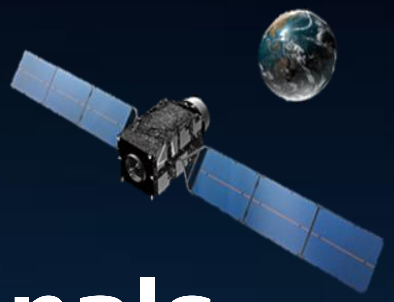


A New Approach of Detecting NLOS Signals Based on Modified Residual Error Check

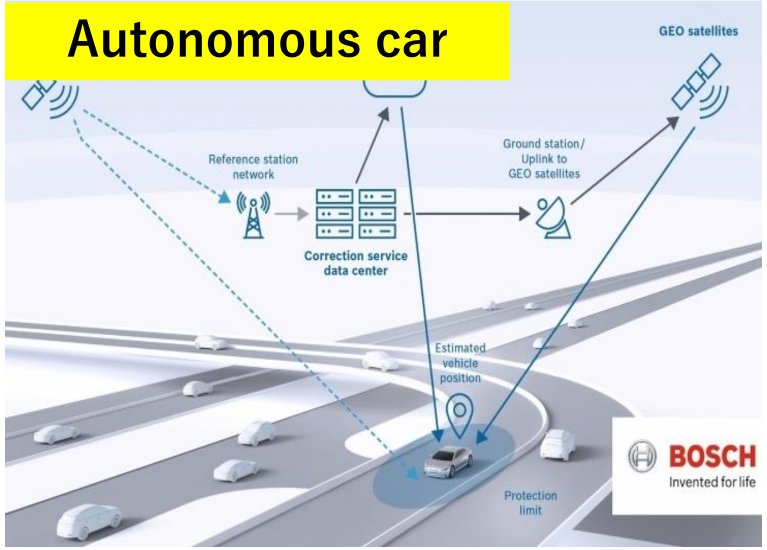
Tomohiro Ozeki, Nobuaki Kubo

Tokyo University of Marine science and Technology (TUMSAT)

Background(GNSS Usage)

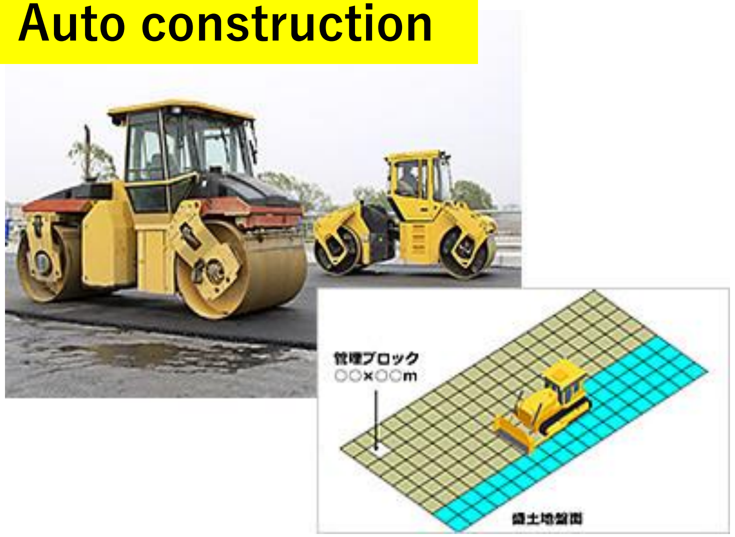
GNSS LAB
Tumsat

Autonomous car



Bosch

Auto construction

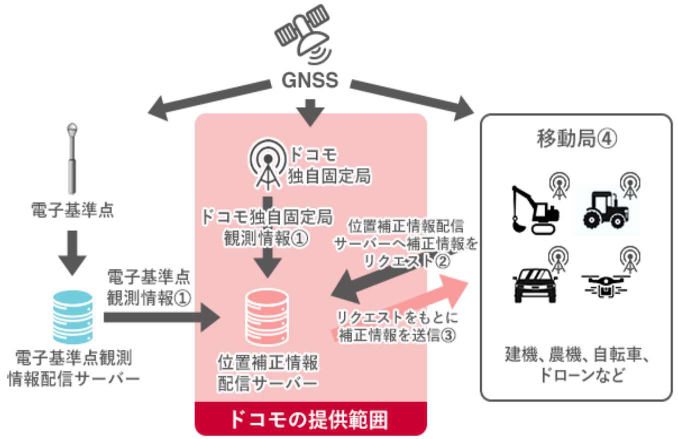


Panasonic

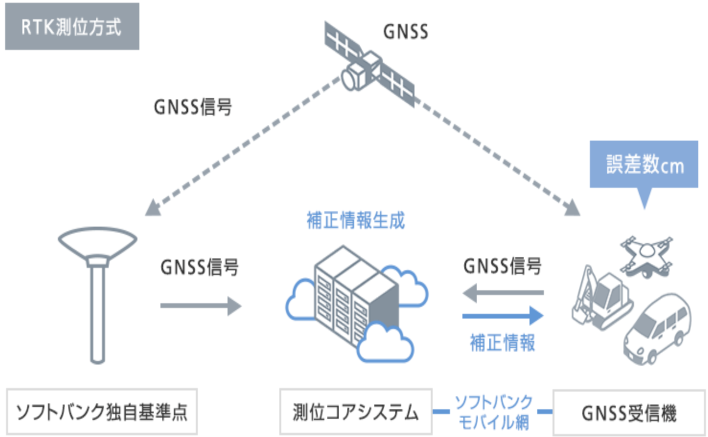
UAV

Quantum-Systems

Correction data Services(JAPAN)

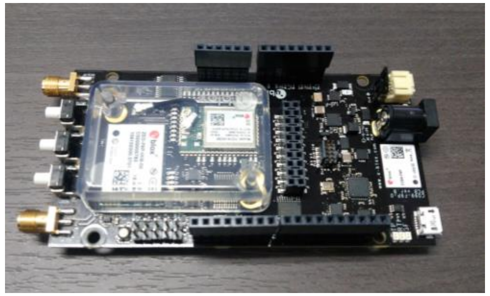


docomo



Softbank

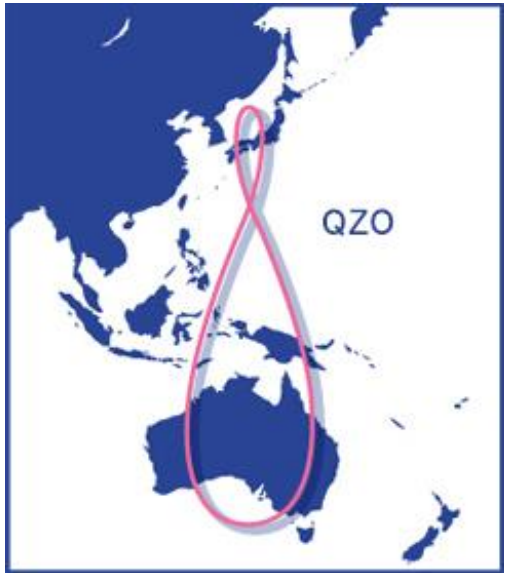
Low cost receiver

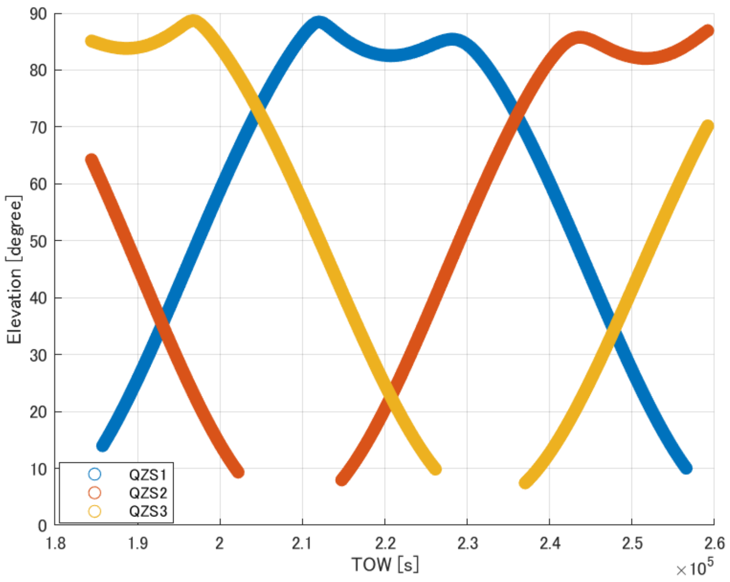


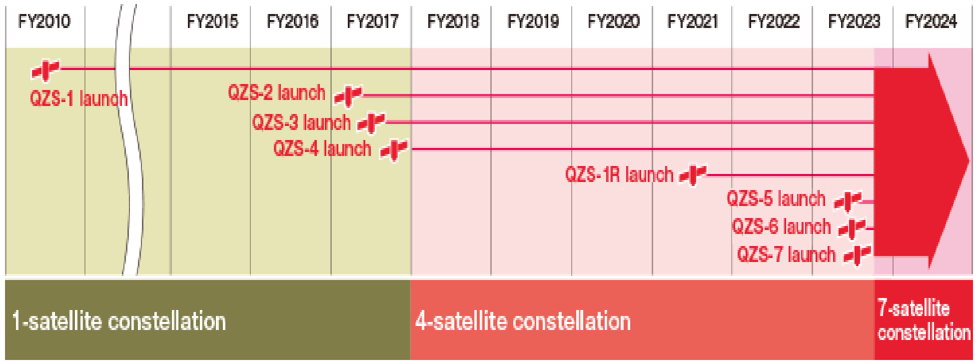
Background(QZSS)

GNSS LAB Tumsat

- QZSS is a Japanese satellite positioning system composed mainly of satellites in quasi-zenith orbits (QZO).
- We can always receive QZSS with an elevation angle of 70 degrees or more!!
- QZSS can be used in an integrated way with GPS, ensuring a sufficient number of satellites for stable, high-precision positioning.

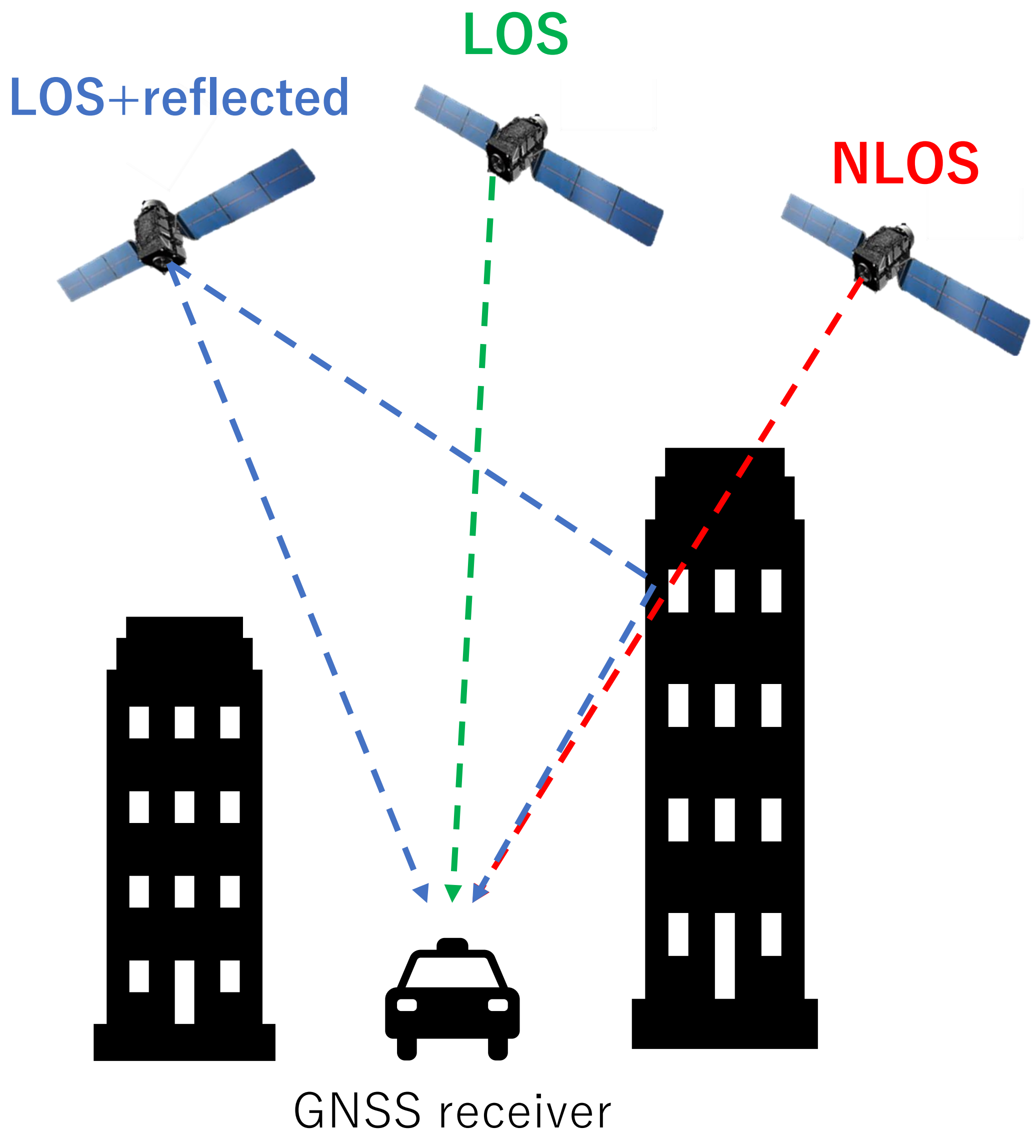






Why do significant GNSS positioning errors occur in dense areas?

GNSS LAB Tumsat



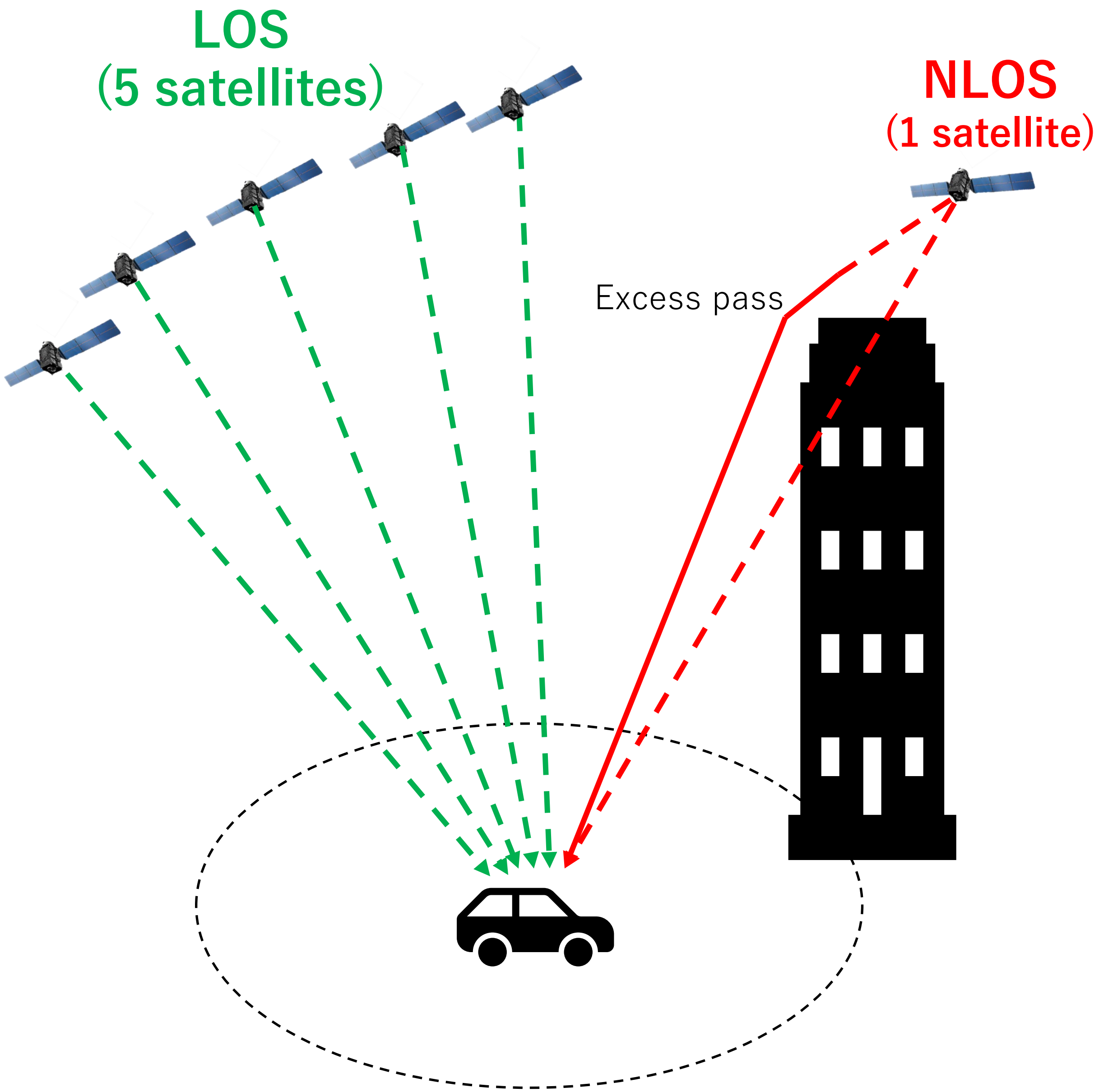
GNSS receiver receives

LOS (Line of sight)signal
&
LOS +reflected signal
&
NLOS(Non-Line-of-sight) signal

As for LOS + reflected signal, **correlator based mitigation** is popular and somehow effective.

As for NLOS signal, **residual based mitigation in least-square** method is somehow effective but not perfect.

Image of positioning error



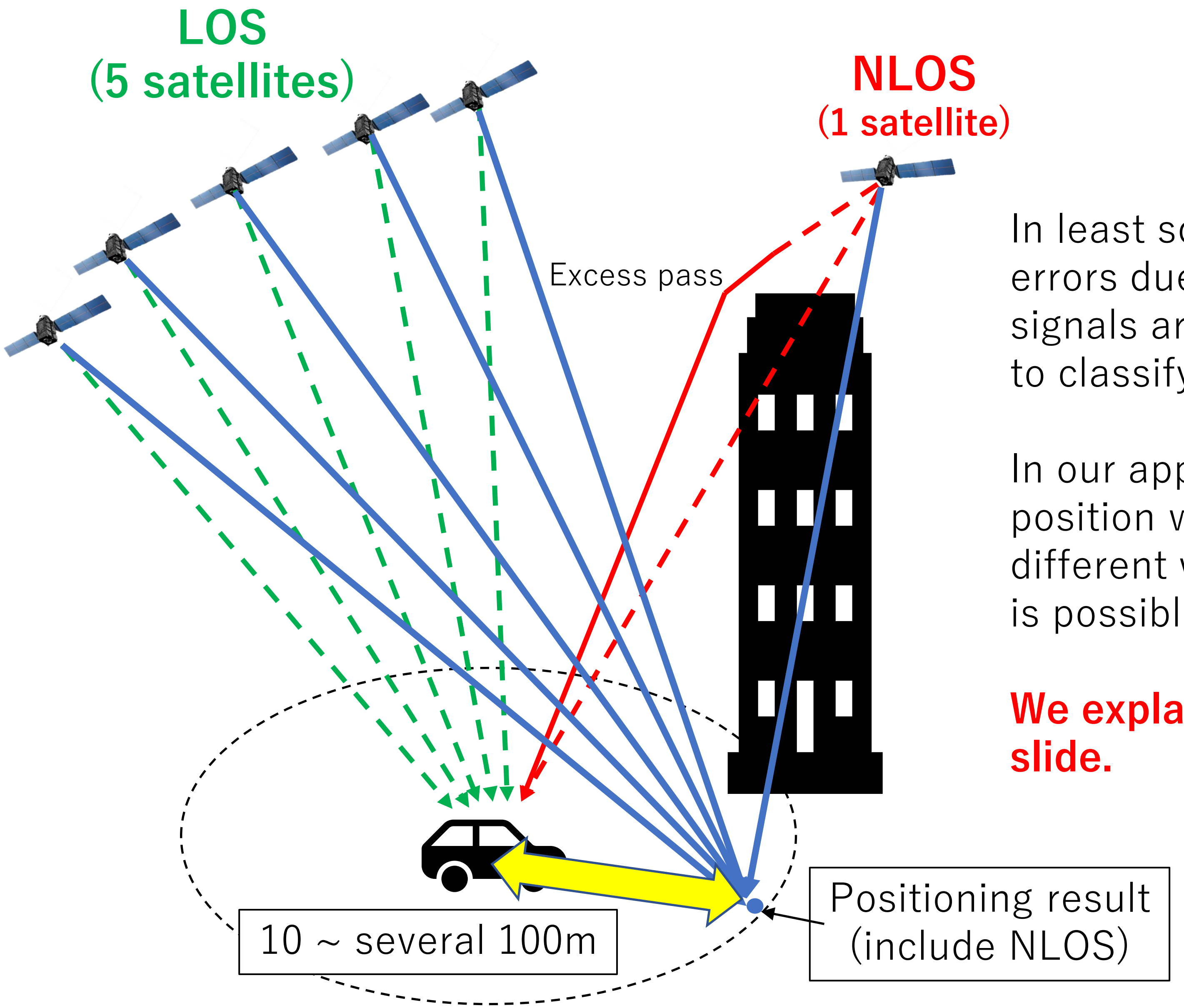
NLOS signal has excess path(multipath error).

In dense urban area,
excess pass easily reached several tens of meters or more.

Thus, if **NLOS** satellite is **not** excluded or de-weighted from positioning, positioning error easily reached several tens of meters or more.

Our approach in the use of residuals

GNSS LAB Tumsat



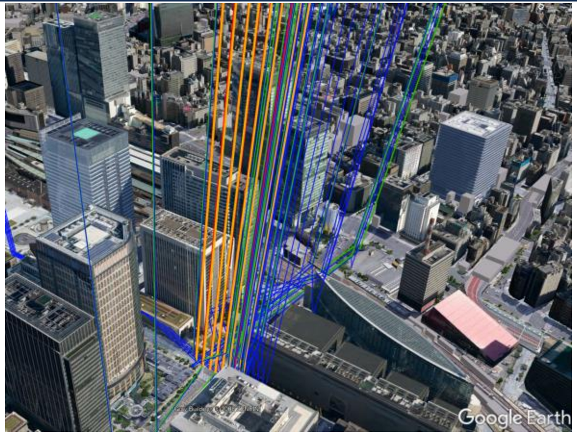
In least square method, when we have large multipath errors due to several NLOS signals, residuals of LOS signals are also large **in blue**. Therefore, it is not easy to classify LOS or NLOS signals.

In our approach, **as a prerequisite**, we know the position with an accuracy of about 10 m (3-sigma) in a different way. Once we know the 10 m level position, it is possible to detect large errors due to NLOS signals.

We explain our approach in detail from the next slide.

Residuals of NLOS as well as LOS signals will be large in blue.

Method of Classification of LOS signal



There are some elegant methods to cope with NLOS signals
by some researchers (Paul Gloves, Li-Ta Hsu, Taro Suzuki etc.).

- Use of 3D building models
- Fish-eye camera
- RHCP or LHCP in antenna
- C/N0
- Lidar, Camera and other sensors
- **Residual error based**
  We propose it with a prerequisite.
  In normal urban area, We can obtain several meters level position using only GNSS.
  In dense urban area, We can obtain 10 meters level position (99% or more) using GNSS/IMU(+speed).

Residual error check ①

GNSS LAB Tumsat

P : pseudorange [m]
ρ : geometric range [m]
c : speed of light [m/s]
dt_{rcv} : receiver clock error [s]
dT_{sat} : satellite clock error [s]
ion : ionospheric error [m]
$tropo$: tropospheric error [m]
mp : multipath error [m]
ε : noise error [m]

Pseudorange from sv1 can be written as follows:

$$P_{rov}^{sv1} = \rho_{rov}^{sv1} + c(dt_{sv1} - dT_{rov}) + ion_{rov}^{sv1} + tropo_{rov}^{sv1} + mp_{rov}^{sv1} + noise$$

Using DGNSS's correction data,
Eliminate satellite clock error, ionospheric error and tropospheric error.

$$P_{rov}^{sv1} \boxed{- cdt_{sv1} - ion_{rov}^{sv1} - tropo_{rov}^{sv1}} = \rho_{rov}^{sv1} + c(-dT_{rov}) + mp_{rov}^{sv1} + noise$$

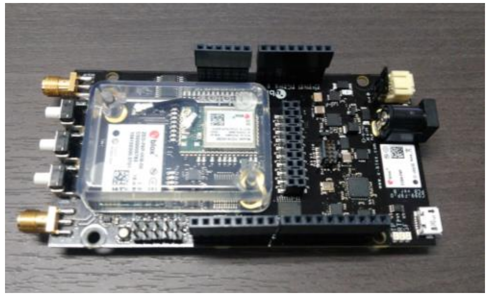
How about geometric range & receiver clock error ?

$$P_{rov}^{sv1} - cdt_{sv1} - ion_{rov}^{sv1} - tropo_{rov}^{sv1} = \boxed{\rho_{rov}^{sv1} + c(-dT_{rov})} + mp_{rov}^{sv1} + noise$$

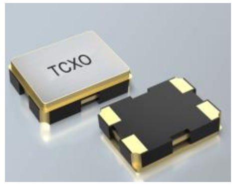
Geometric range can be estimated with a prerequisite as mentioned. (GNSS/IMU (+ maybe speed)). How about receiver clock error ?

How to estimate receiver clock error

GNSS receiver



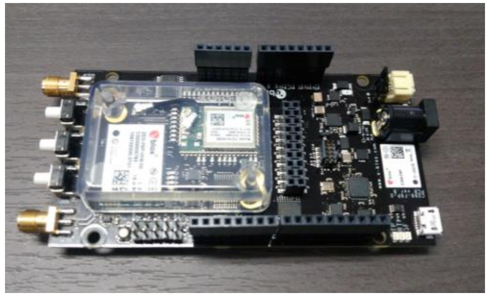
TCXO



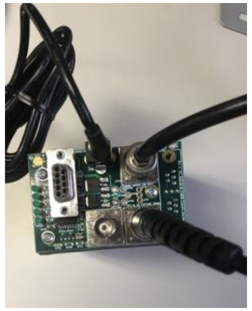
(*)

GNSS receiver uses TCXO.
It's very cheap, but unstable and difficult to predict clock error.

GNSS receiver



Rubidium atomic clock

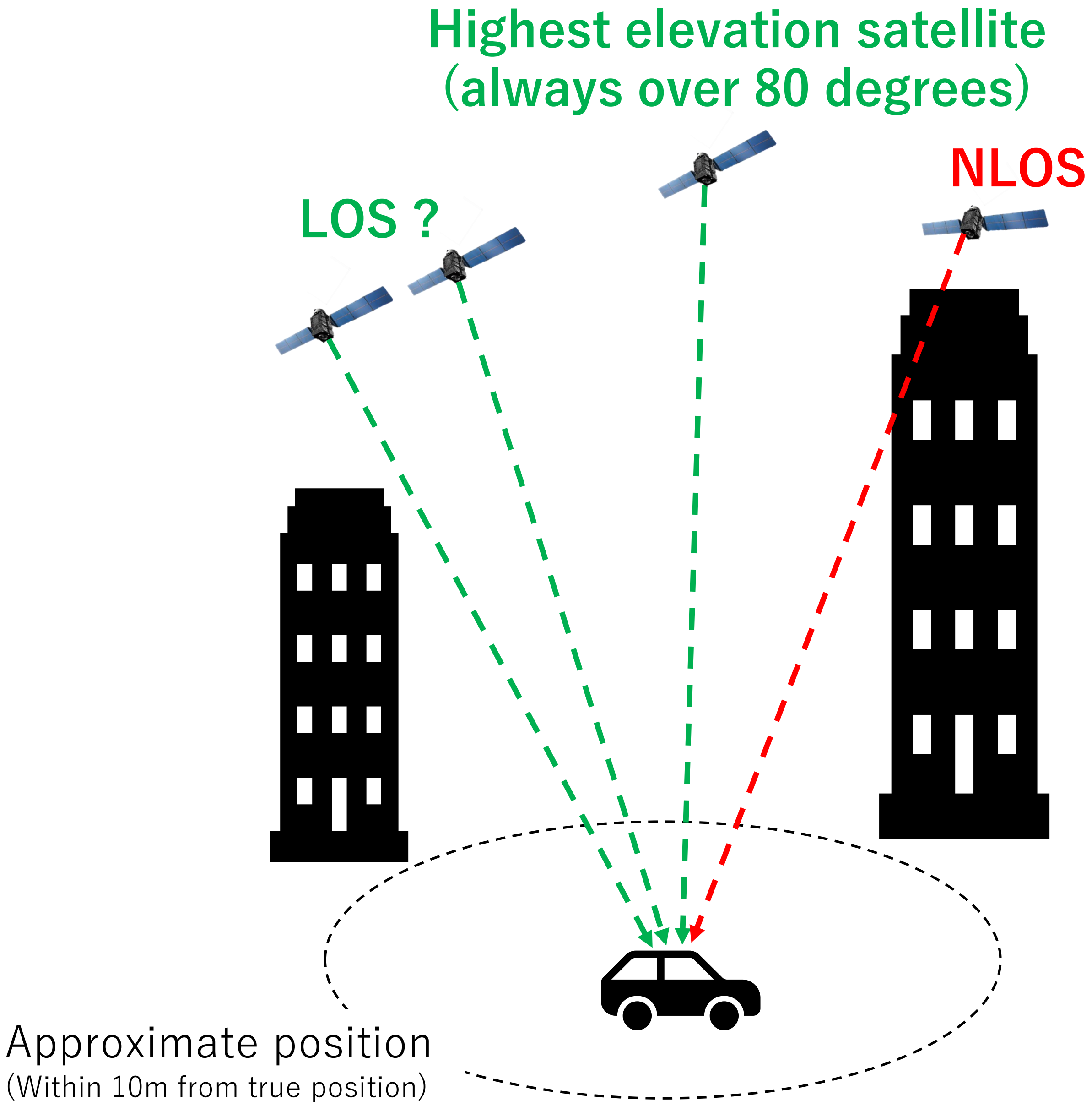


Rubidium atomic clock is very stable and it's easy to predict clock error, but expensive for big commercial use.

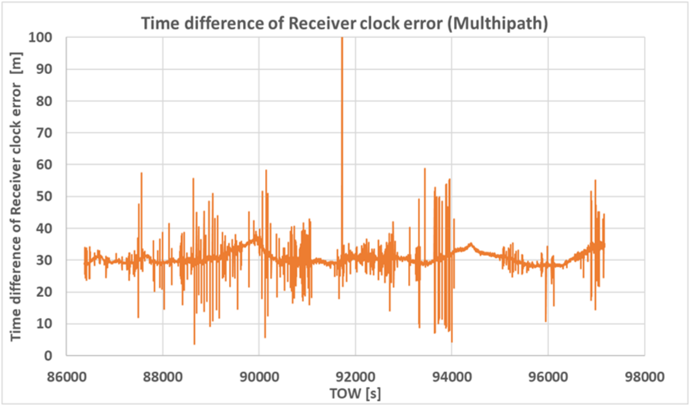
We propose new method for estimating receiver clock error.

(*)https://www.petermann-technik.com/products/quartz-crystal-oscillators/details/tcxo-16x12mm-lp.html

How to estimate receiver clock error



In general, Estimation error of receiver clock error has large errors when receiving NLOS signals is large.



Pseudorange of satellite with the highest elevation has less multipath error. (over 80 degrees)

Using approximate position and ephemeris & satellite with the highest elevation,
Receiver clock error can be estimated more accurately.

Residual error check ②

GNSS LAB Tumsat

P : pseudorange [m]
ρ : geometric range [m]
c : speed of light [m/s]
dt_{rcv} : receiver clock error [s]
dT_{sat} : satellite clock error [s]
ion : ionospheric error [m]
$tropo$: tropospheric error [m]
mp : multipath error [m]
ε : noise error [m]

Pseudorange from sv1 can be written as follows:

$$P_{rov}^{sv1} = \rho_{rov}^{sv1} + c(dt_{sv1} - dT_{rov}) + ion_{rov}^{sv1} + tropo_{rov}^{sv1} + mp_{rov}^{sv1} + noise$$

Using DGNSS's correction data,
Eliminate satellite clock error, ionospheric error and tropospheric error

$$P_{rov}^{sv1} - cdt_{sv1} - ion_{rov}^{sv1} - tropo_{rov}^{sv1} = \rho_{rov}^{sv1} + c(-dT_{rov}) + mp_{rov}^{sv1} + noise$$

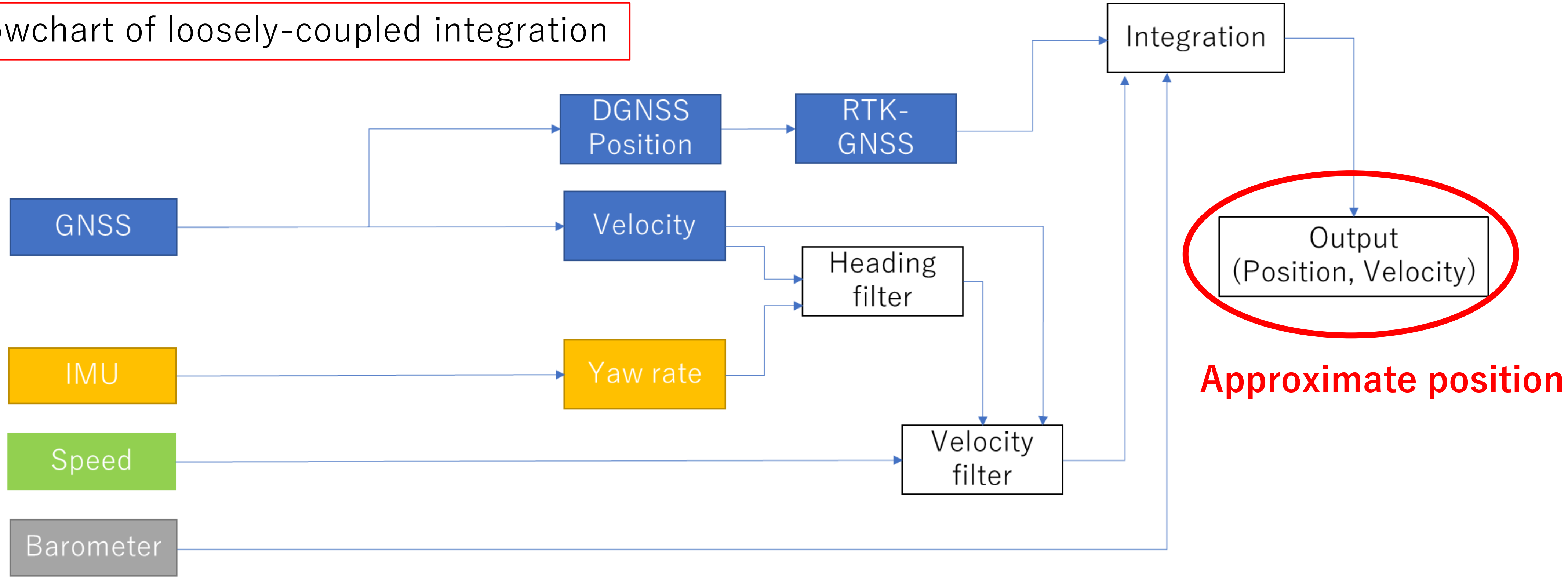
Geometric range & receiver clock error can be estimated by approximate position and ephemeris & satellite with the highest elevation

$$P_{rov}^{sv1} - cdt_{sv1} - ion_{rov}^{sv1} - tropo_{rov}^{sv1} - \rho_{rov}^{sv1} - c(-dT_{rov}) = mp_{rov}^{sv1} + noise$$

We can use more accurate residual for satellite selection !

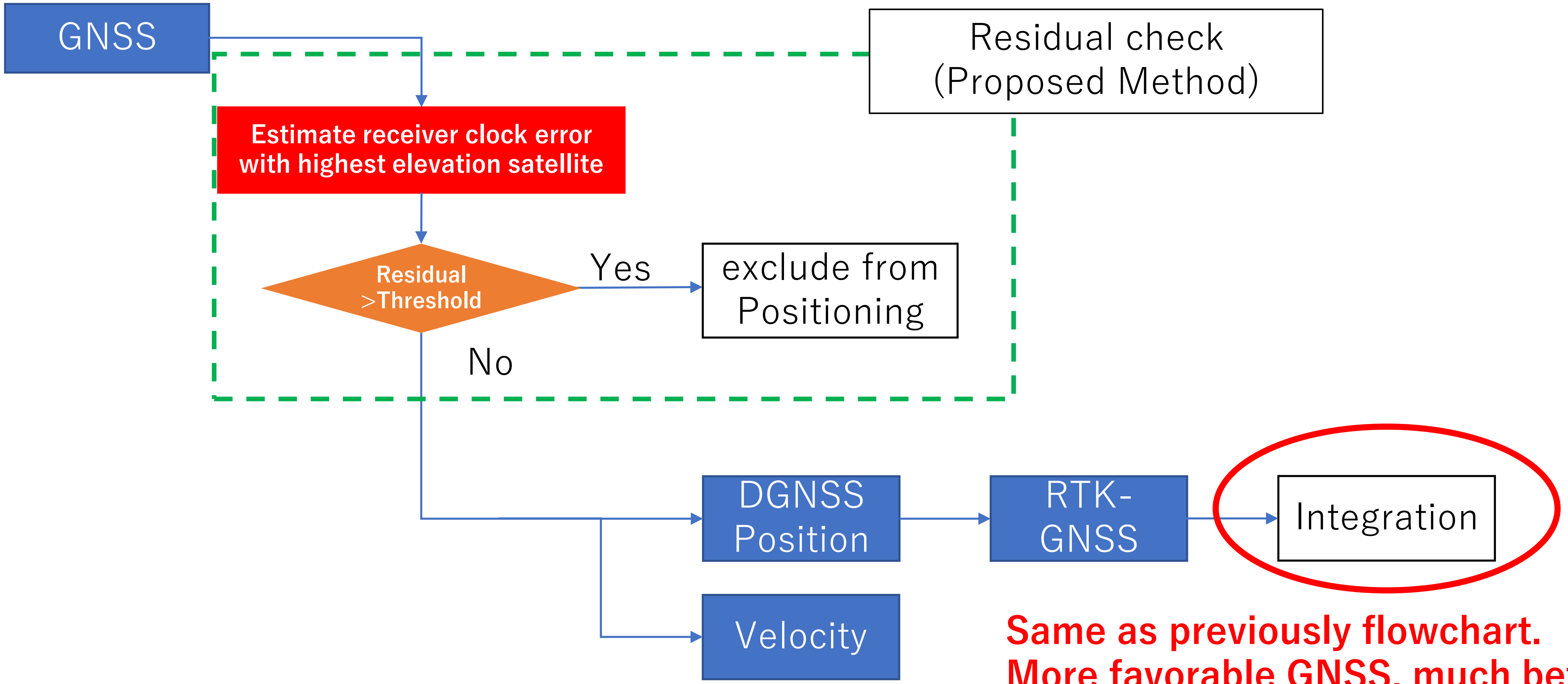
Approximate position generation

Flowchart of loosely-coupled integration



We have developed loosely-coupled based GNSS/IMU/Speed/Barometer integration method.
It is possible to achieve the accuracy of 10 m (99.7%) in position.
As an approximate position, this output can be used later.
Also, we have developed tightly-coupled based integration. In this case, clock bias will be estimated simultaneously and we recently confirmed it is also available for this purpose.

Based on approximate position,



Same as previously flowchart.
More favorable GNSS, much better integration

Aim : Less integrated error and
increasing the number of reliable Fixed solutions

Altitude provided by Barometer

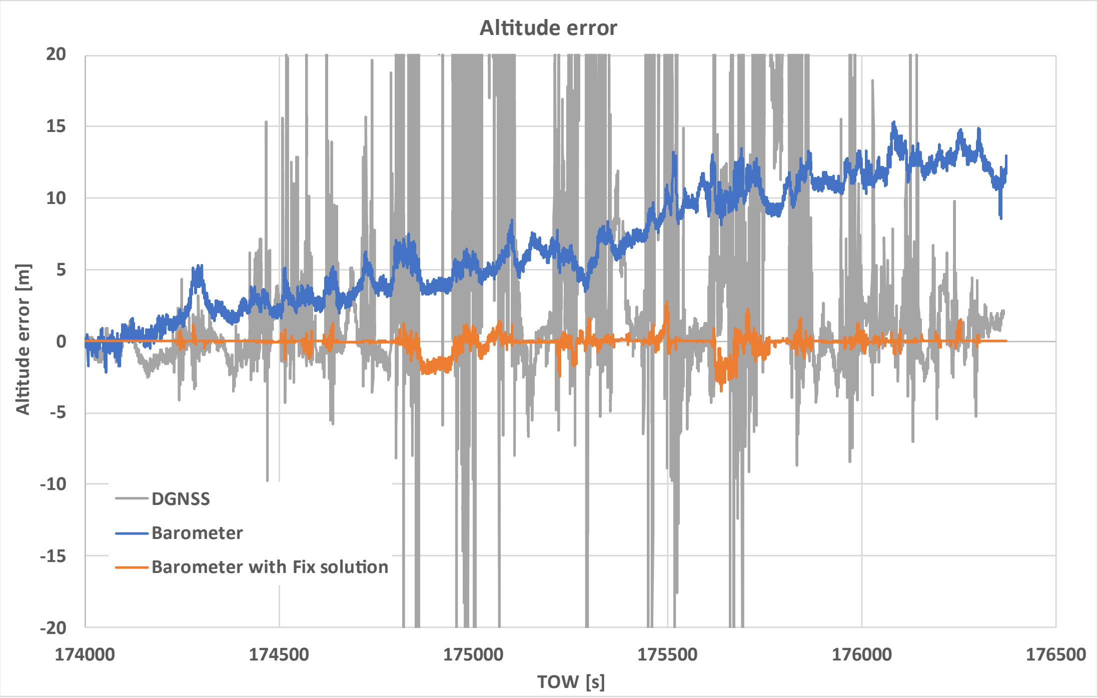
GNSS LAB Tumsat

- Transform to Altitude by Barometer

  ✓ Reference pressure provided by Japan meteorological agency by each 10 minuets.
  ✓ Reference absolute altitude is RTK-FIX solution.

$$ALT(0) - ALT(obs) = -8.3 \times (P(0) - P(obs))$$

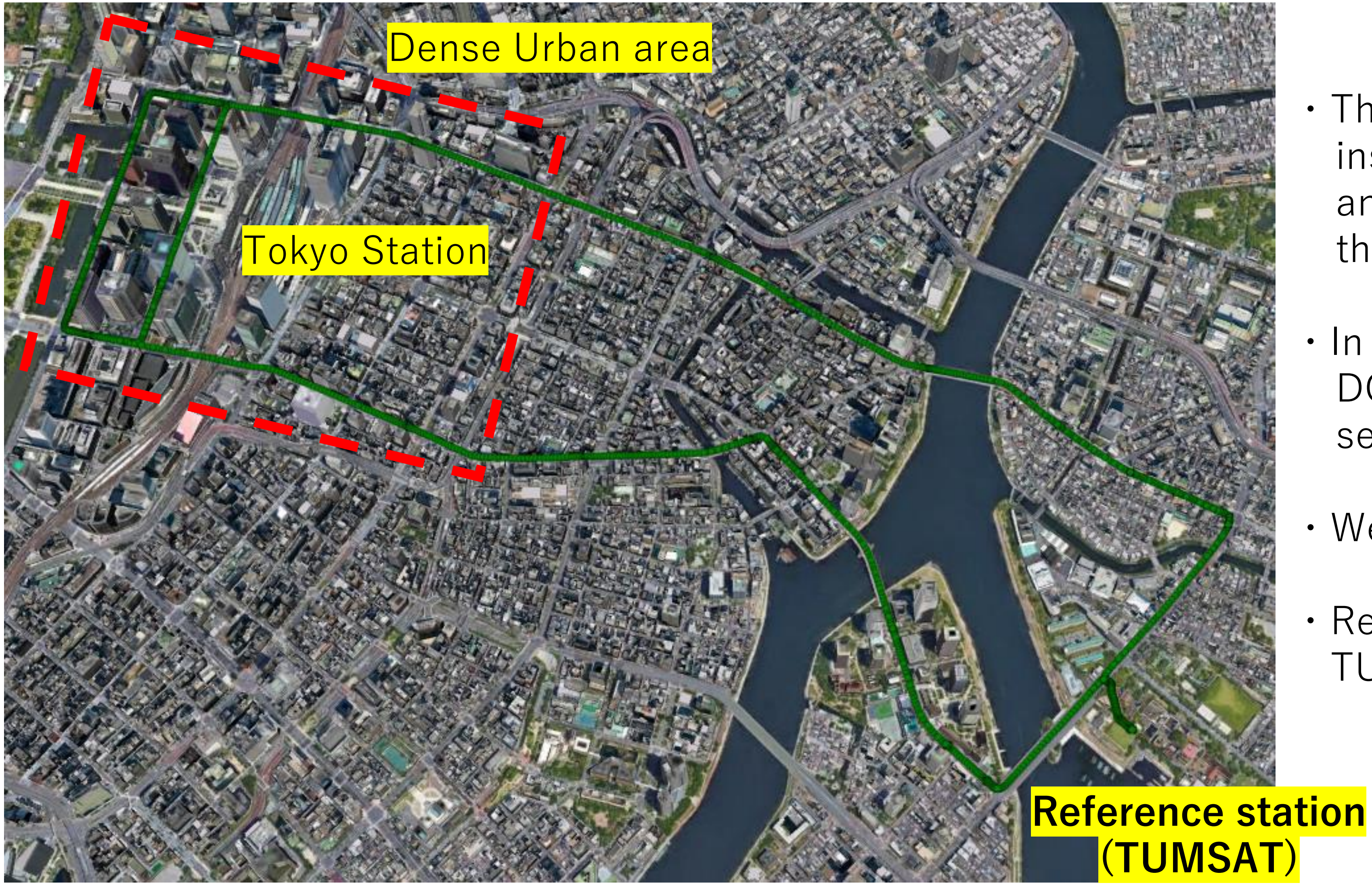
$ALT(0)$: Absolute altitude provided by RTK-Fix solution
$P(0)$: Atmosheric barometric pressure observation provided by Japan meteorological agency by each 10 minuets



	Average [m]	STD [m]
Barometer	6.729684	4.158354
Barometer with Fix solutions	-0.09718	0.511082
DGNSS	14.66662	43.42141

Experiment(route)

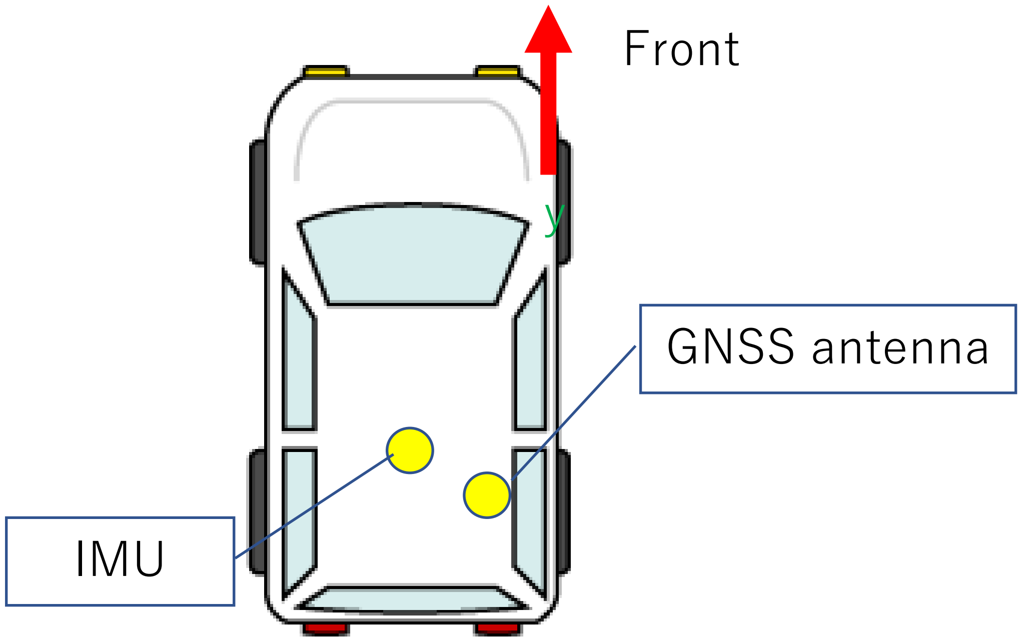
GNSS LAB Tumsat

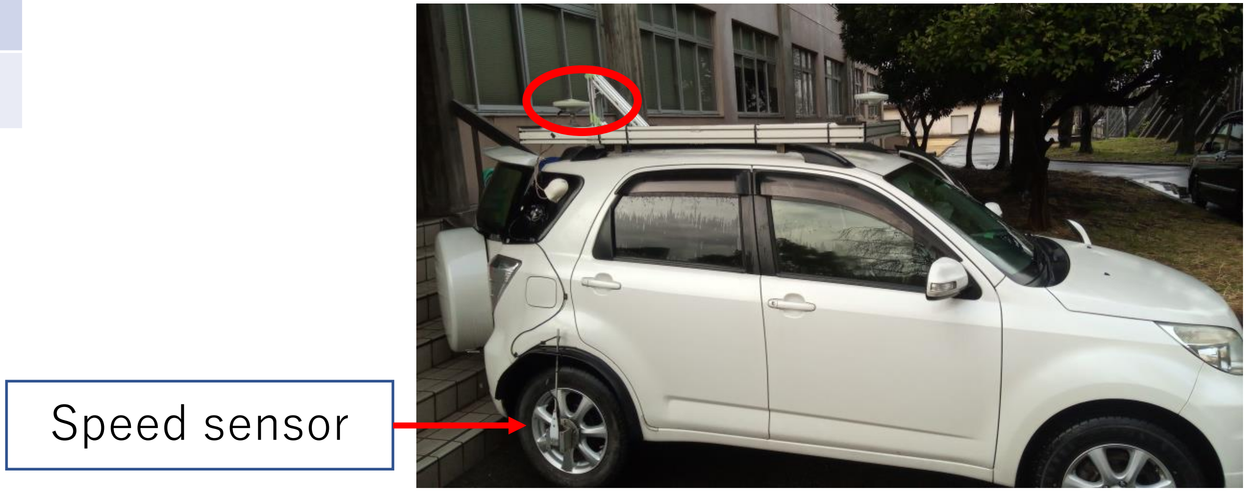


- The data was obtained using car installed with GNSS receiver, IMU and Speed sensor and We drive along the route.
- In Dense Urban area (Red frame), DGNSS positioning error easily reached several tens of meters or more.
- We've run the three times.
- Reference station is installed at TUMSAT(Our laboratory)

Experiment(Equipment)

Equipment	Model Name
GNSS receiver	u-blox F9P (base/rover)
GNSS antenna (rover)	Aero Antenna AT1675
GNSS antenna (Base)	Trimble Zephyr 2 Geodetic
IMU(with Barometer)	STMicro
Speed sensor	POSLV-520
Reference position	POSLV-520





Experiment(Common parameter)

GNSS LAB Tumsat

- GNSS setting

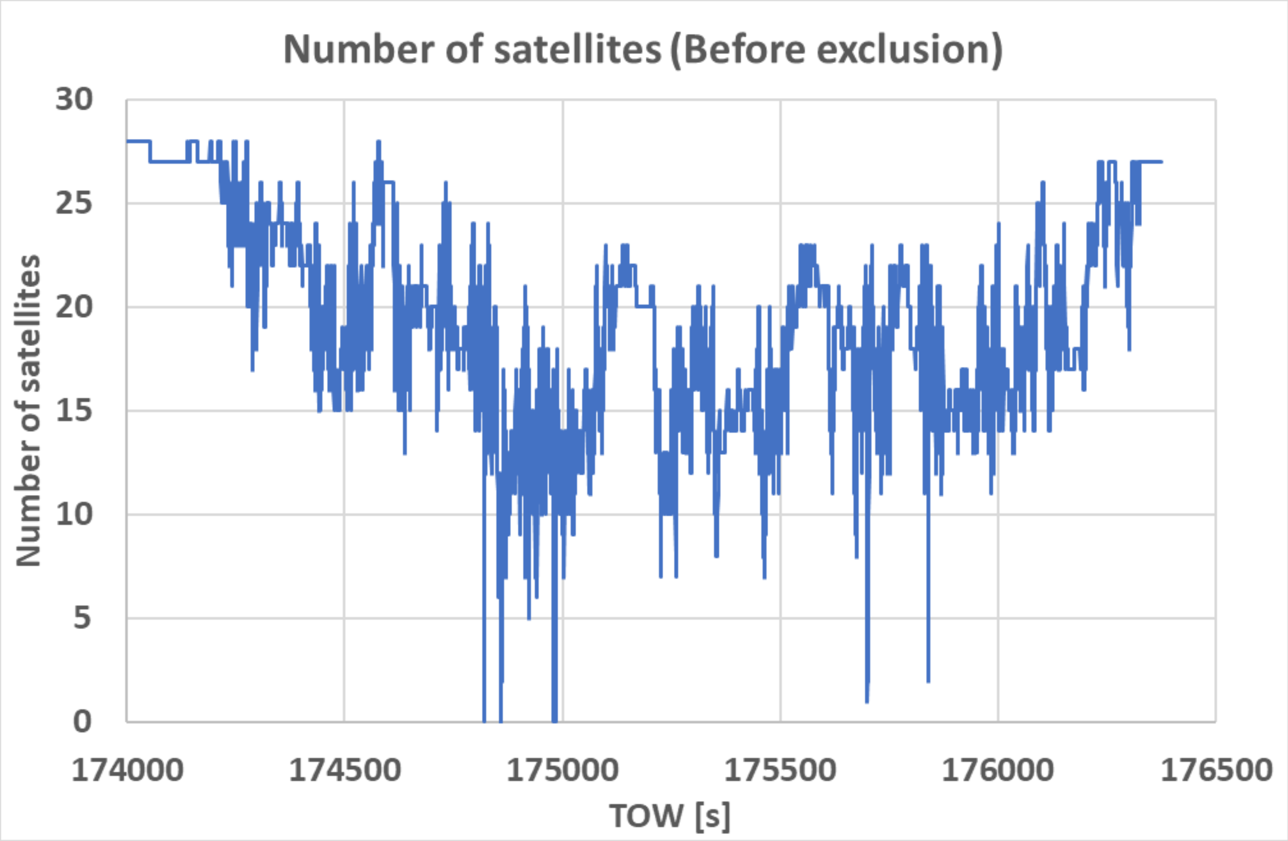
Item	Parameter
Mask angle	15 degrees
Maximum DOP	10.0(HDOP)/20(VDOP)
Minimum SNR	30 dB-Hz
Code phase measurements	Tracked
Carrier phase measurements	Tracked
LLI(only RTK-GNSS)	Tracked and half-cycle resolved
Threshold for Residual	15m
Satellites	GPS/QZSS/GALILEO/BDS/GLONASS

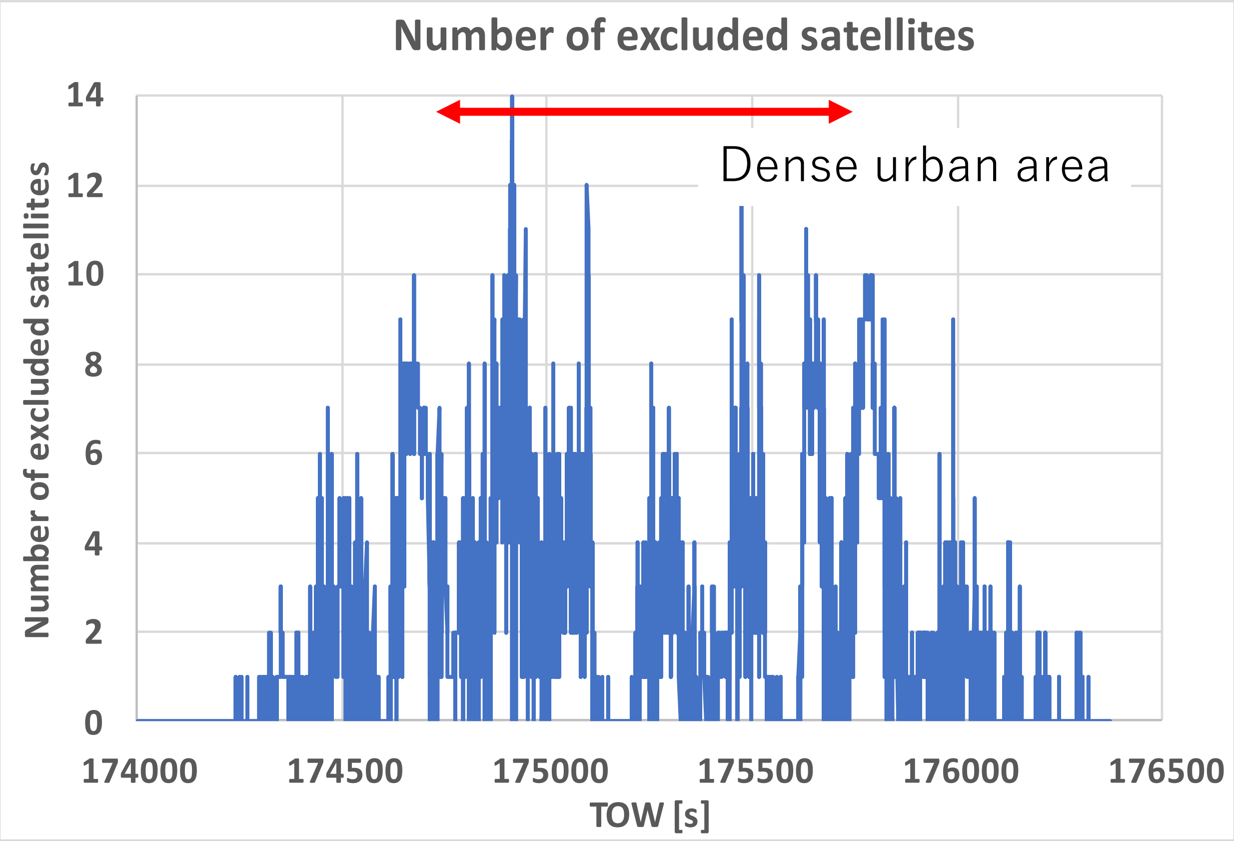
- Frequency

Sensor	Frequency
GNSS	5 Hz
IMU	50 Hz
Speed sensor	50 Hz

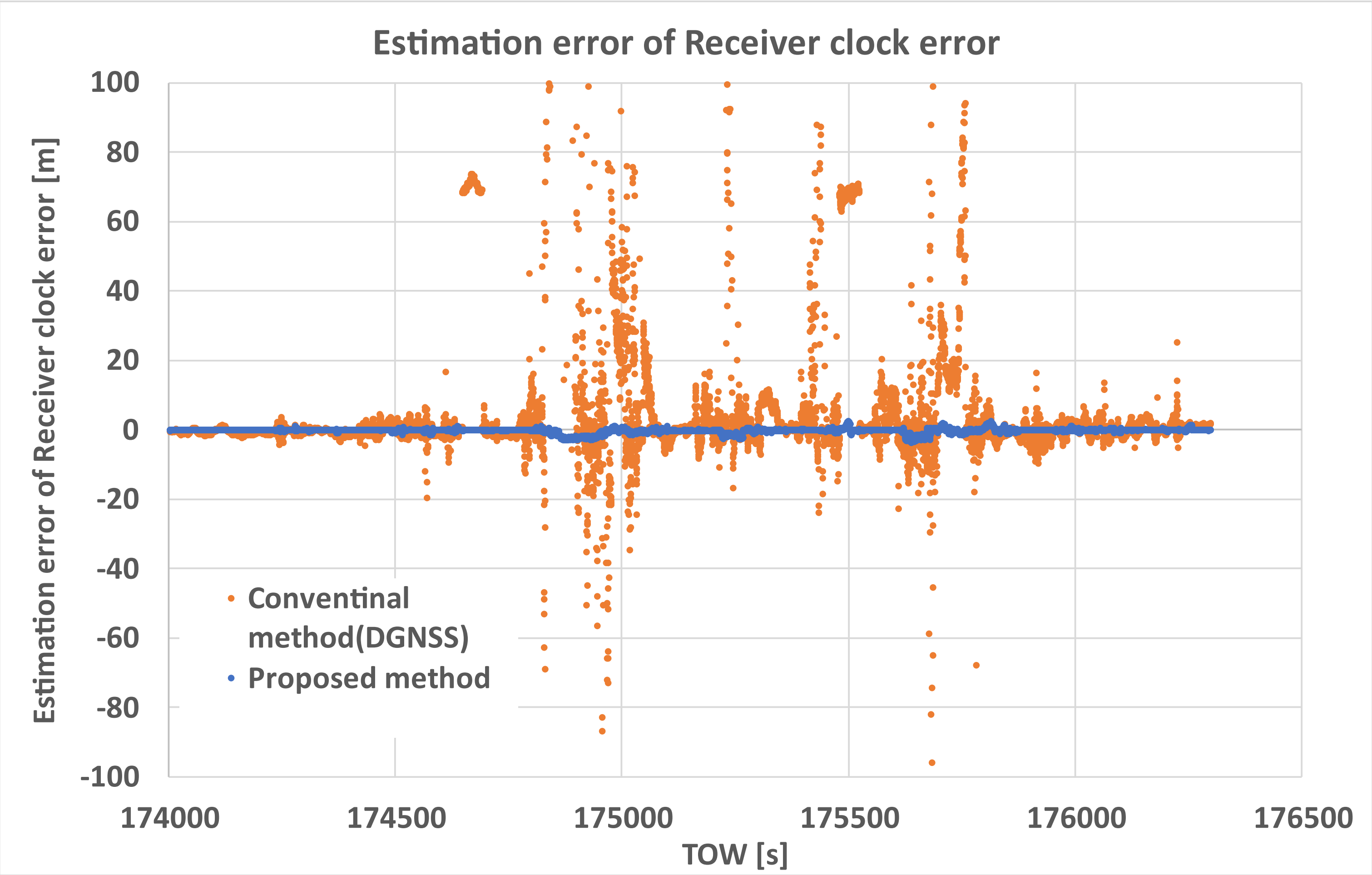
Result(Lap1_Number of satellite & Number of excluded satellite)

GNSS LAB Tumsat

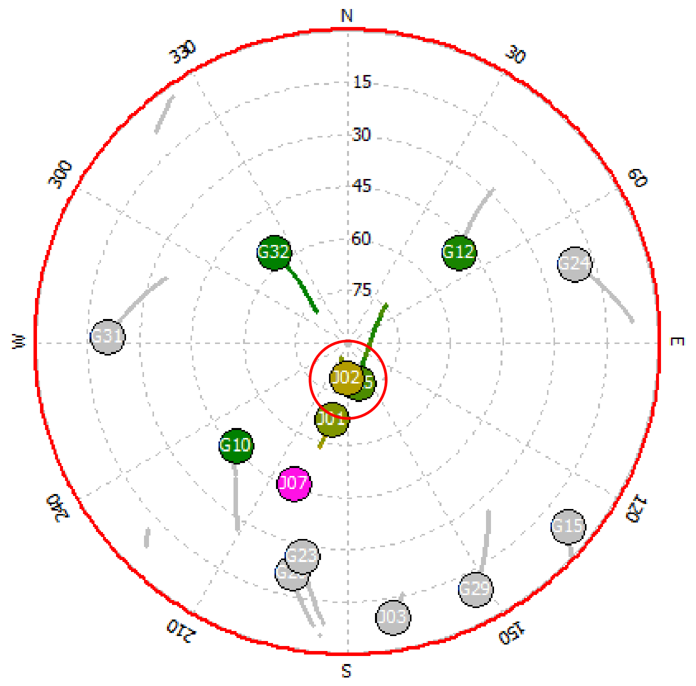




Result(Lap1_Estimation accuracy of Receiver clock error)



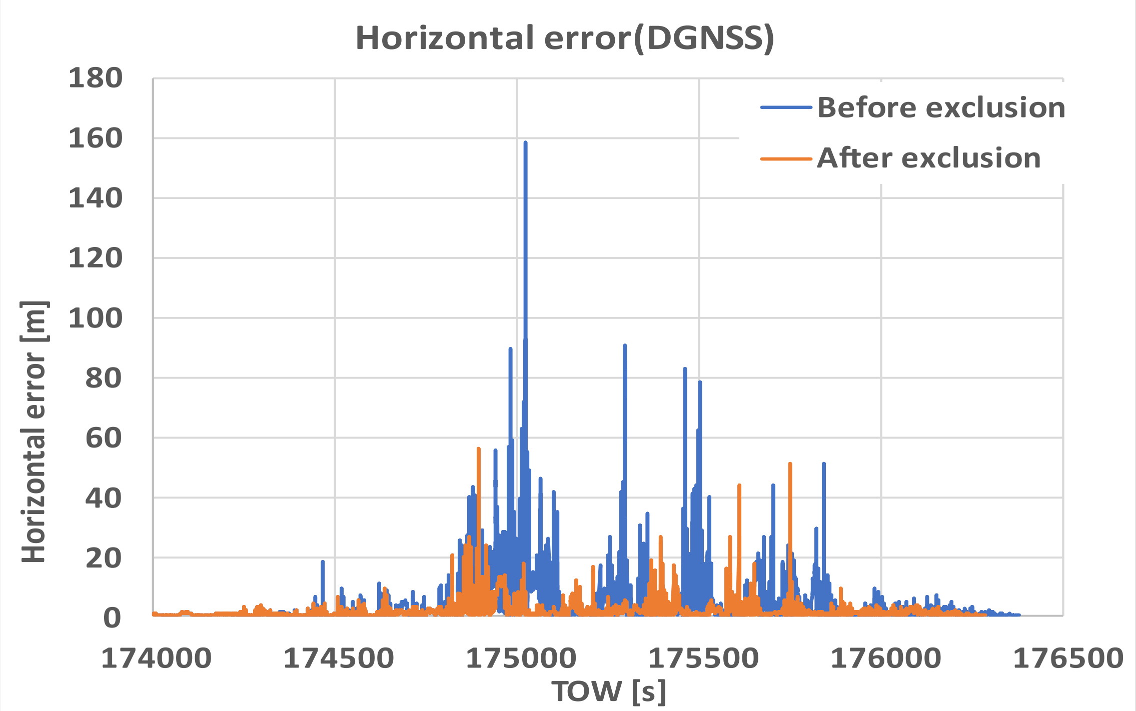
Skyplot

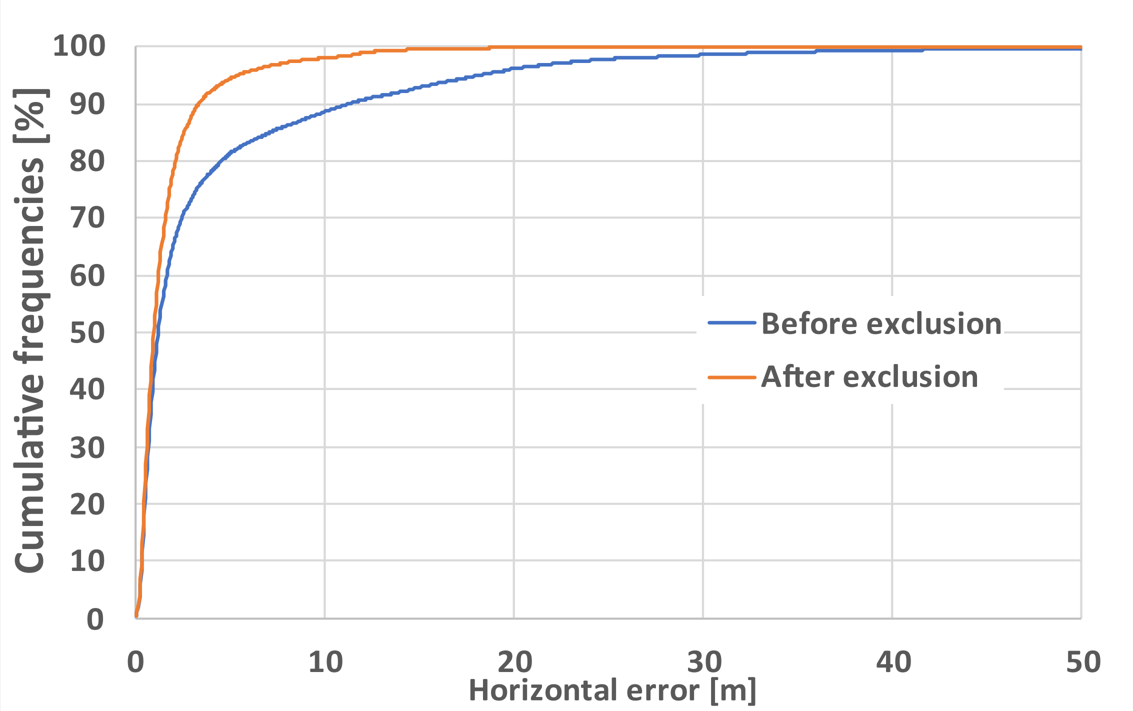


Use J02 for estimation of Receiver clock error

Result(Lap1_Position error of DGNSS)

GNSS LAB Tumsat





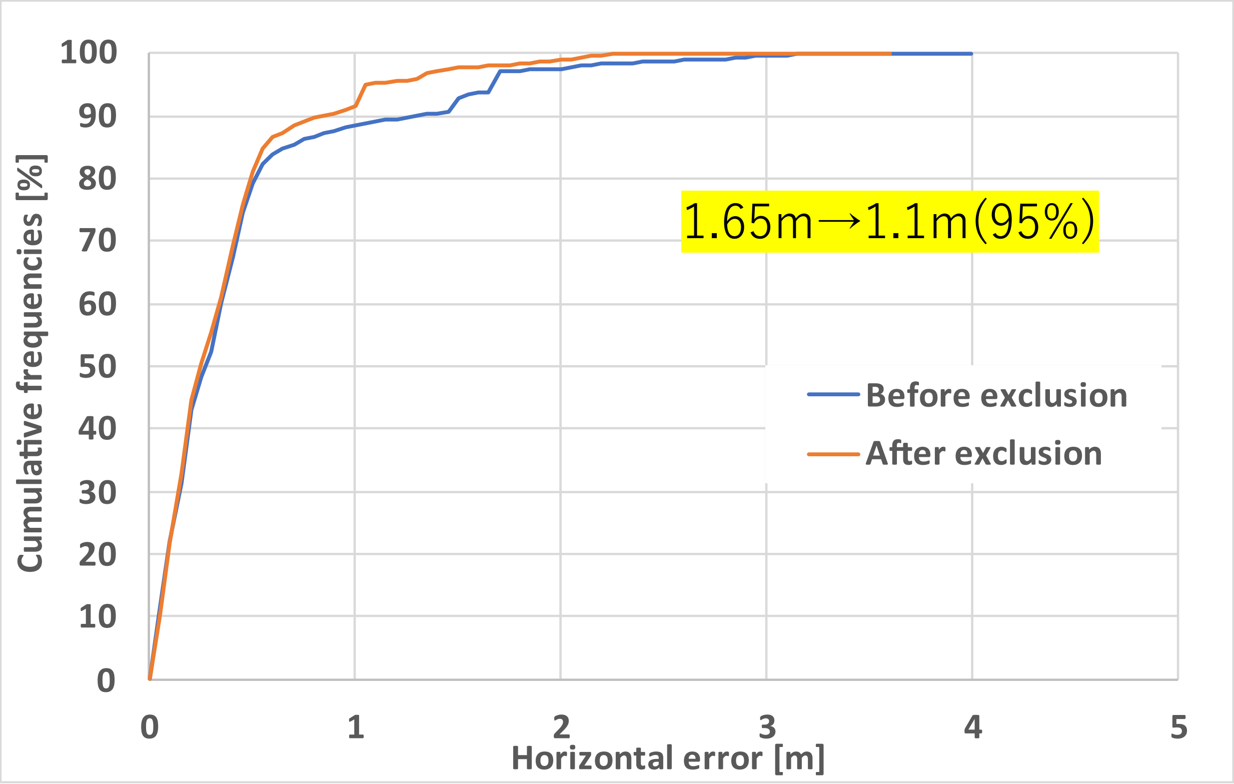
	Before exclusion	After Exclusion
Position error	3.86m (average) 7.31m (STD) 158.21 (max)	1.59m (average) 2.37m (STD) 56.32 (max)
Number of positioning	11814	11804

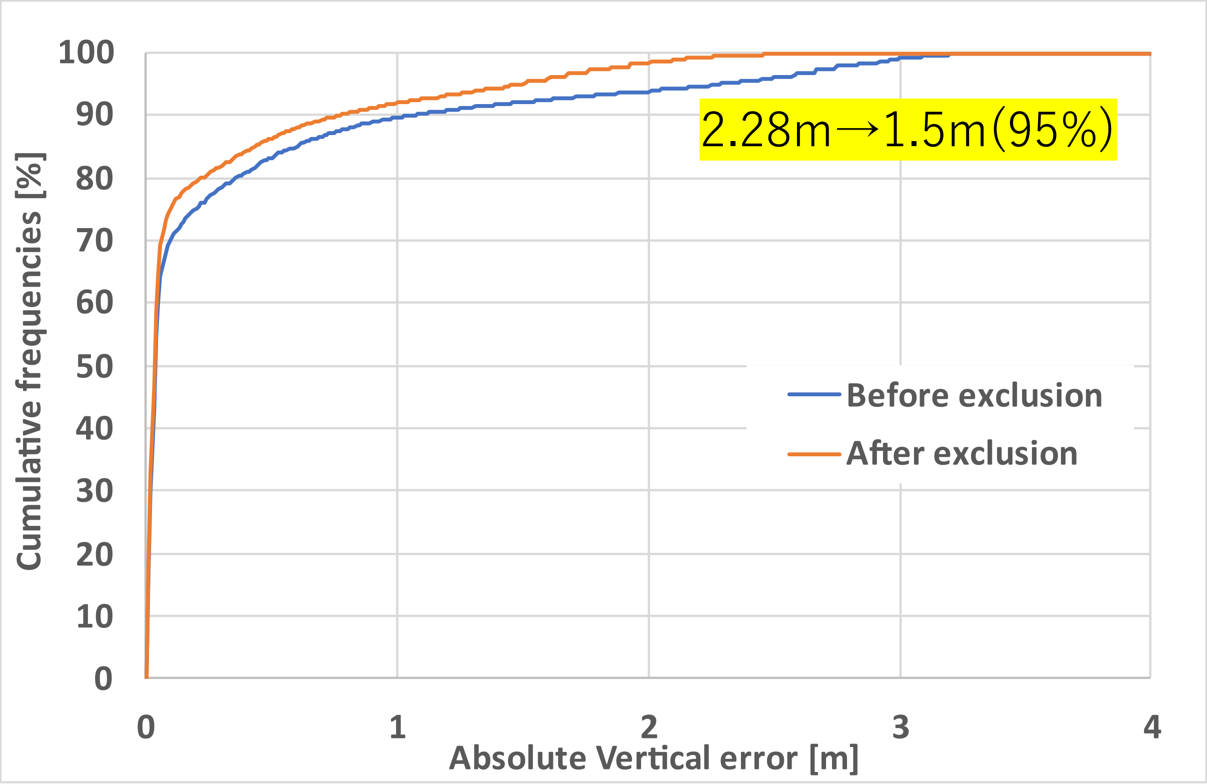
Result(Lap1_RTK-GNSS & Integrated Positioning)

GNSS LAB Tumsat

RTK-GNSS	Number of Fix(Fix rate)	Number of miss Fix(*)
Before exclusion	8177(68.9%)	33
After exclusion	8768(74.3%)	5

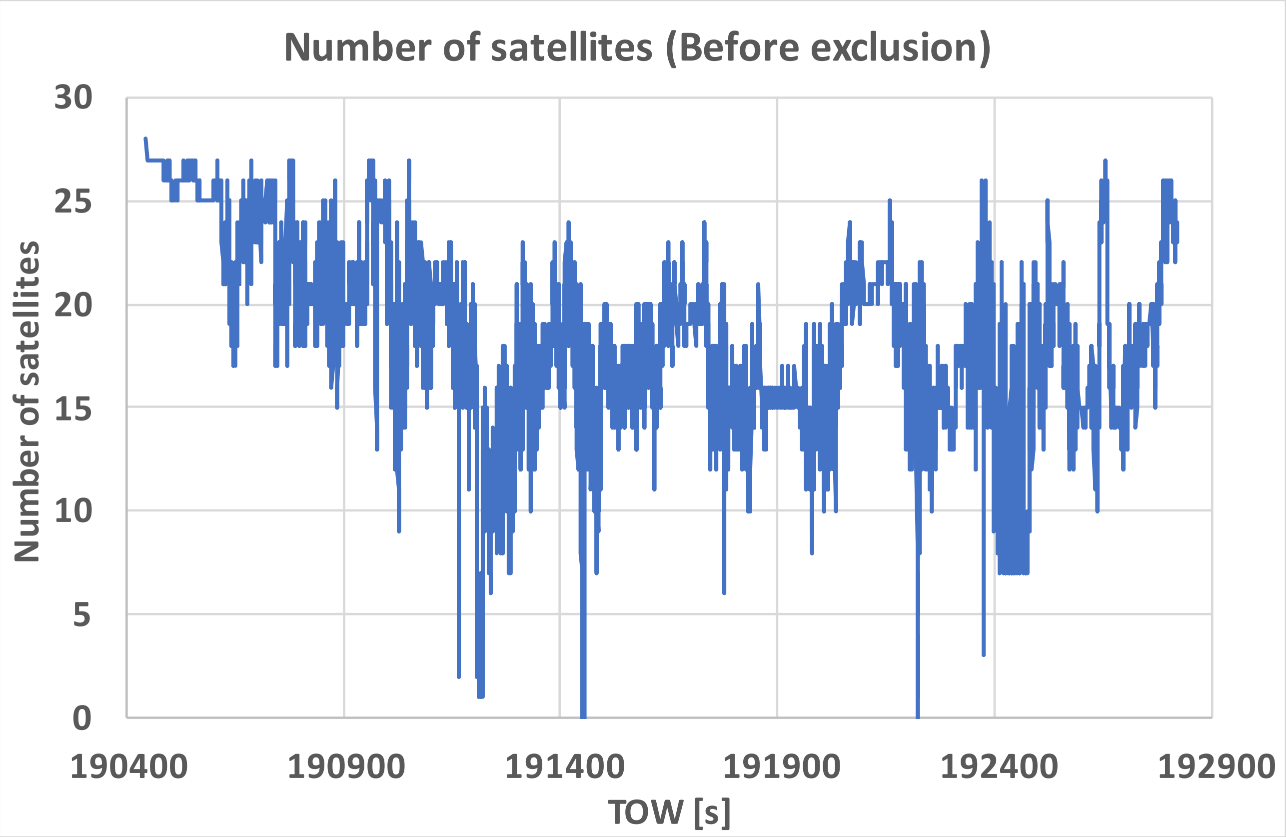
Miss Fix ：Horizontal error of 0.5 m or more or
Altitude error of 1.0 m or more

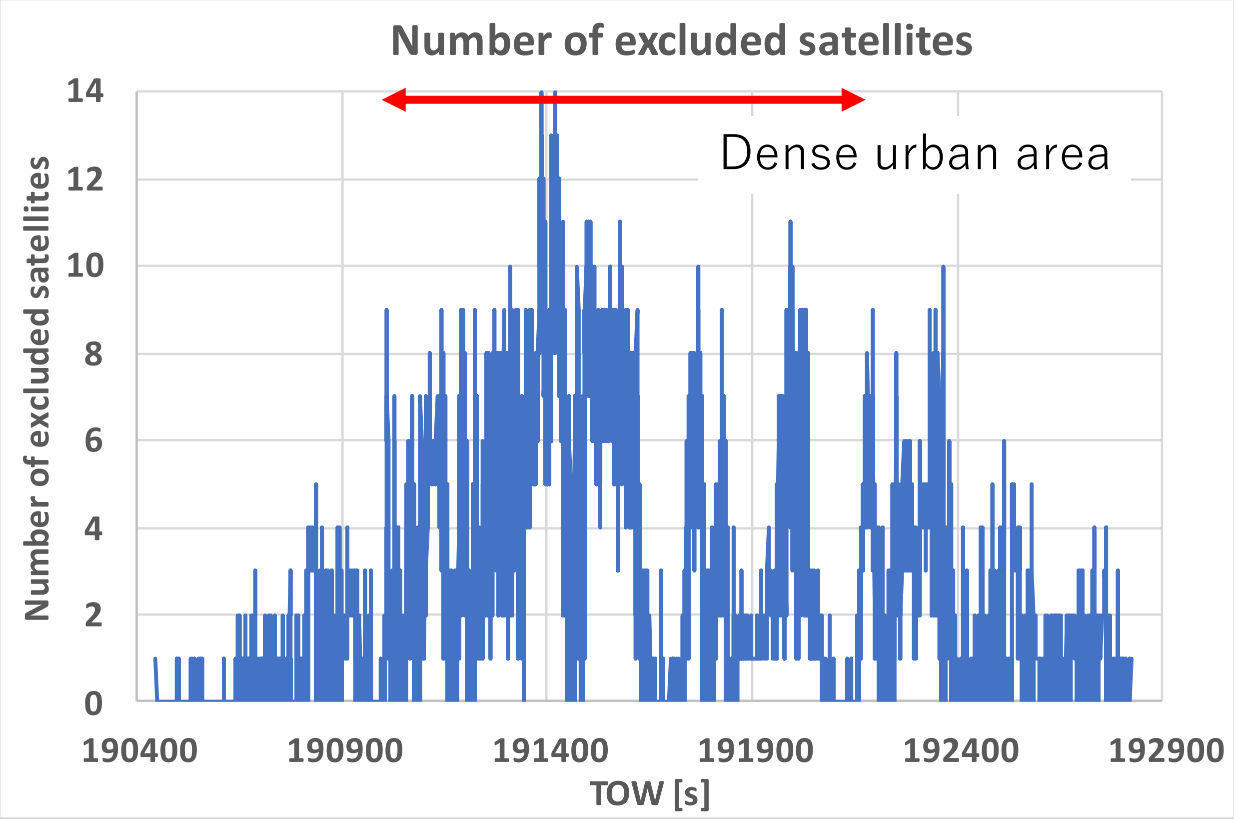




Result(Lap4_Number of satellite & Number of excluded satellite)

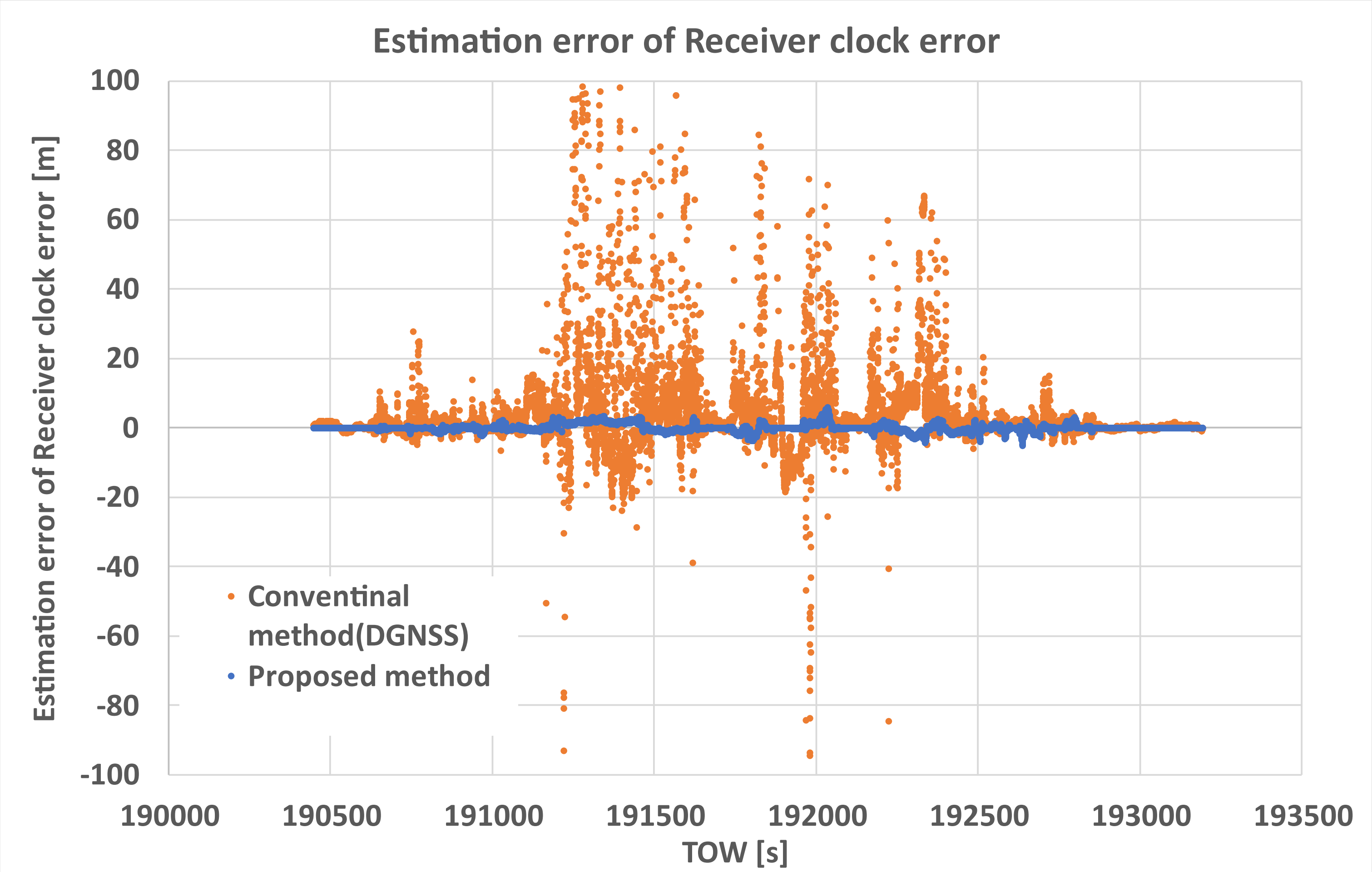
GNSS LAB Tumsat



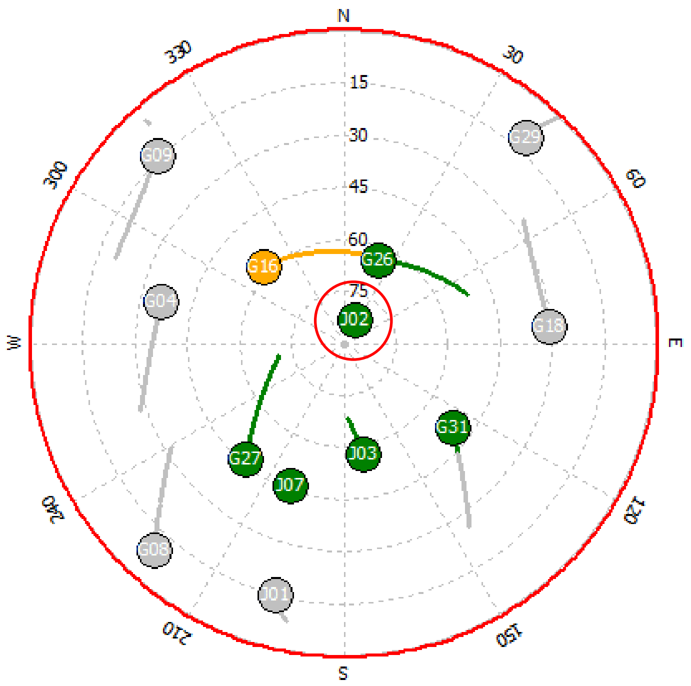


Result(Lap4_Estimation accuracy of Receiver clock error)

GNSS LAB Tumsat



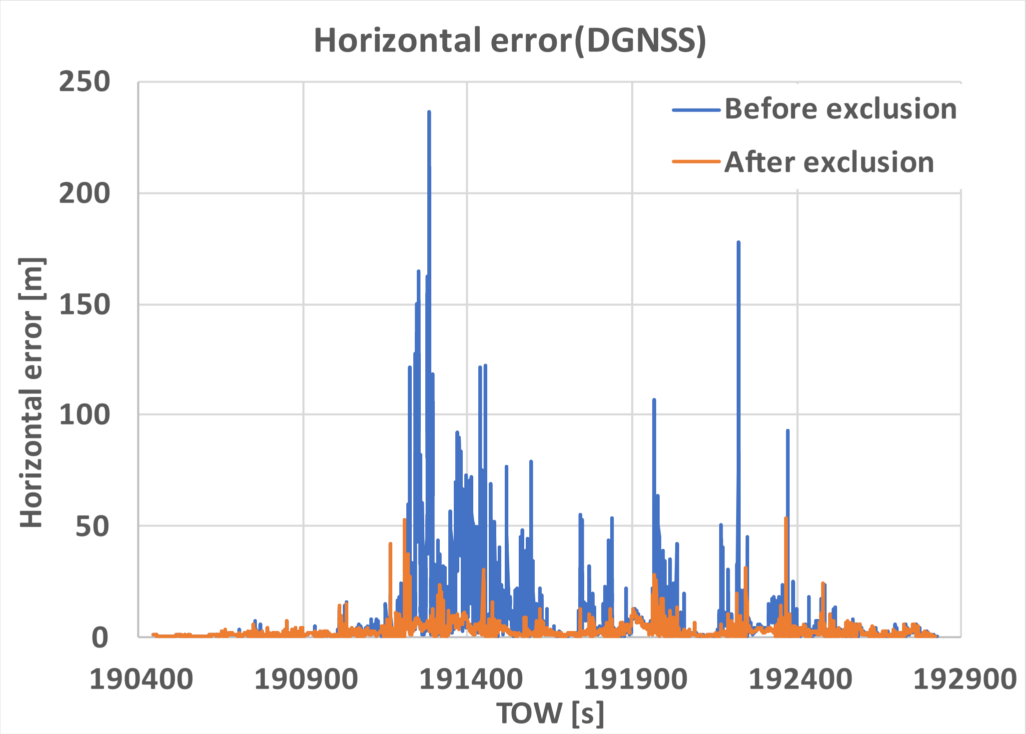
Skyplot

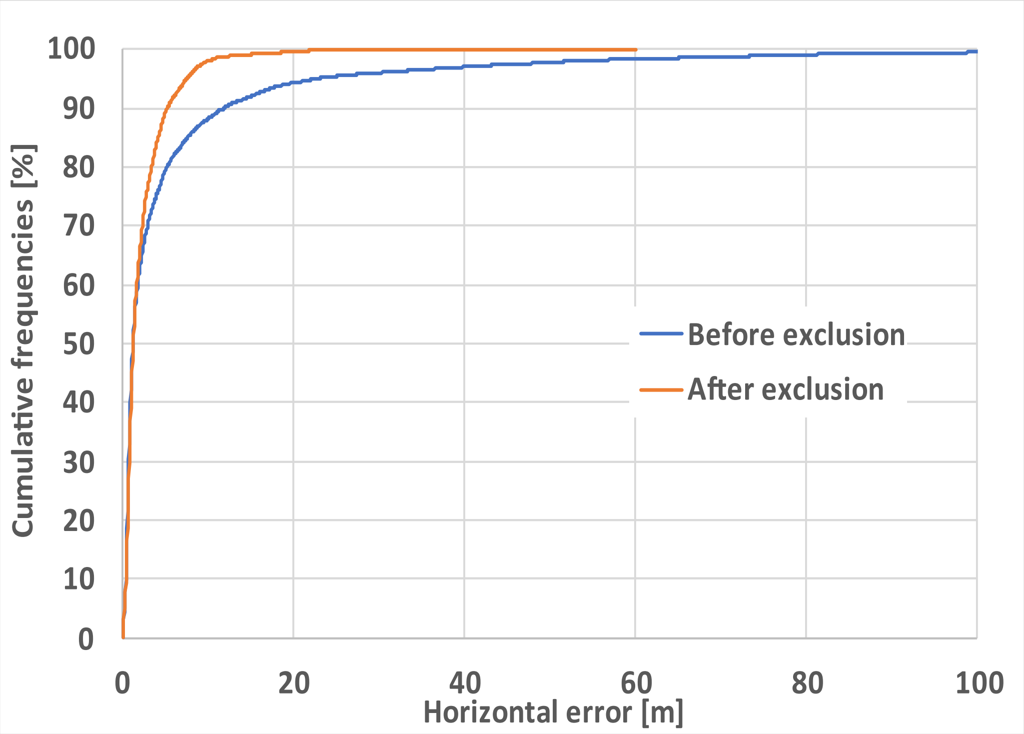


Use J02 for estimation of Receiver clock error

Result(Lap4_Position error of DGNSS)

GNSS LAB Tumsat





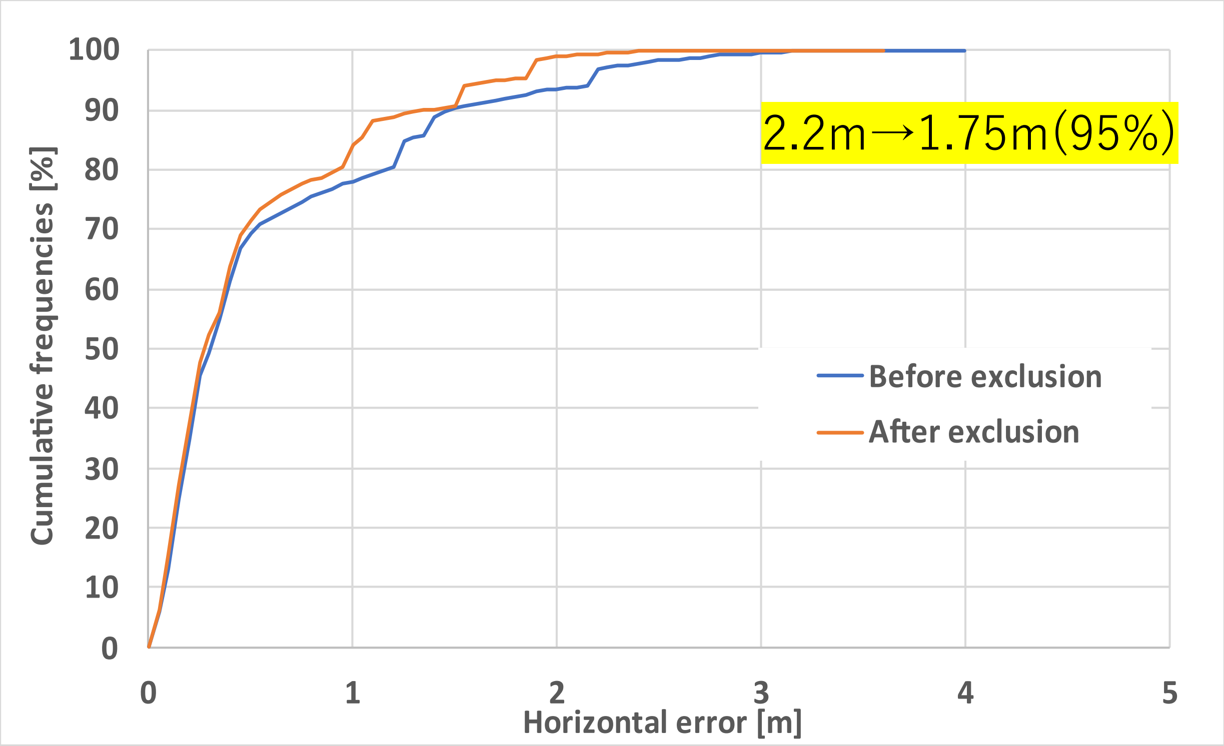
	Before exclusion	After Exclusion
Position error	5.25m (average) 14.62m (STD) 236.68 (max)	2.04m (average) 2.67m (STD) 53.79 (max)
Number of positioning	13653	13635

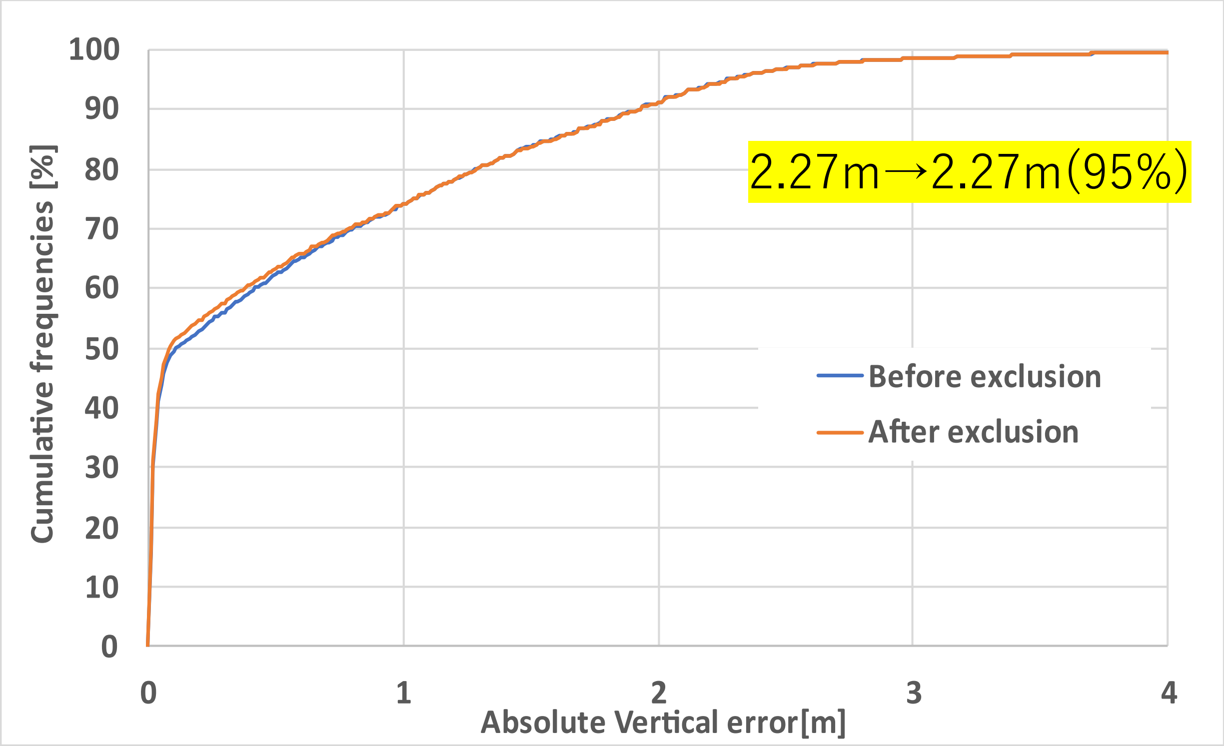
Result(Lap4_RTK-GNSS & Integrated Positioning)

GNSS LAB Tumsat

RTK-GNSS	Number of Fix(Fix rate)	Number of miss Fix(*)
Before exclusion	6432(47.1%)	23
After exclusion	6620(48.5%)	15

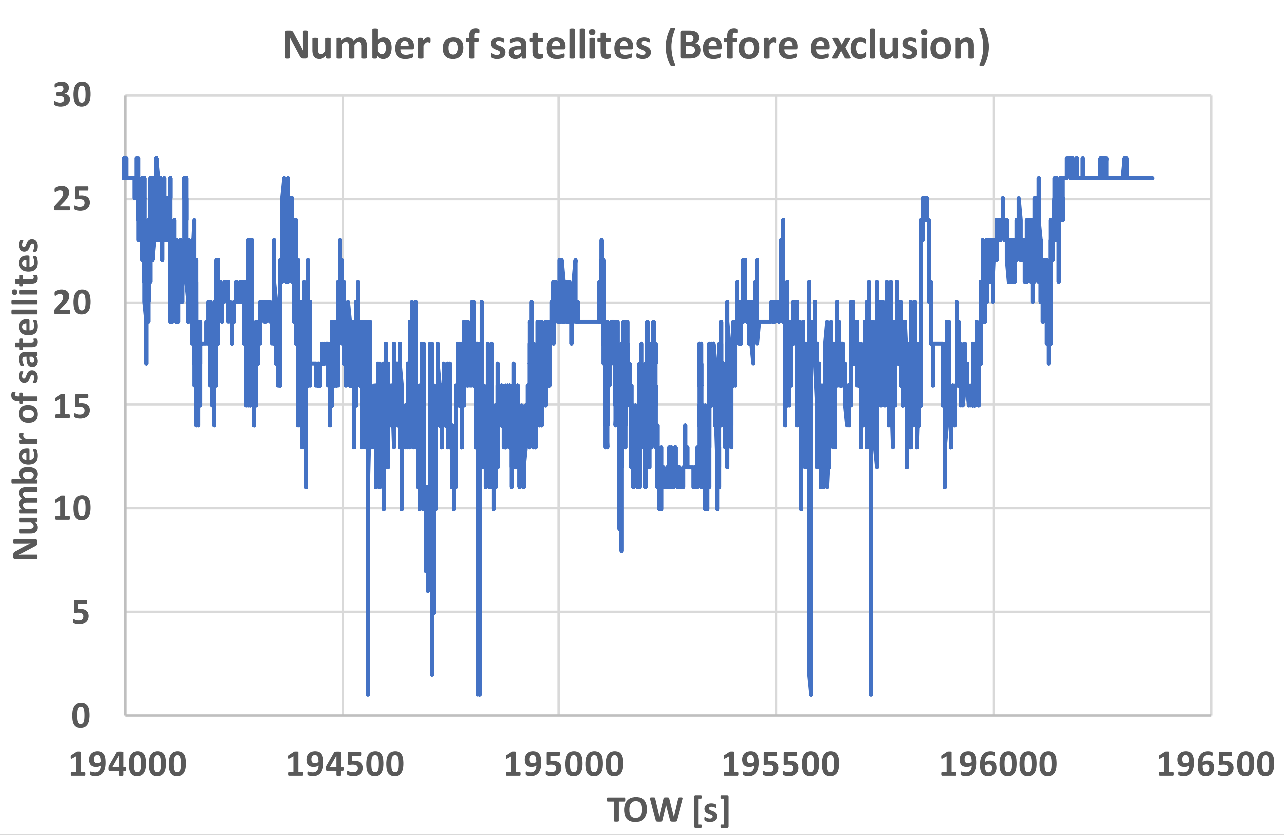
Miss Fix ：Horizontal error of 0.5 m or more or
Altitude error of 1.0 m or more

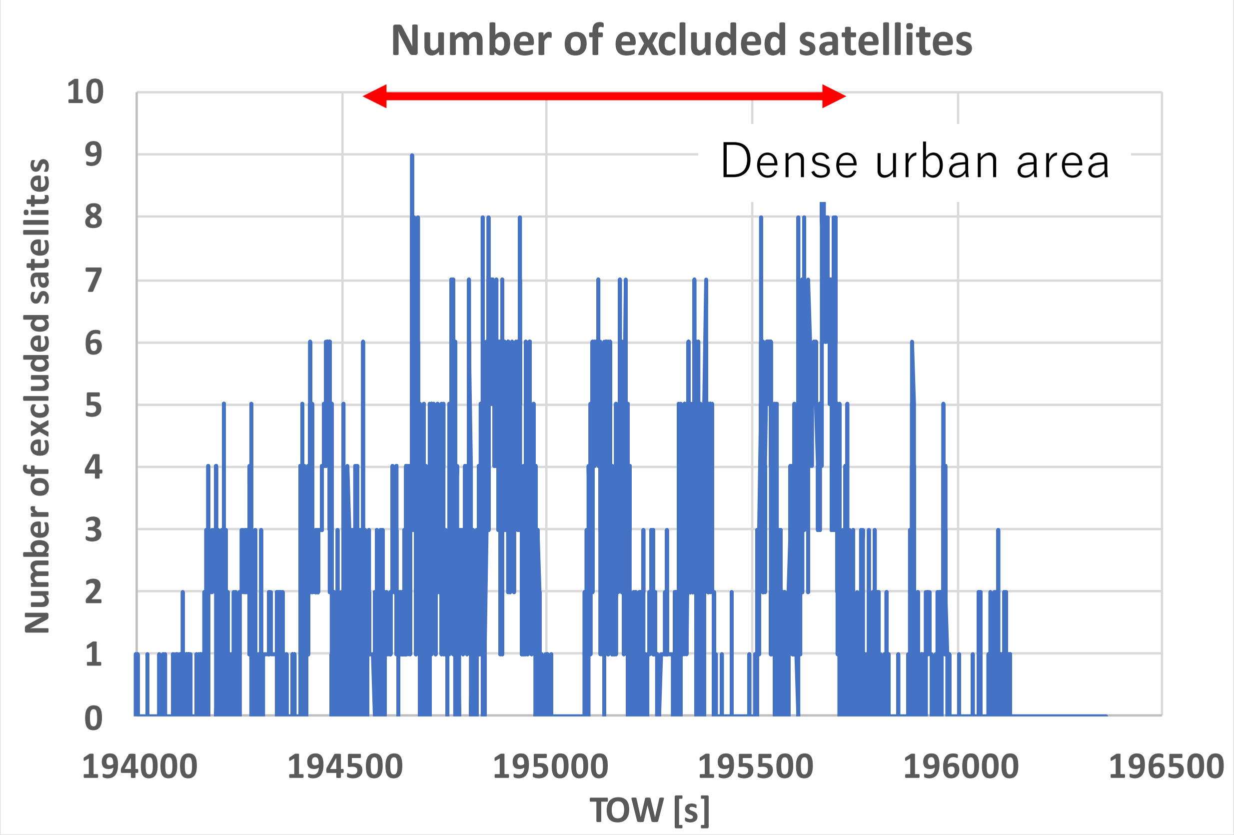




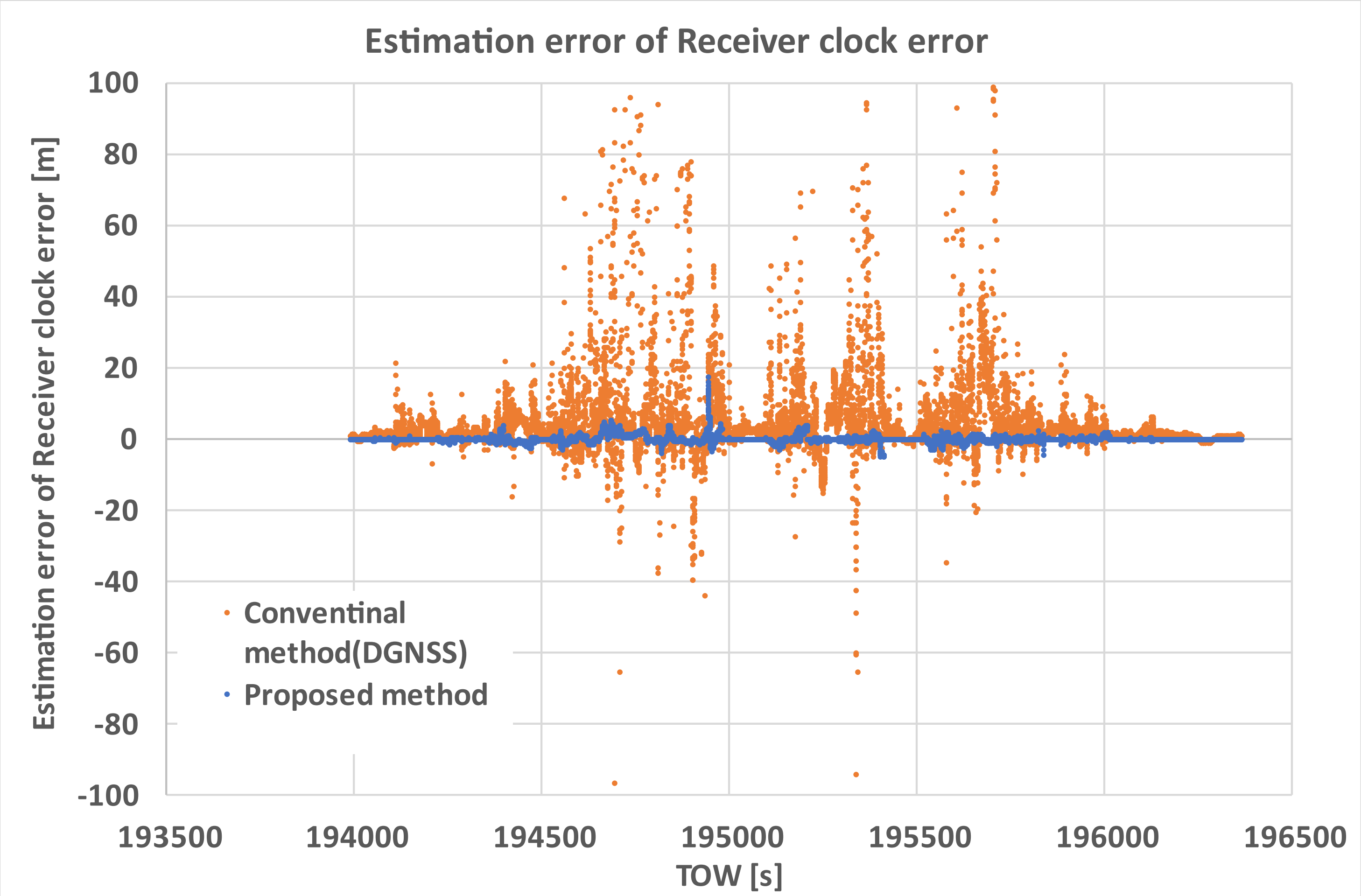
Result(Lap5_Number of satellite & Number of excluded satellite)

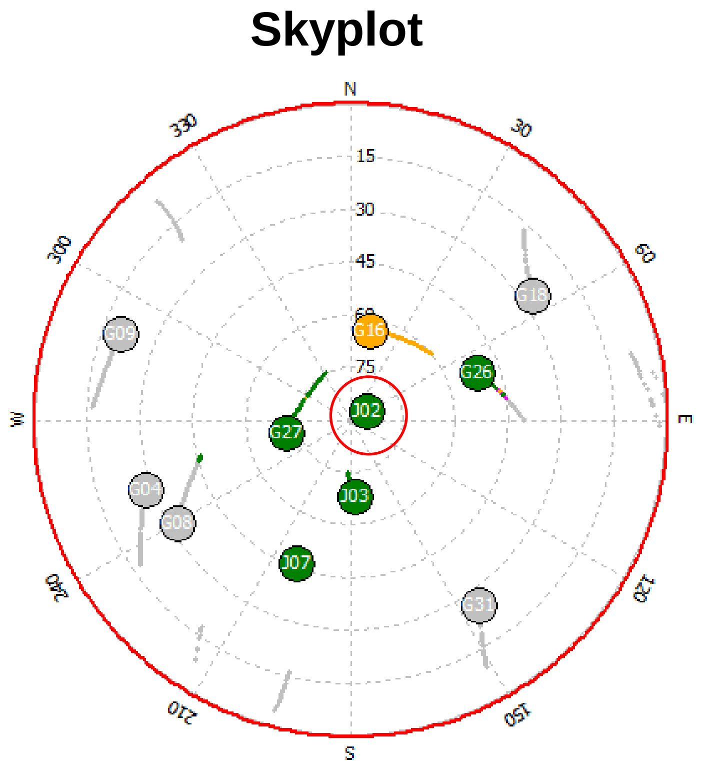
GNSS LAB Tumsat





Result(Lap5_Estimation accuracy of Receiver clock error)

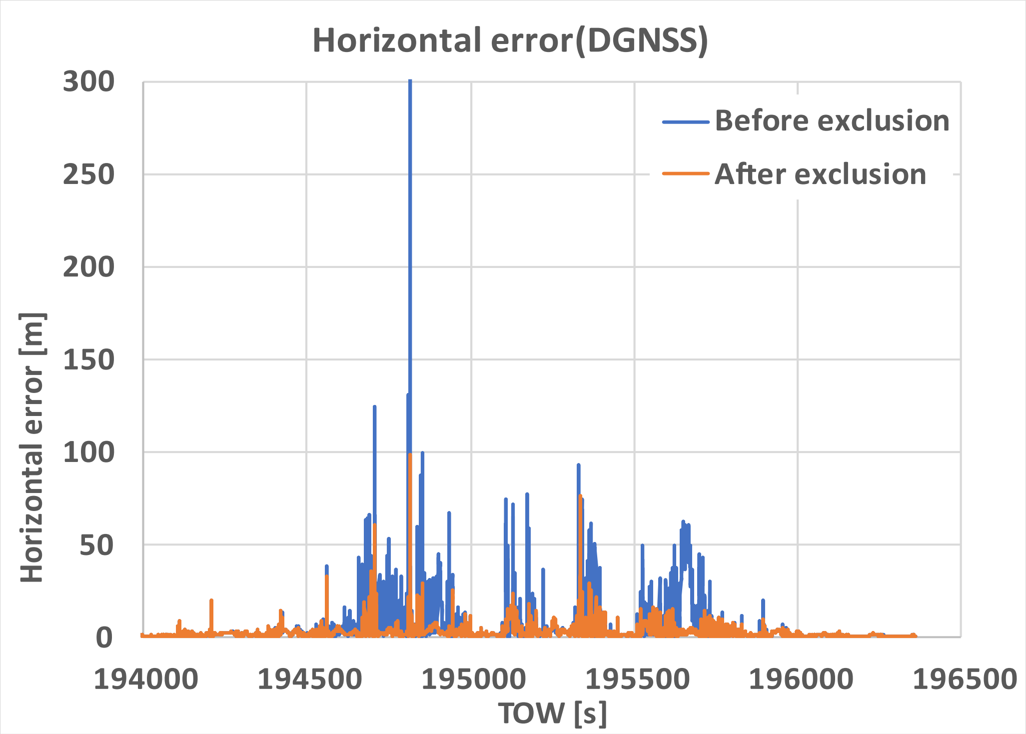


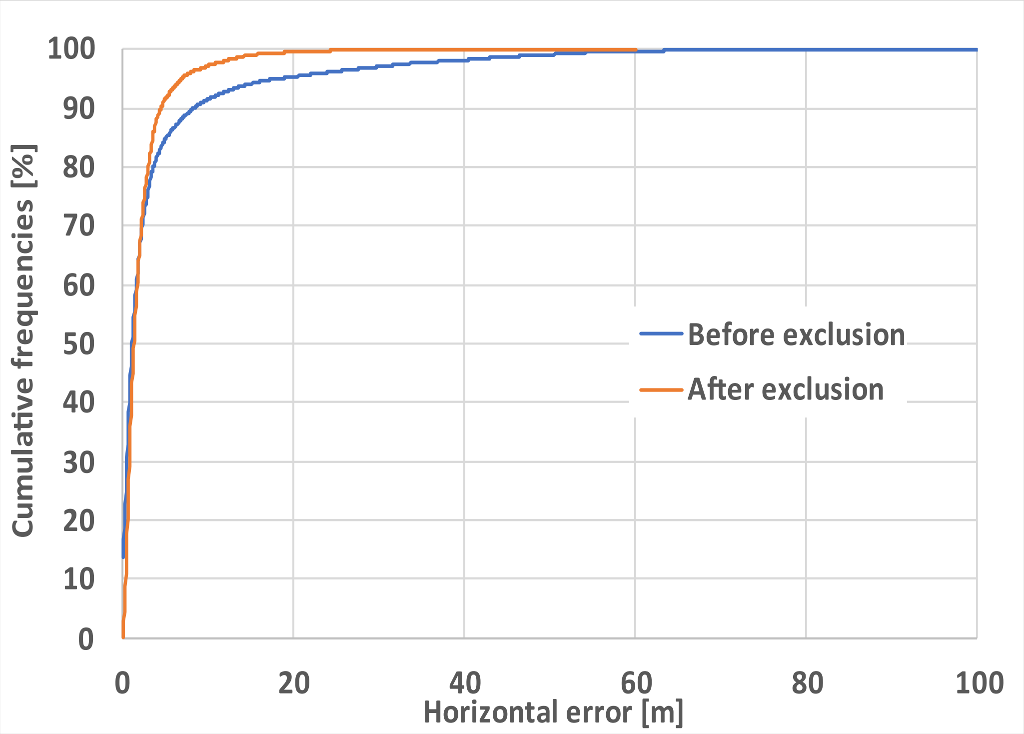


Use J02 for estimation of Receiver clock error

Result(Lap3_Position error of DGNSS)

GNSS LAB Tumsat





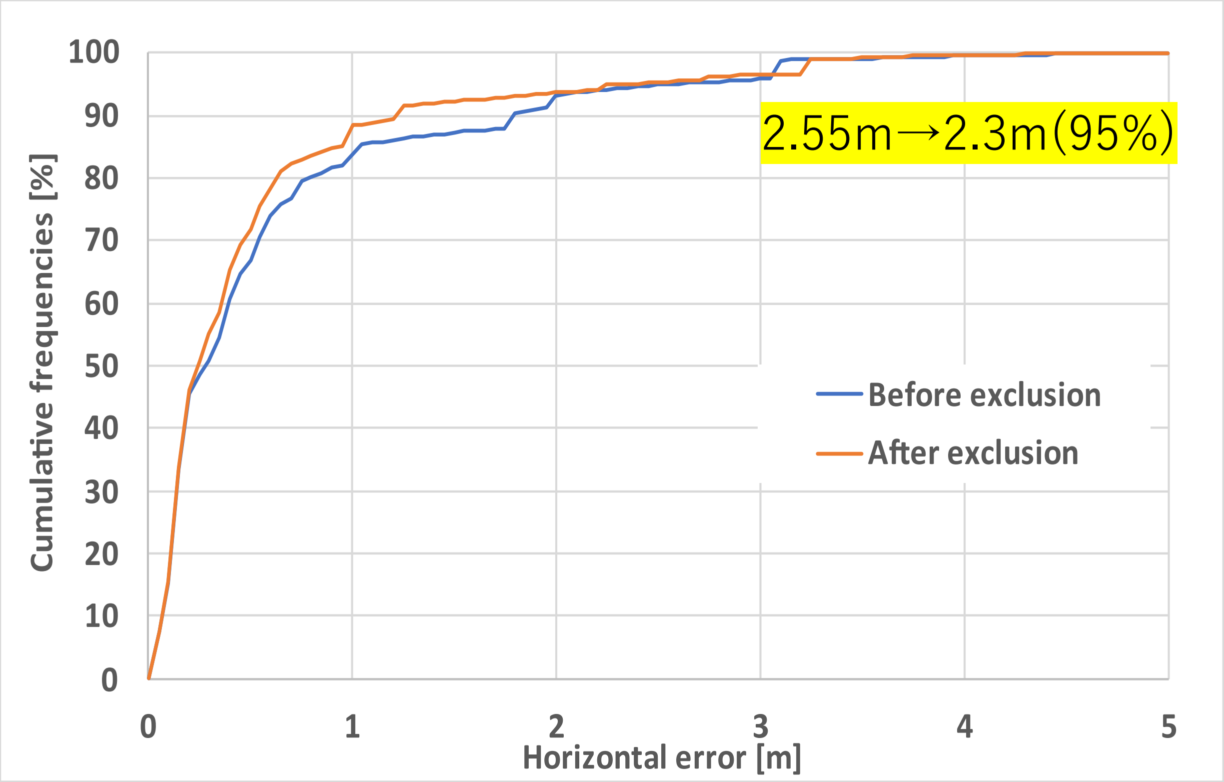
	Before exclusion	After Exclusion
Position error	3.81m (average) 9.22m (STD) 397.79(max)	2.22m (average) 3.09m (STD) 98.74 (max)
Number of positioning	11837	11835

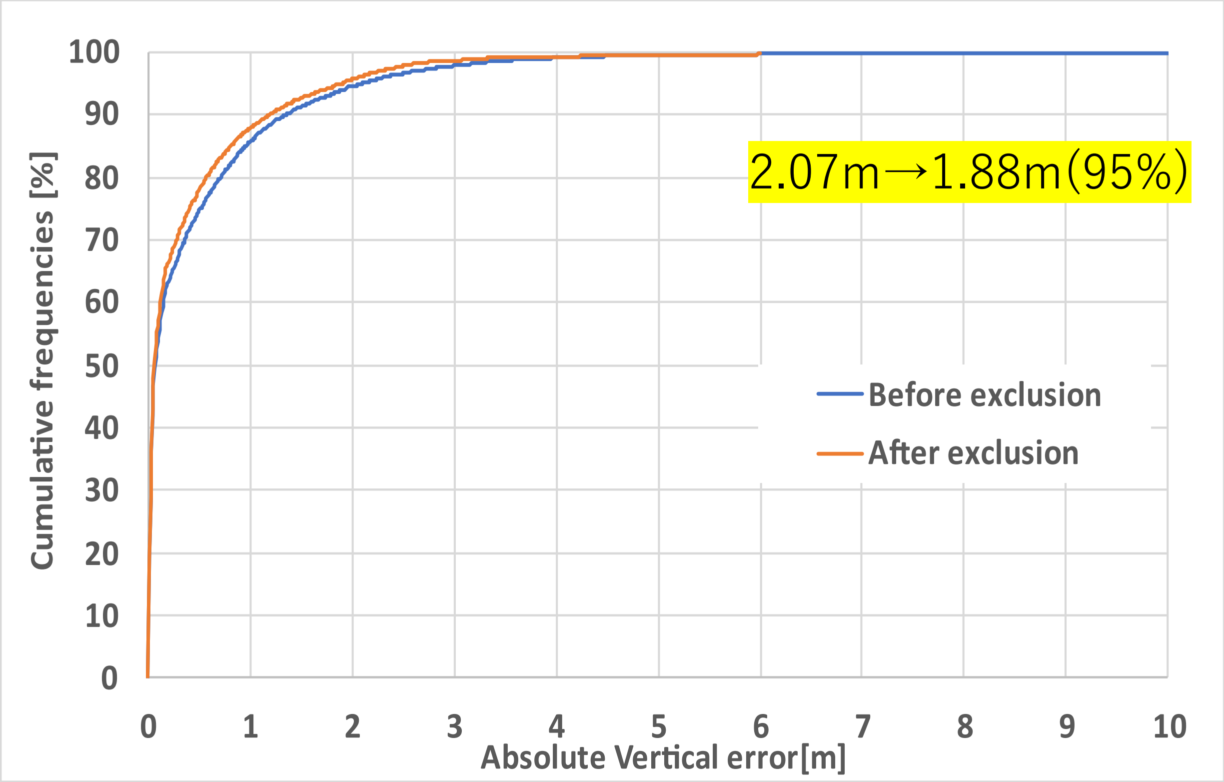
Result(Lap3_RTK-GNSS & Integrated Positioning)

GNSS LAB Tumsat

RTK-GNSS	Number of Fix(Fix rate)	Number of miss Fix(*)
Before exclusion	6452(54.5%)	52
After exclusion	6847(57.8%)	40

Miss Fix ：Horizontal error of 0.5 m or more or
Altitude error of 1.0 m or more





Summary

We proposed modified Residual Error Check.

- Successful estimation of receiver clock error without using an atomic clock.
- DGNSS positioning error is greatly improved.
- In RTK-GNSS, Fix rate is improved and the number of miss-fixes is also down.
- With the improvement of DGNSS and RTK, the integration results have also been improved.

For future work,
We will investigate the possibility of using dual-antennas for residual error check.
(In this study, only use single-antenna)