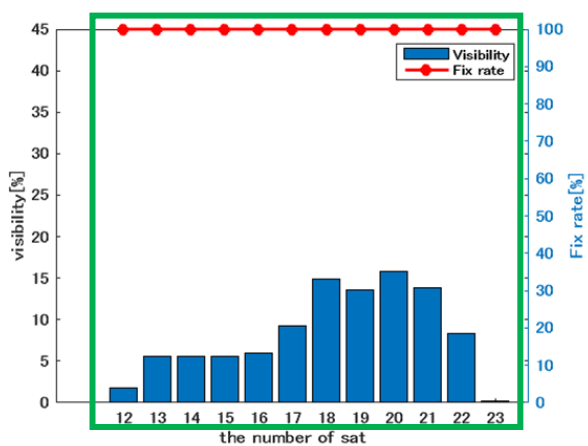


Satellite system Combination	Fix rate (SV=10)[%]
G	100.0
G+Q	100.0
G+Q+E	99.2
G+Q+E+B	100.0
G+R	80.6

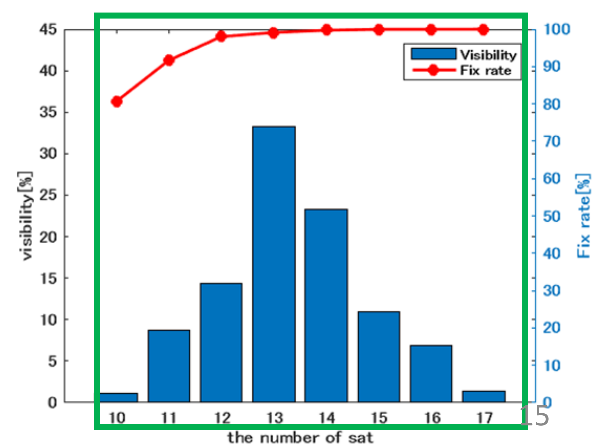
[GPS/QZSS/Galileo]



[GPS/QZSS/Galileo/BeiDou]



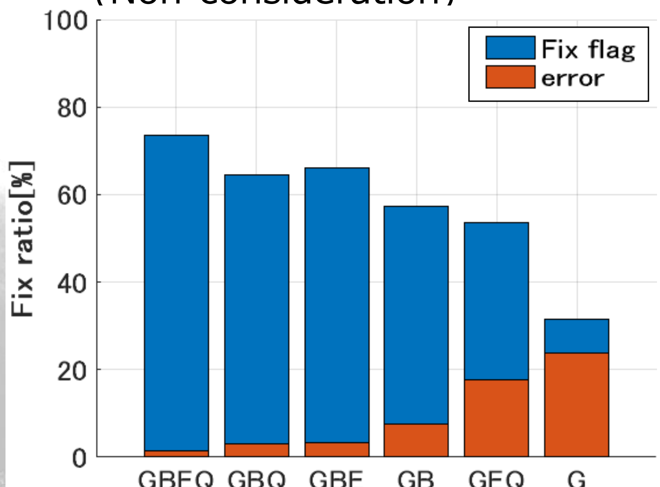
[GPS/Glonass]



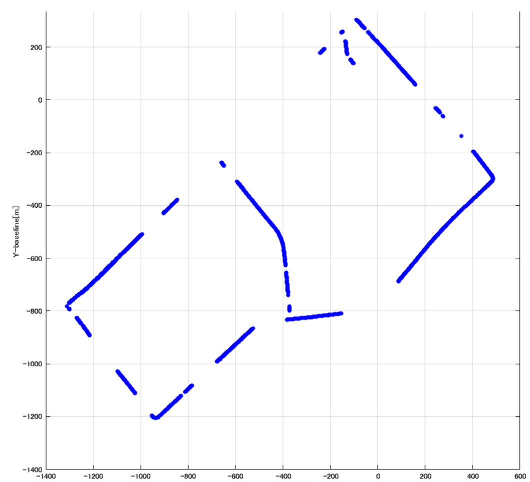
Result [RTK-GNSS (GPS/QZS/BeiDou/Galileo)]

	Fix rate	H_error>50cm
RTKLIB 2.4.2 b9 (best setting)	4456/6740 =66.1[%]	39 epochs (max 89.4 m)
Laboratory RTK engine	4987/6740 =74.0[%]	91 epochs (max 5.3 m)
+More than 10 satellites	3521/6740 =52.2[%]	0 epochs

◆ Every system combination of this experiment (Non-consideration)



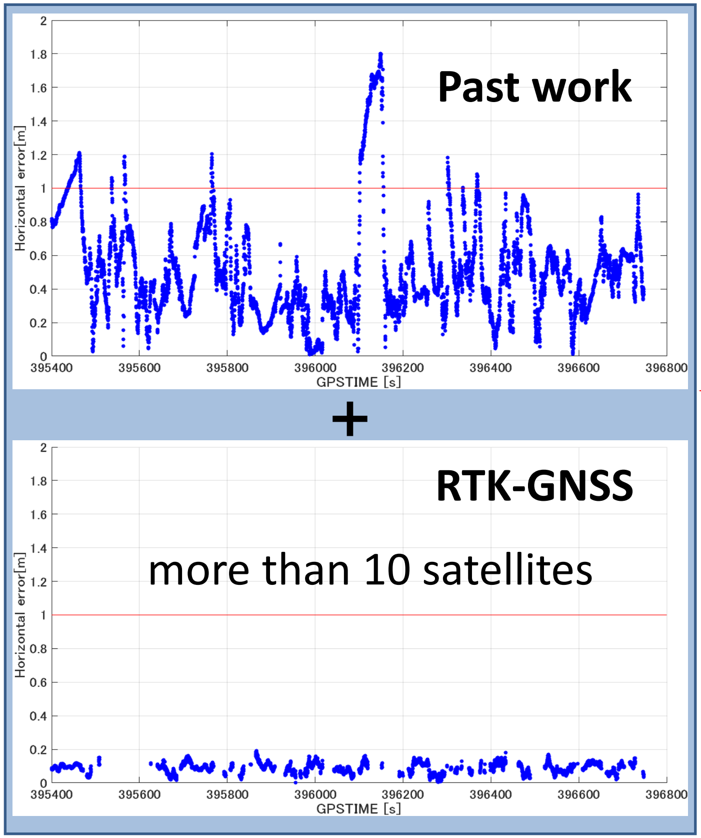
◆ Horizontal distribution of this experiment (More than 10 satellites)

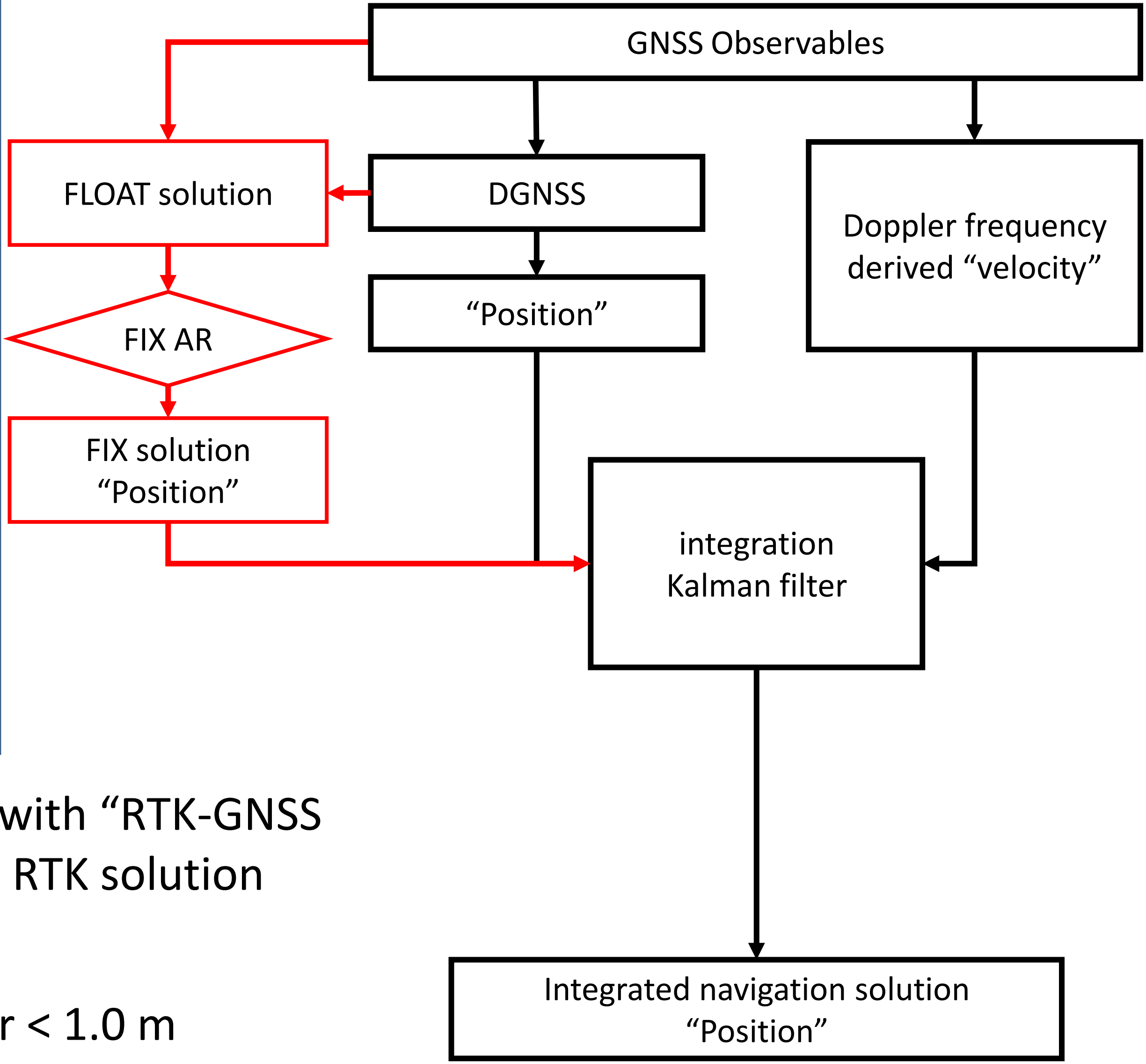


• Route image

It was dotted with fix solutions, but they included a big error.

Coupling "past work" with "RTK-GNSS"

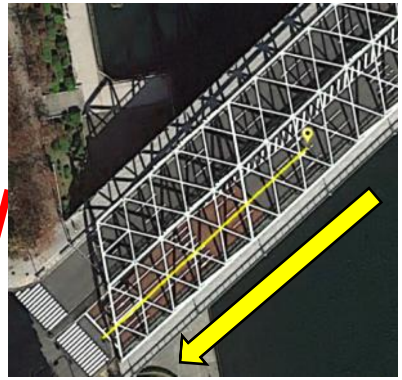




DGNSS positions are replaced with "RTK-GNSS positions" when we have valid RTK solution

Target
⇒Maximum horizontal error < 1.0 m

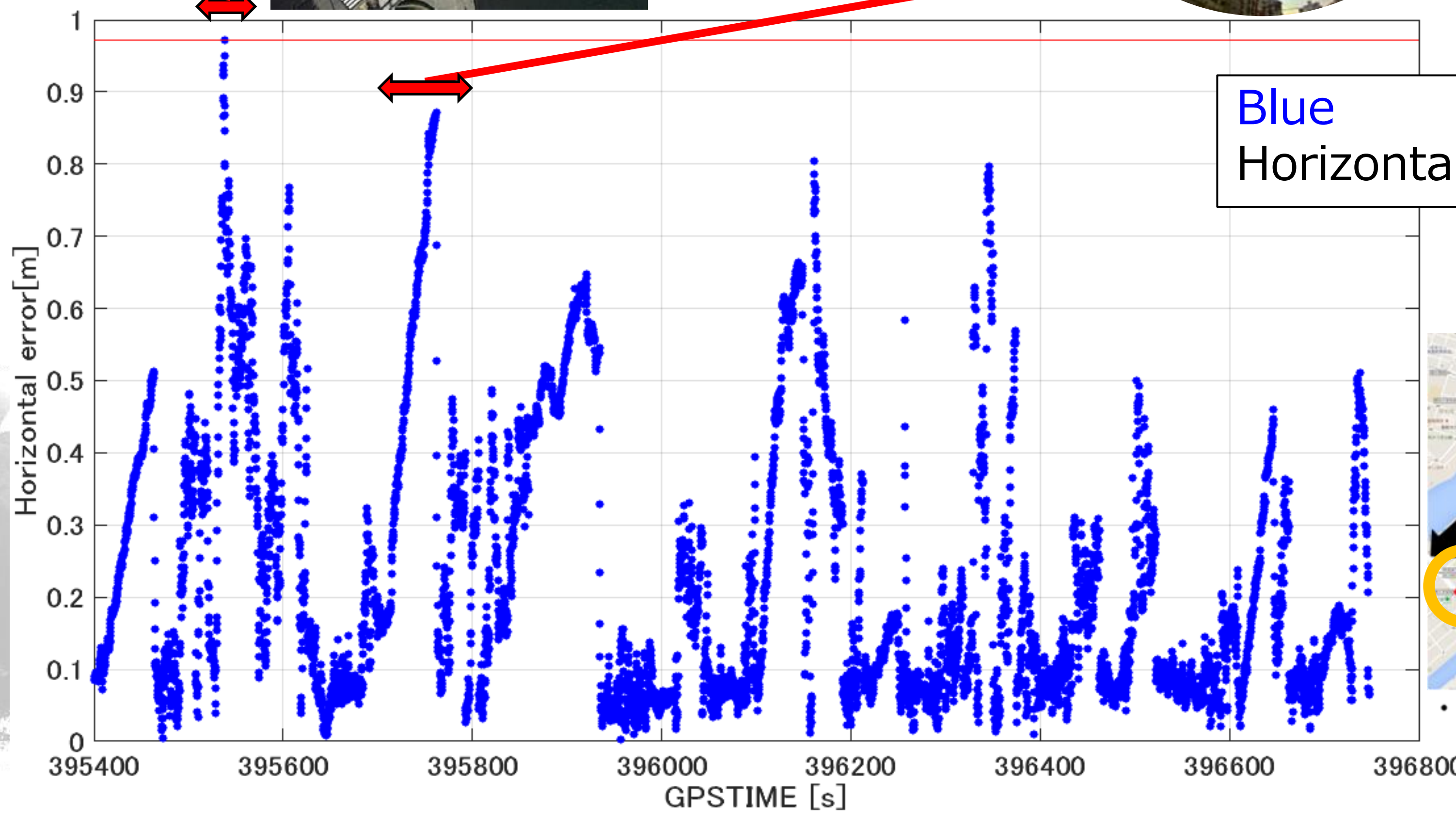
Result [The newly integrated performance]



Through
the truss bridge

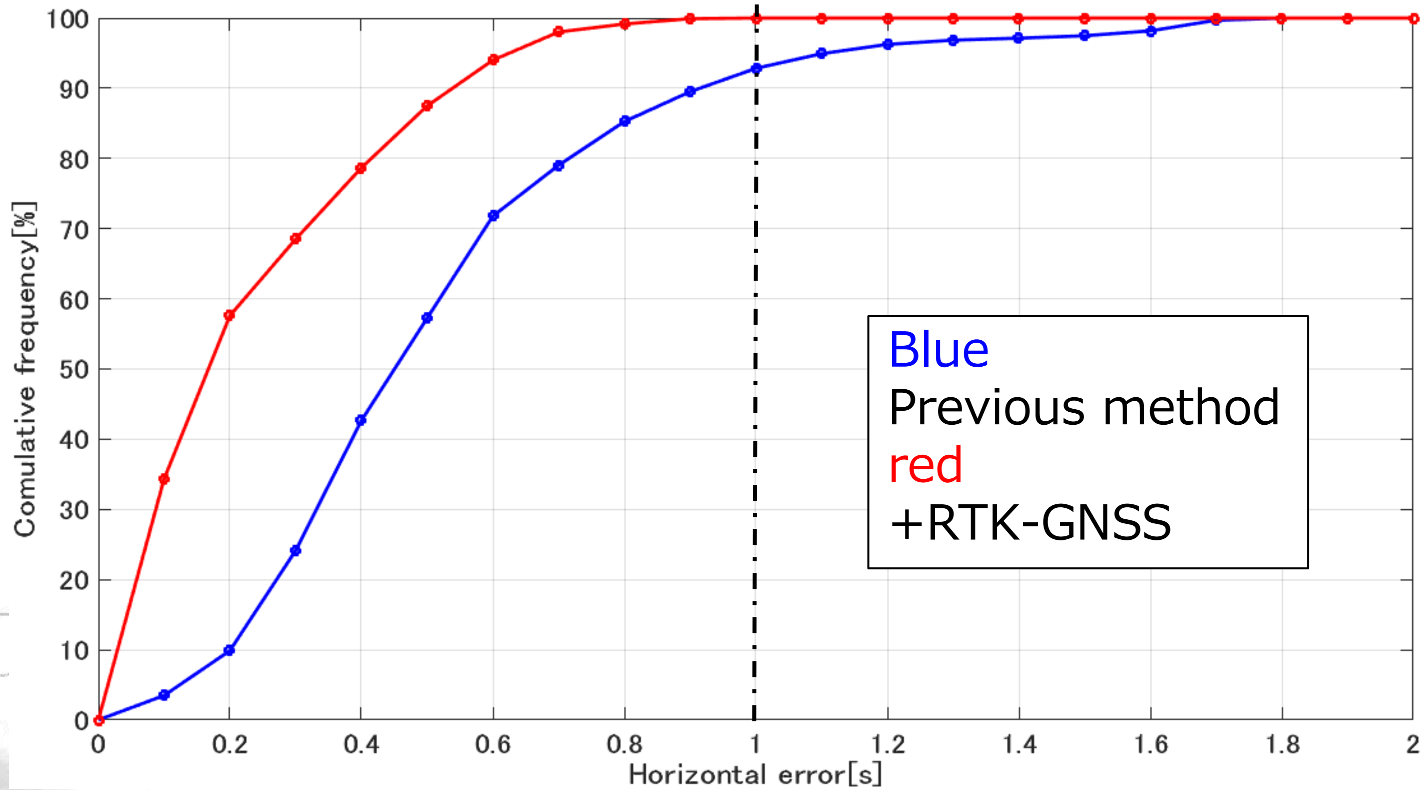
stop
at a red light

Sky image



• Route image

Result [Cumulative distribution]



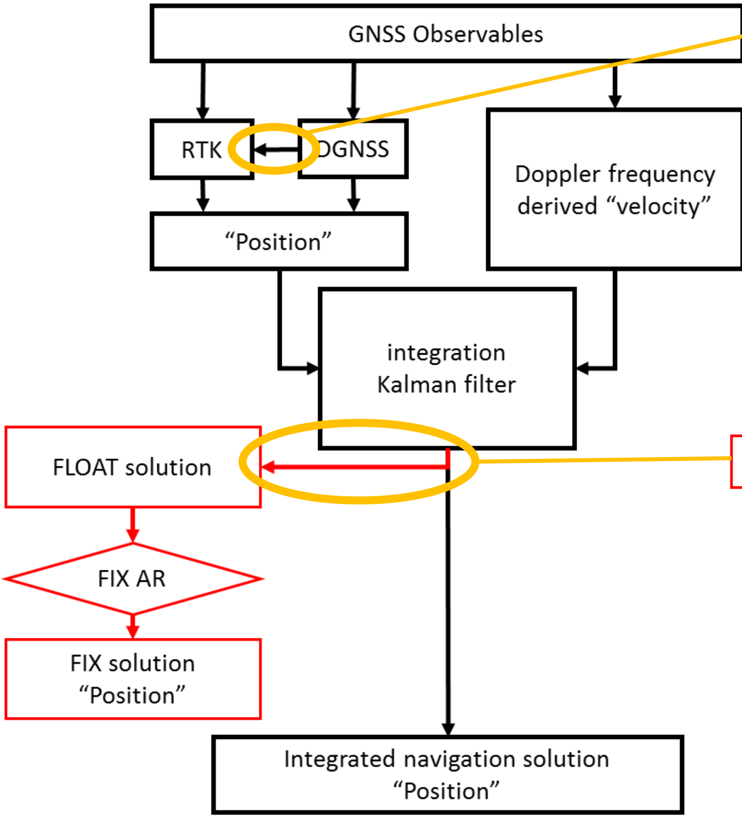
	Max horizontal error	% less than 1.0 m
Previous method	1.80 m	92.8 %
+RTK-GNSS	**0.97 m**	**100 %**

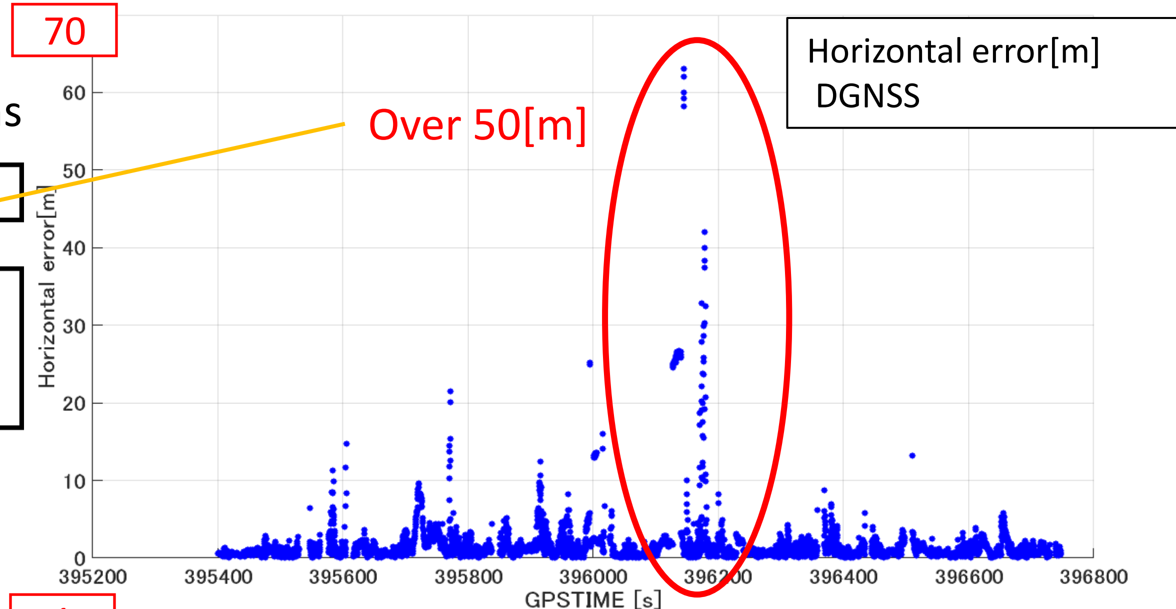
Further improvement of RTK-GNSS

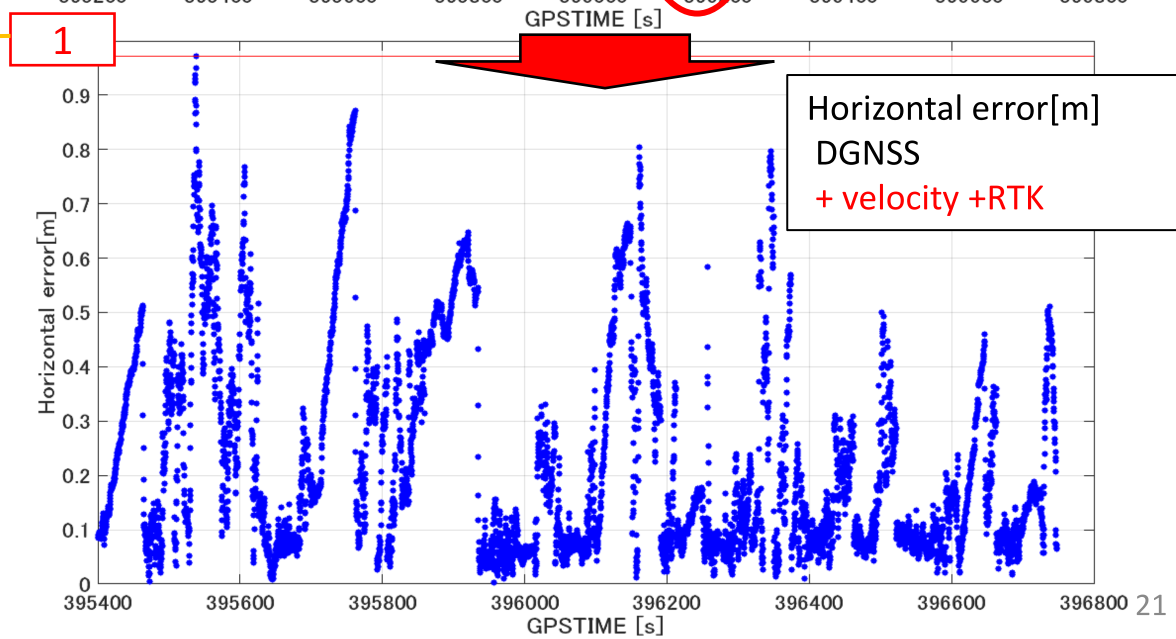
- Providing good float solutions enables the performance of an RTK to improve.
- Over 10-20 m errors are frequently seen near buildings in the case of normal code-based positions as float solutions.
- We produced new float solutions, meaning the outputs of the code, velocity and RTK-based integrated results mentioned earlier.

Further improvement of RTK-GNSS

◆ We produced new float solutions

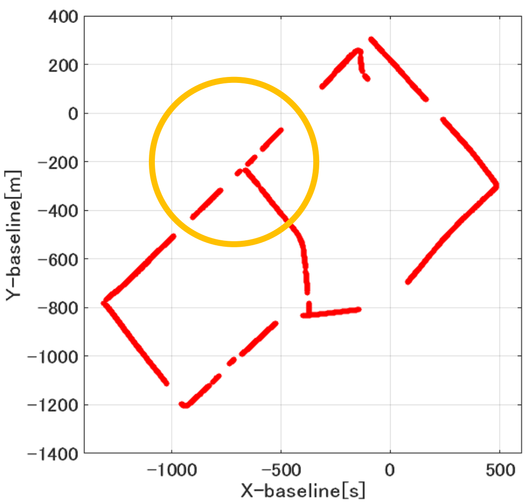




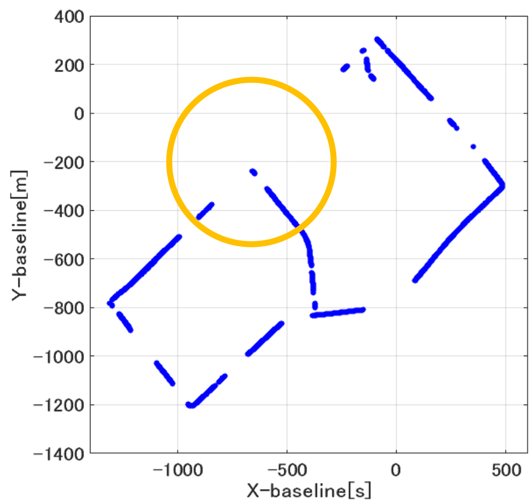


Further improvement of RTK-GNSS

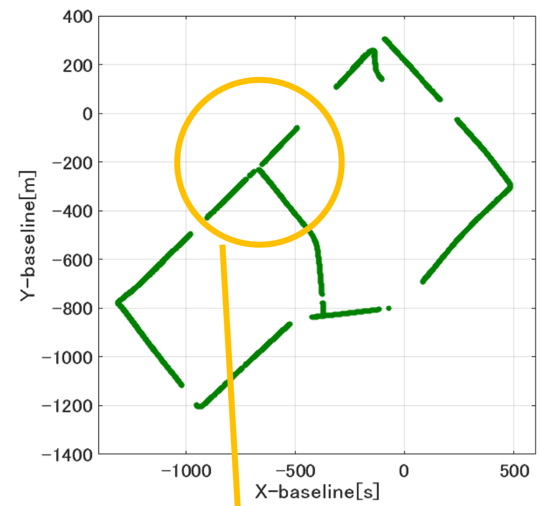
- Non-consideration



- More than 10 satellites



- Produced new float solutions



	Fix rate	error>50cm	Maximum
RTK-GNSS (GQBE)	74.0 [%]	91 epochs	5.36 m
More than 10 SVs	52.2 [%]	0 epochs	0.18 m
Produced new float solutions	**82.4 [%]**	**16 epochs**	**0.97 m**

Conclusion

- We confirmed that receiver bias was included in a certain satellite system in DGNSS(single difference method).
- We showed the correlation of available number of the satellites and Fix rate in single-frequency RTK-GNSS.
- In normal urban areas, we achieved <u>100% within 2.0m using code and Doppler.</u> <u>100 % within 1.0 m by adding RTK solutions.</u>
- In addition, fix rate increased by using the improved float solution. Also wrong fixes including large error decreased a lot.

Future issues:

- Dense reference stations are required for low-cost RTK.
- We need to check the performance under poor constellation. But future GNSS is promising because of development of multi-GNSS.