The Possibility of Precise Automobile Navigation using GPS/QZS L5 and (Galileo E5) Pseudo-ranges

ION-ITM 2013

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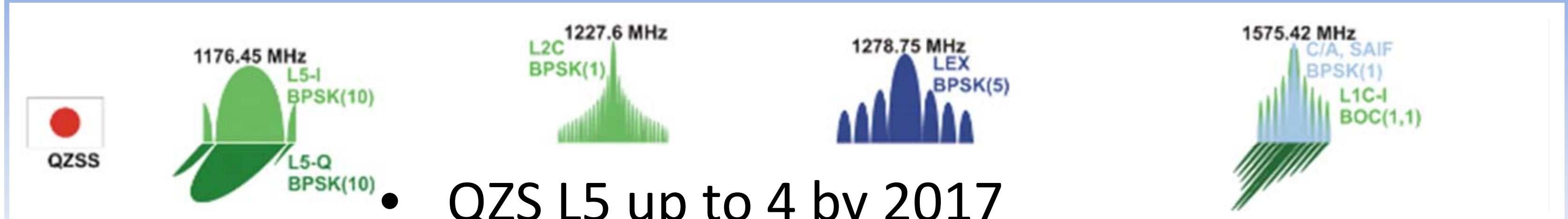
Outline

- Background
- Objective
- Multipath error estimation methods
- Static and kinematic experiment
- Test results
- Conclusion

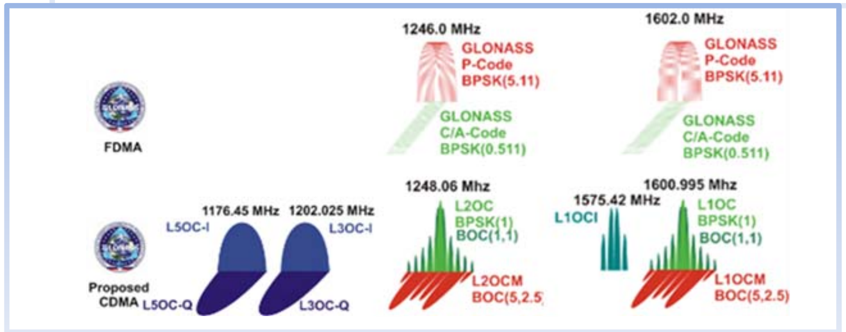
Background

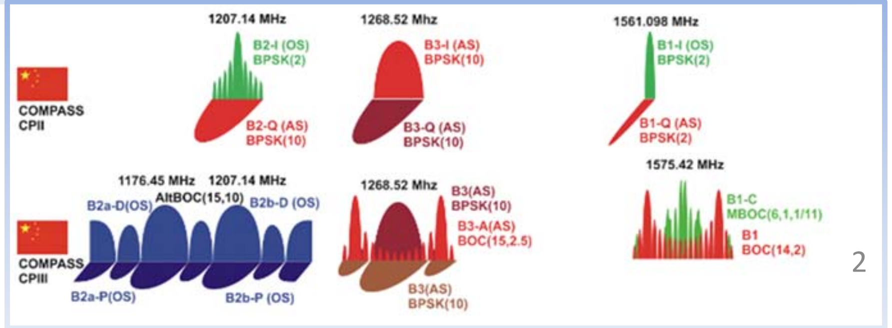
- GPS L5 up to 24 by 2021
- L5 is broadcast from 3 satellites (PRN1/24/25)



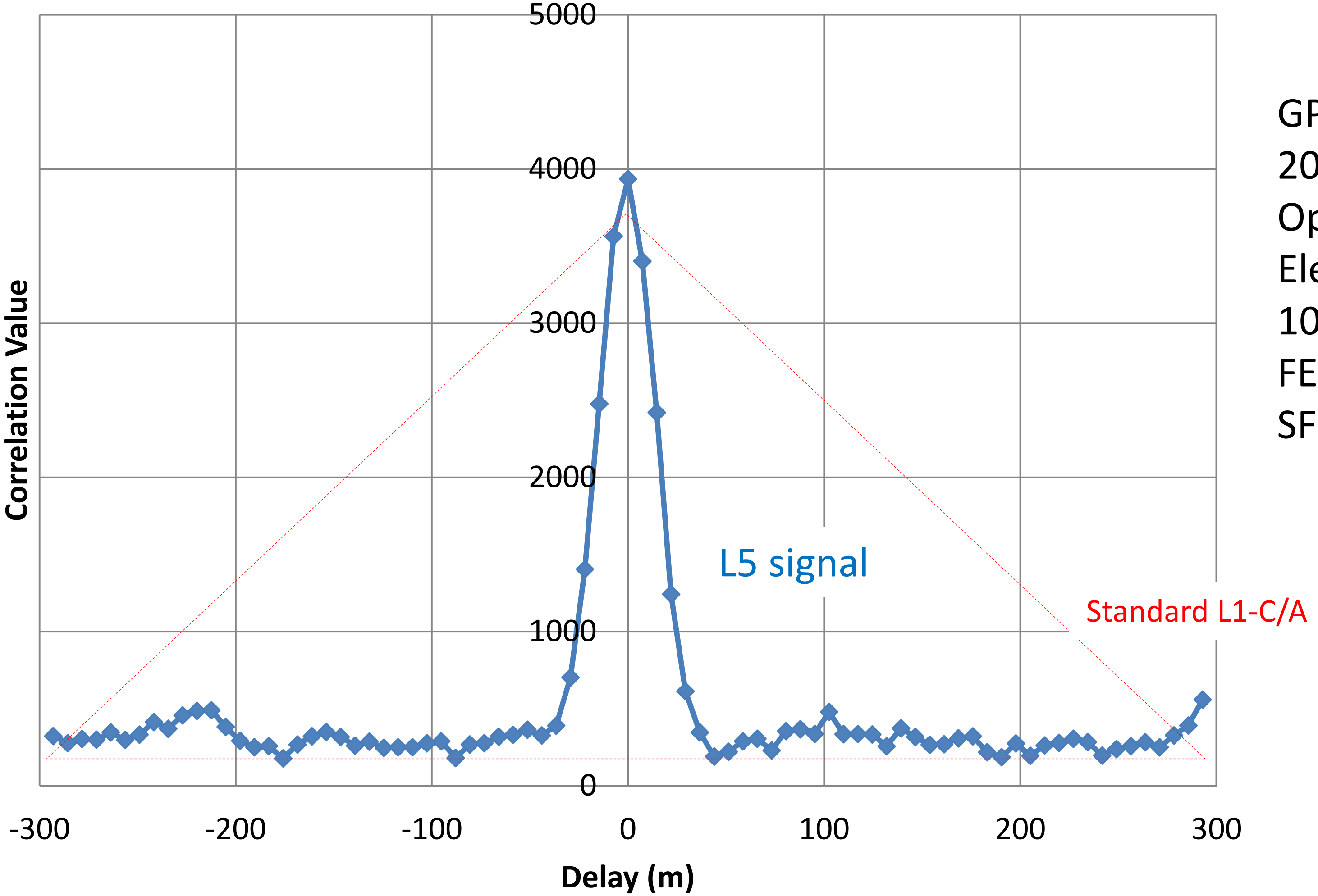
- QZS L5 up to 4 by 2017

- Galileo E5 AltBOC :cm level accuracy under open sky





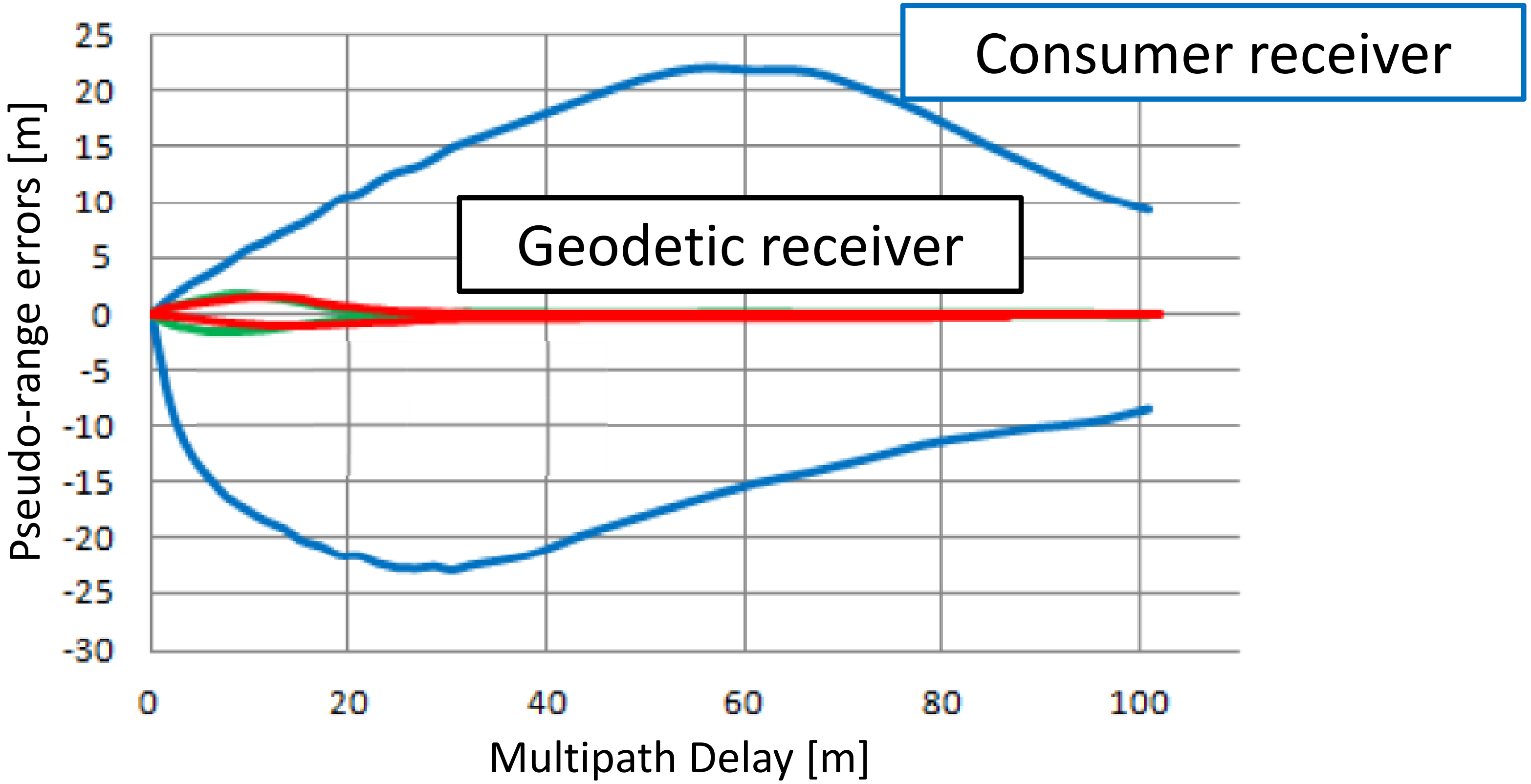
L5 Signal Tracking by SDR (PRN1)



GPS PRN1
2012/8/16
Open-Sky
Elevation:45 deg.
10ms Integration
FE: Fraunhofer
SF: 40.96MHz

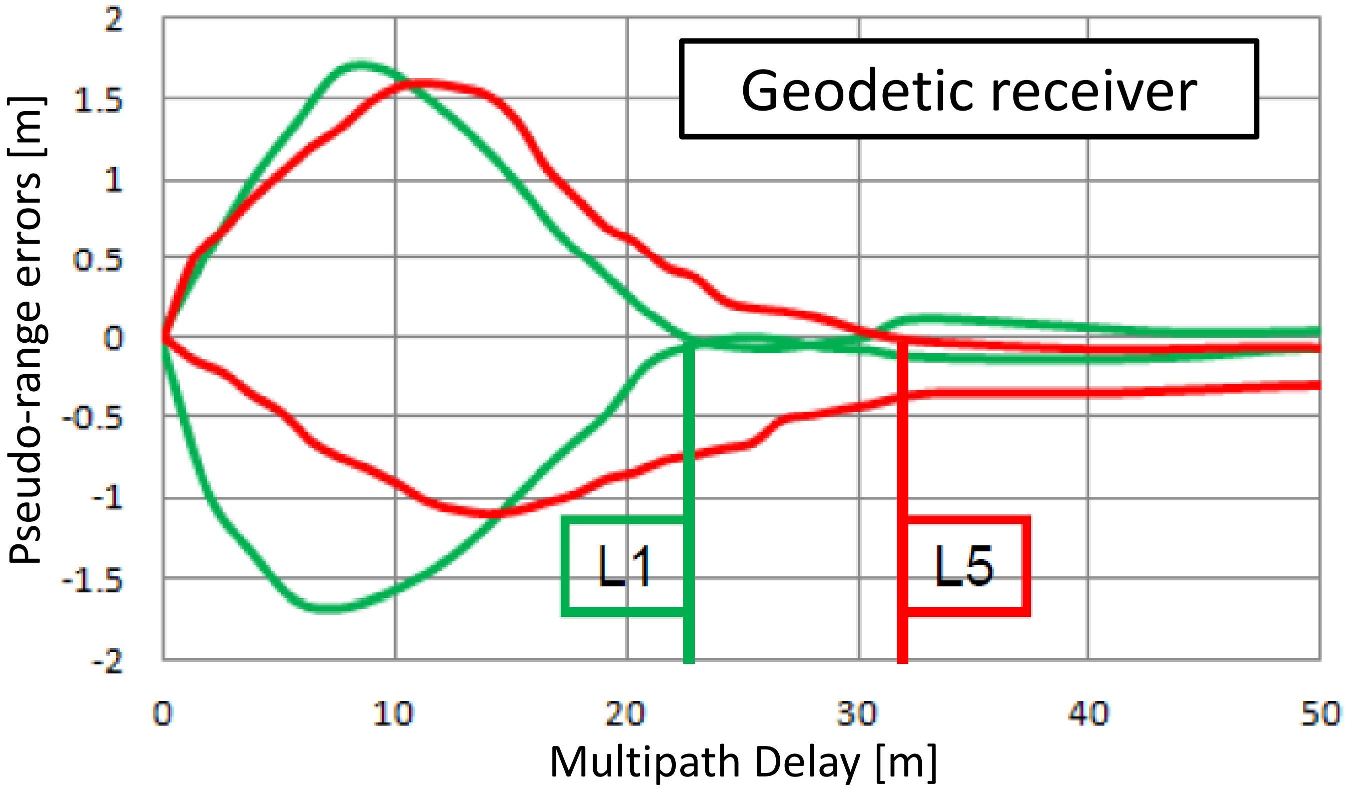
Multipath Envelope

(hardware simulator check: MP is set 6dB lower than Direct)



Consumer receiver is vulnerable to multipath delay even over 100m

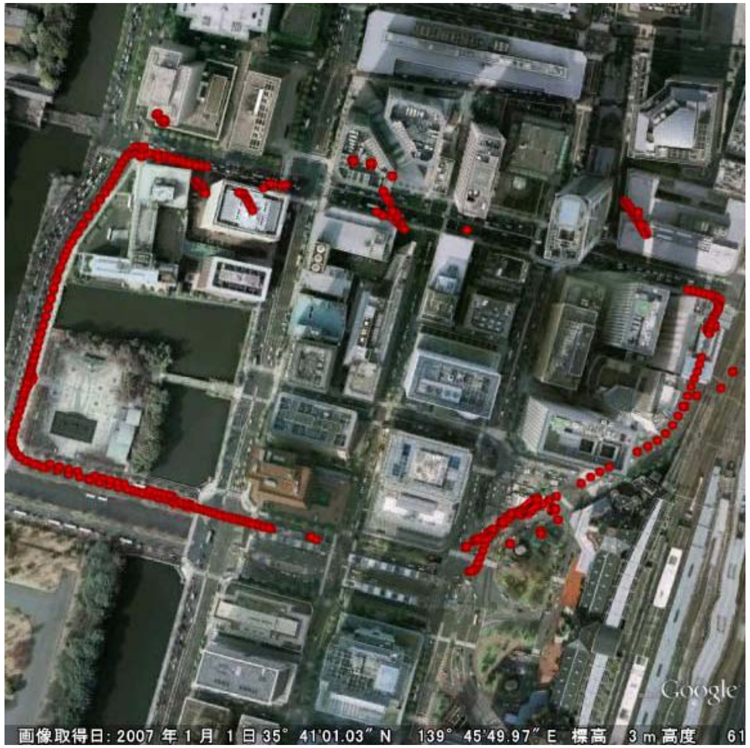
Multipath Envelope (close up)



small difference between L1 and L5
⇒ Multipath in L1 has been improved

Performance in Urban Areas

Vehicles in dense urban areas with geodetic receiver



DGPS in Tokyo

RTK in Tokyo

Several applications require high accuracy (RTK)
⇒ far from perfect at present

Objective

- Pseudo-range observations from L5 in both GPS and QZS are basically robust against multipath.
- It can be used for high reliable and accurate application without Ambiguity Resolution.
- L5 performance has not been investigated because satellites with L5 are few.

The Question: Dose pseudo-ranges of new signals really work well in urban areas ?

Estimation of Multipath Error

- Code-Carrier difference(cc-differnce)
  - Effective for static data
  - Cycle slip happens a lot for kinematic data

  ⇒ **impossible to extract multipath**
  for kinematic data
- Proposed method

⇒Separating Multipath Errors for Vehicle

CC-difference

CC-difference L1 = $P1 – 4.0915 \times \Phi 1 + 3.0915 \times \Phi 2$

CC-difference L5 = $P5 – 3.5212 \times \Phi 5 + 3.5212 \times \Phi 1$

P : Pseudo-range measurement

Φ : Carrier phase measurement

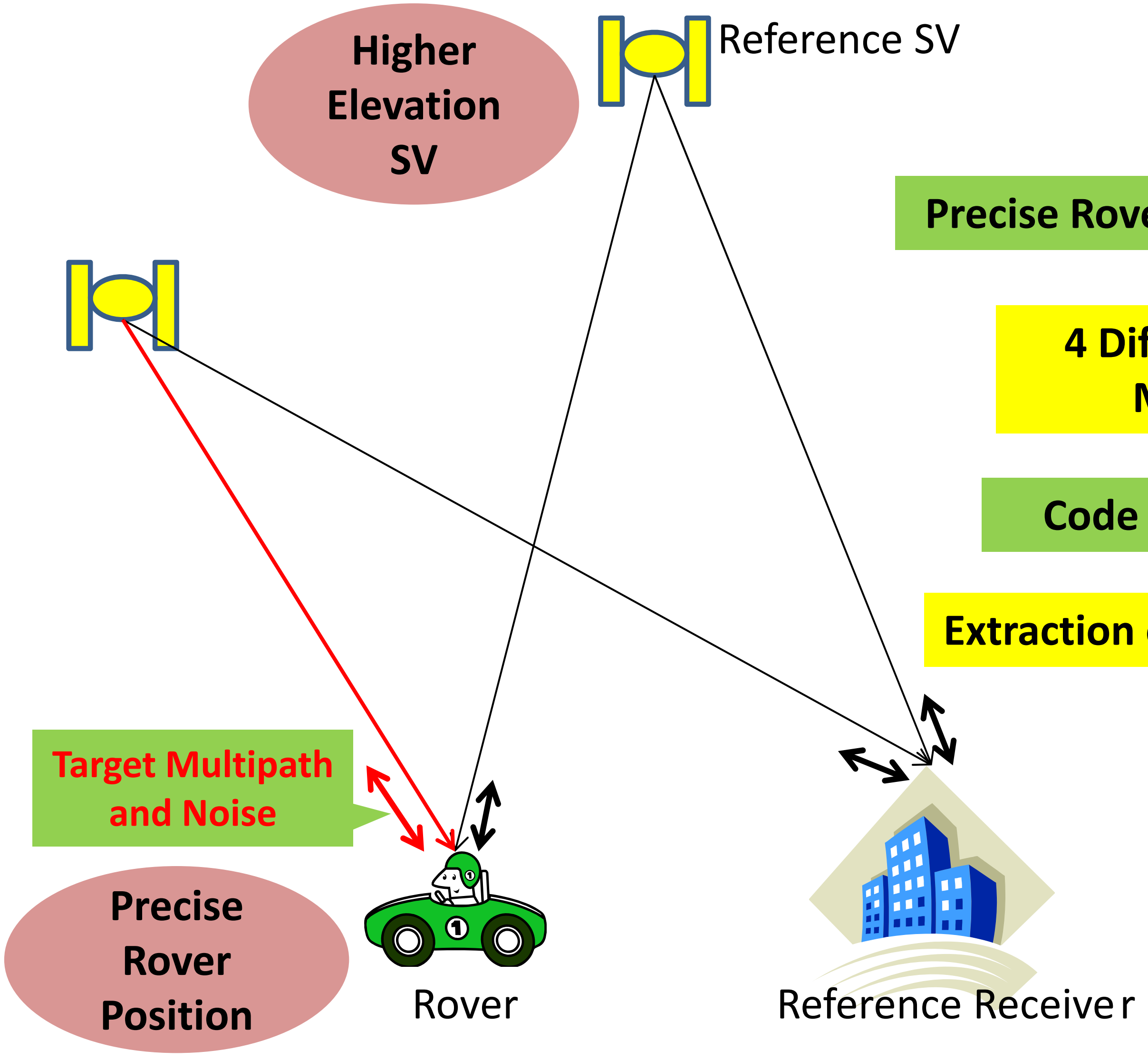
- Dual-frequency receivers can effectively remove the ionospheric delay
- Offset average

•Use both Pseudo-range and Carrier phase

•Effective for only static data

Proposed Method

Separating Multipath Errors for Vehicle



Precise Rover Position + Double Difference

↓

4 Different Combinations of Multipath and Noise

↓

Code minus Carrier Difference

↓

Extraction of Target Multipath and Noise

Separating Multipath Errors for Vehicle

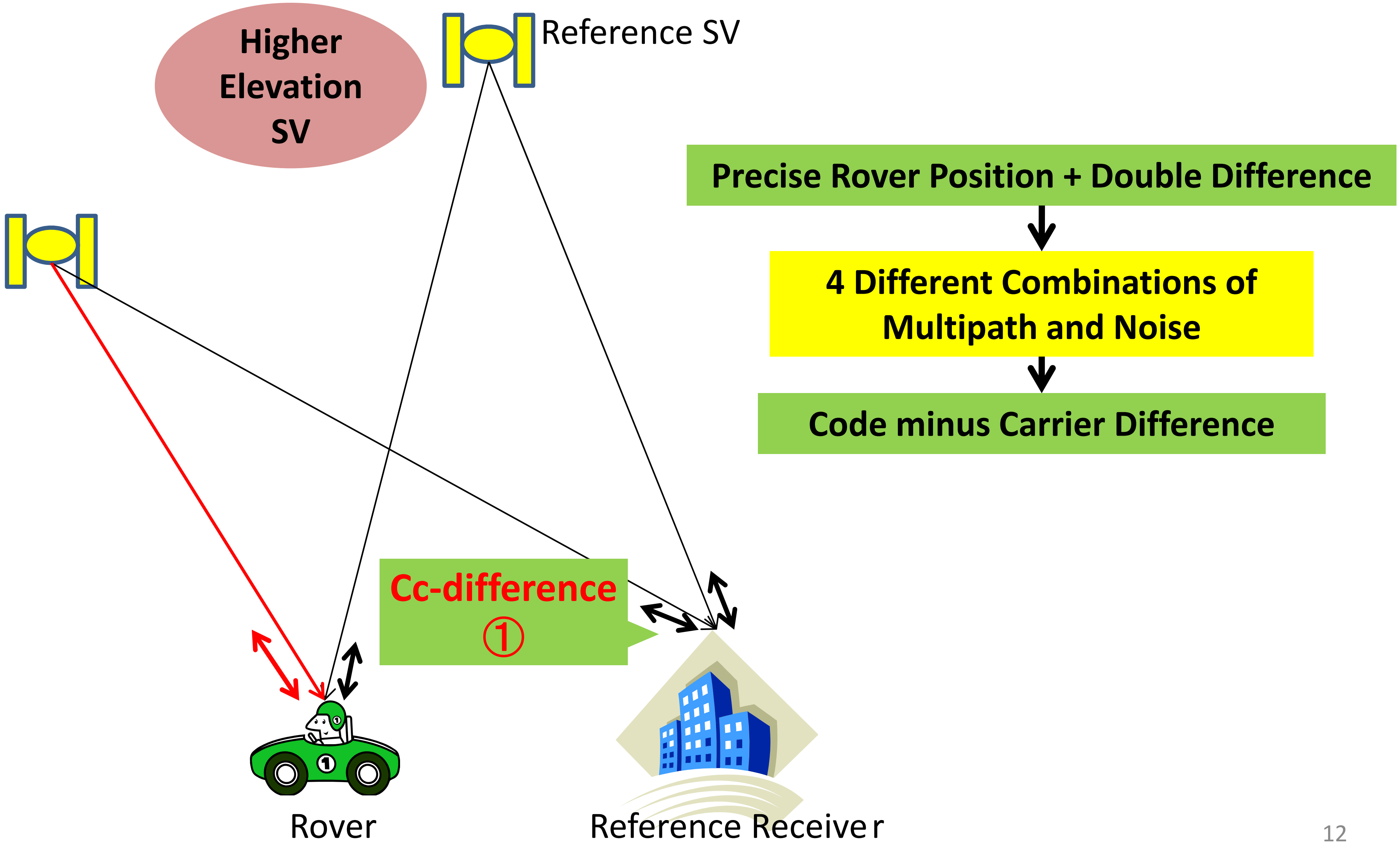
$$
\begin{aligned}
&\boxed{P_{rov\_ref}^{sv1\_sv2}} = \\
&= \rho_{rov}^{sv1} + c(dt_{sv1} - dT_{rov}) + ion_{rov}^{sv1} + tropo_{rov}^{sv1} + mp_{rov}^{sv1} + noise_{rov}^{sv1} \\
&- \left[\rho_{ref}^{sv1} + c(dt_{sv1} - dT_{ref}) + ion_{ref}^{sv1} + tropo_{ref}^{sv1} + mp_{ref}^{sv1} + noise_{ref}^{sv1}\right] \\
&- \left[\rho_{rov}^{sv2} + c(dt_{sv2} - dT_{rov}) + ion_{rov}^{sv2} + tropo_{rov}^{sv2} + mp_{rov}^{sv2} + noise_{rov}^{sv2}\right] \\
&+ \left[\rho_{ref}^{sv2} + c(dt_{sv2} - dT_{ref}) + ion_{ref}^{sv2} + tropo_{ref}^{sv2} + mp_{ref}^{sv2} + noise_{ref}^{sv2}\right] \\
&= \boxed{\rho_{rov}^{sv1} - \rho_{ref}^{sv1} + \rho_{rov}^{sv2} - \rho_{ref}^{sv2}} \\
&+ \boxed{(mp_{rov}^{sv1} + noise_{rov}^{sv1})} - \boxed{(mp_{ref}^{sv1} + noise_{ref}^{sv1})}_{\text{①}} \\
&- \boxed{(mp_{rov}^{sv2} + noise_{rov}^{sv2})}_{\text{②}} + \boxed{(mp_{ref}^{sv2} + noise_{ref}^{sv2})}_{\text{③}}
\end{aligned}
$$

$$
\boxed{\text{Target}} = \underset{\text{Raw Data}}{\boxed{}} - \underset{\text{Measure-ments}}{\boxed{}} + \underbrace{\boxed{\text{①}} + \boxed{\text{②}} - \boxed{\text{③}}}_{\text{Computed by each }\textbf{CC-Difference}}
$$

sv1 : Target SV   sv2 : QZS (Elevation angle > 80)

Proposed Method

Separating Multipath Errors for Vehicle



Precise Rover Position + Double Difference

↓

4 Different Combinations of Multipath and Noise

↓

Code minus Carrier Difference

Separating Multipath Errors for Vehicle

$$\begin{aligned}
\boxed{P_{rov\_ref}^{sv1\_sv2}} &= (P_{rov}^{sv1} - P_{ref}^{sv1}) - (P_{rov}^{sv2} - P_{ref}^{sv2}) \\
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&\quad - \left[\rho_{ref}^{sv1} + c(dt_{sv1} - dT_{ref}) + ion_{ref}^{sv1} + tropo_{ref}^{sv1} + mp_{ref}^{sv1} + noise_{ref}^{sv1}\right] \\
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&\quad + \left[\rho_{ref}^{sv2} + c(dt_{sv2} - dT_{ref}) + ion_{ref}^{sv2} + tropo_{ref}^{sv2} + mp_{ref}^{sv2} + noise_{ref}^{sv2}\right] \\
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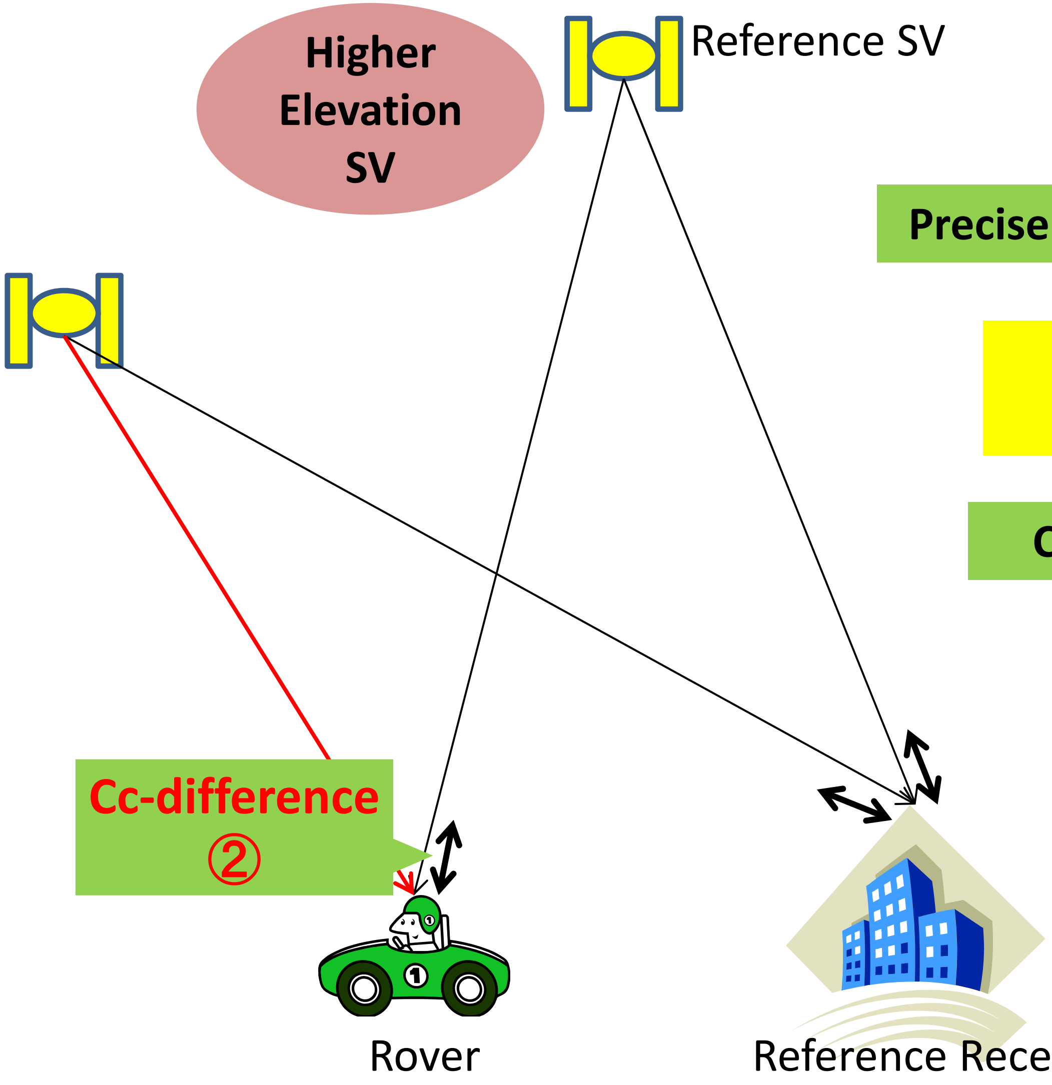
&\quad + (mp_{rov}^{sv1} + noise_{rov}^{sv1}) - \underset{\text{①}}{\boxed{(mp_{ref}^{sv1} + noise_{ref}^{sv1})}} \\
&\quad - \underset{\text{②}}{\boxed{(mp_{rov}^{sv2} + noise_{rov}^{sv2})}} + \underset{\text{③}}{(mp_{ref}^{sv2} + noise_{ref}^{sv2})}
\end{aligned}$$

$$\boxed{\text{Target}} = \underset{\text{Raw Data}}{\boxed{}} - \underset{\text{Measure-ments}}{\boxed{}} + \underbrace{\boxed{\text{①}} + \boxed{\text{②}} - \boxed{\text{③}}}_{\text{Computed by each } \textbf{CC-Difference}}$$

sv1 : Target SV sv2 : QZS (Elevation angle > 80)

Proposed Method

Separating Multipath Errors for Vehicle



Precise Rover Position + Double Difference

4 Different Combinations of Multipath and Noise

Code minus Carrier Difference

Separating Multipath Errors for Vehicle

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\end{aligned}
$$

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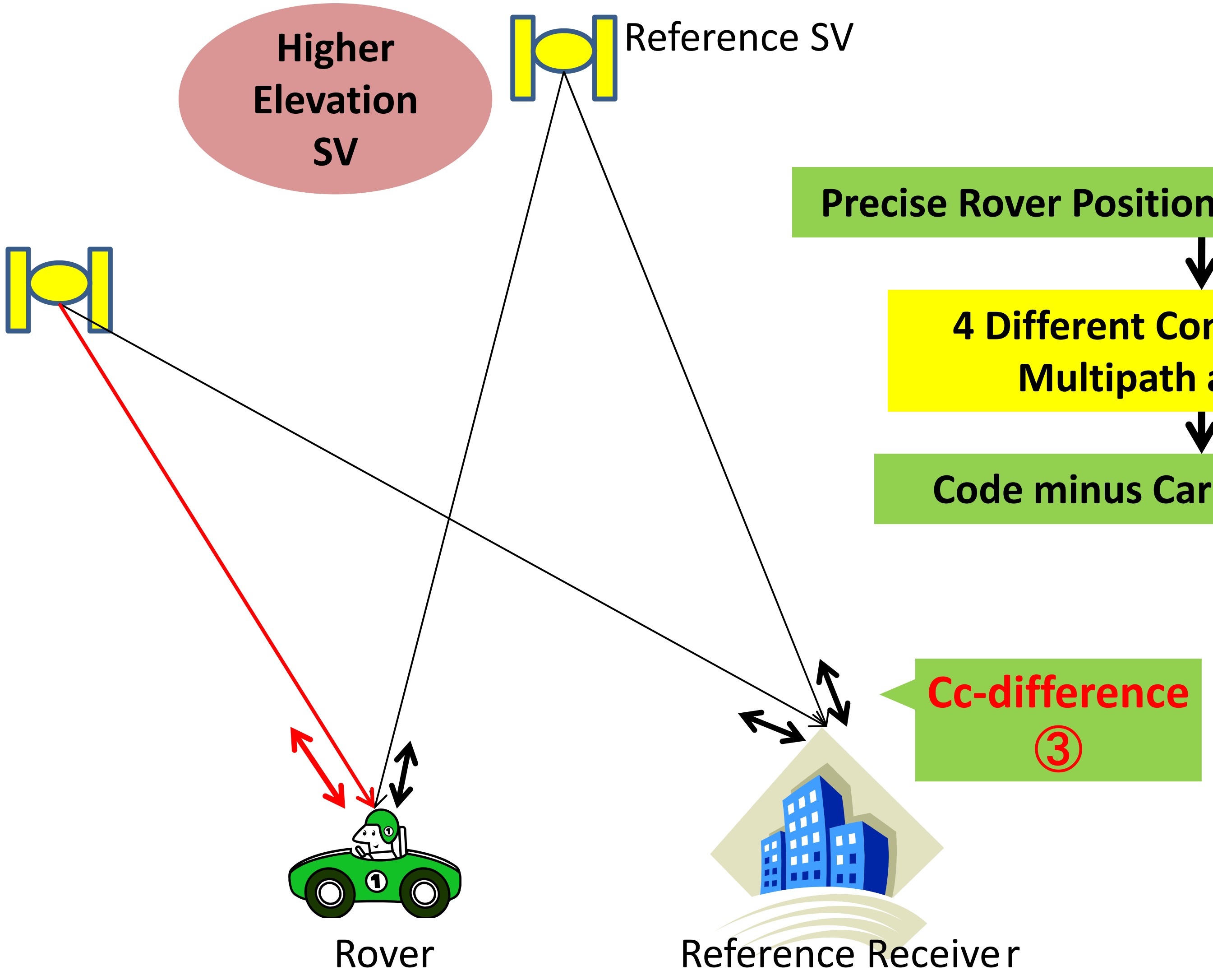
\boxed{\text{Target}} = \underset{\text{Raw Data}}{\boxed{}} - \underset{\text{Measure-ments}}{\boxed{}} + \underbrace{\boxed{\text{①}} + \boxed{\text{②}} - \boxed{\text{③}}}_{\text{Computed by each } \textbf{CC-Difference}}
$$

sv1 : Target SV   sv2 : QZS (Elevation angle > 80)

Proposed Method

Separating Multipath Errors for Vehicle



Precise Rover Position + Double Difference

4 Different Combinations of Multipath and Noise

Code minus Carrier Difference

Cc-difference ③

Separating Multipath Errors for Vehicle

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&+ \left[\rho_{ref}^{sv2} + c(dt_{sv2} - dT_{ref}) + ion_{ref}^{sv2} + tropo_{ref}^{sv2} + mp_{ref}^{sv2} + noise_{ref}^{sv2}\right] \\
&= \boxed{\rho_{rov}^{sv1} - \rho_{ref}^{sv1} + \rho_{rov}^{sv2} - \rho_{ref}^{sv2}} \\
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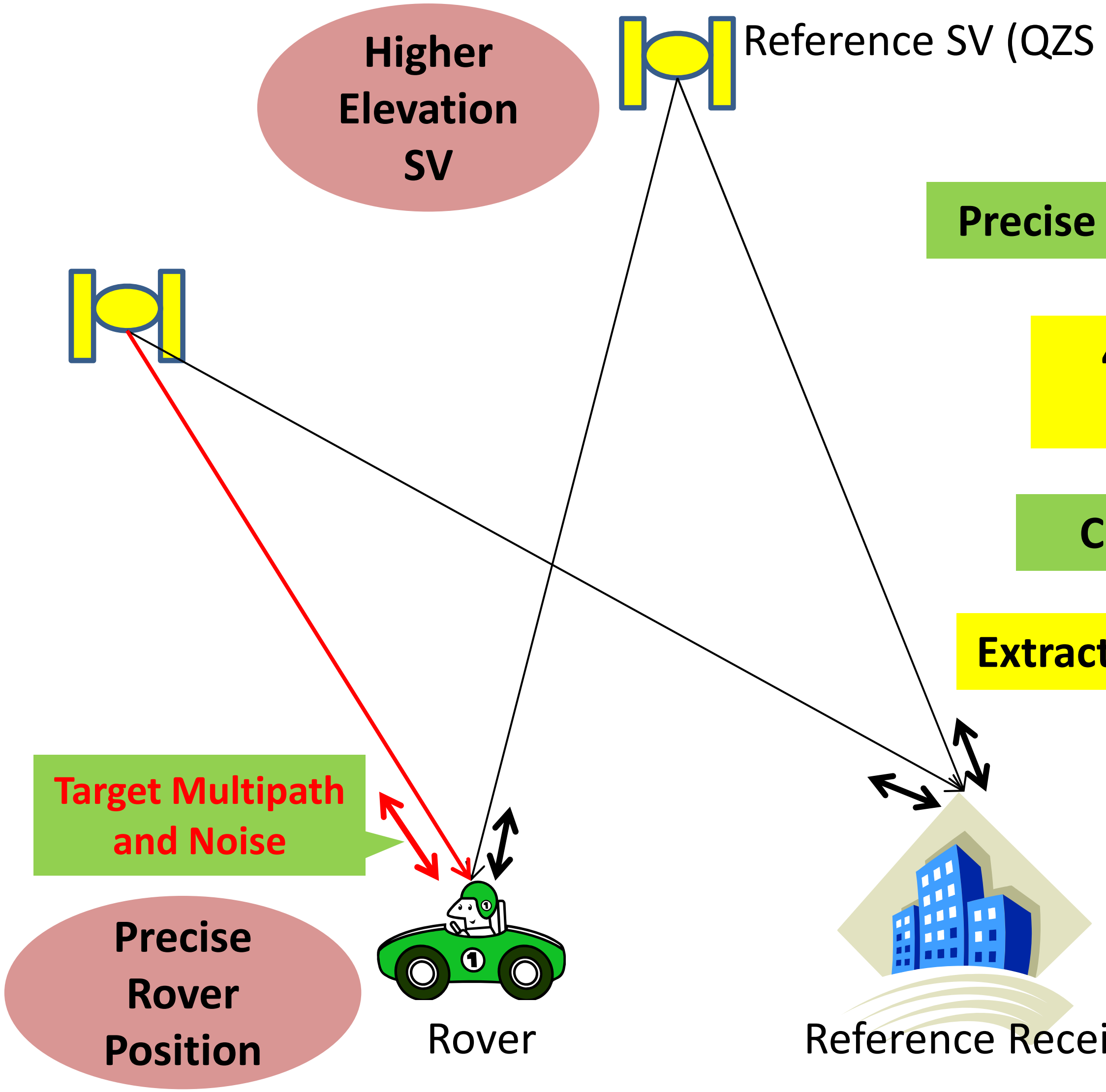
\end{aligned}
$$

$$
\boxed{\text{Target}} = \underset{\text{Raw Data}}{\boxed{\phantom{\text{Raw Data}}}} - \underset{\text{Measurements}}{\boxed{\phantom{\text{Raw Data}}}} + \underbrace{\boxed{①} + \boxed{②} - \boxed{③}}_{\text{Computed by each }\textbf{CC-Difference}}
$$

sv1 : Target SV   sv2 : QZS (Elevation angle > 80)

Proposed Method

Separating Multipath Errors for Vehicle



Precise Rover Position + Double Difference

↓

4 Different Combinations of Multipath and Noise

↓

Code minus Carrier Difference

↓

Extraction of Target Multipath and Noise

Test and Results

1. Static Test 1 (*Toyosu,Tokyo*)

   long distance (approx. 30m) from building

2. Static Test 2 (*campas,Tokyo*)

   short distance (<10m) from building

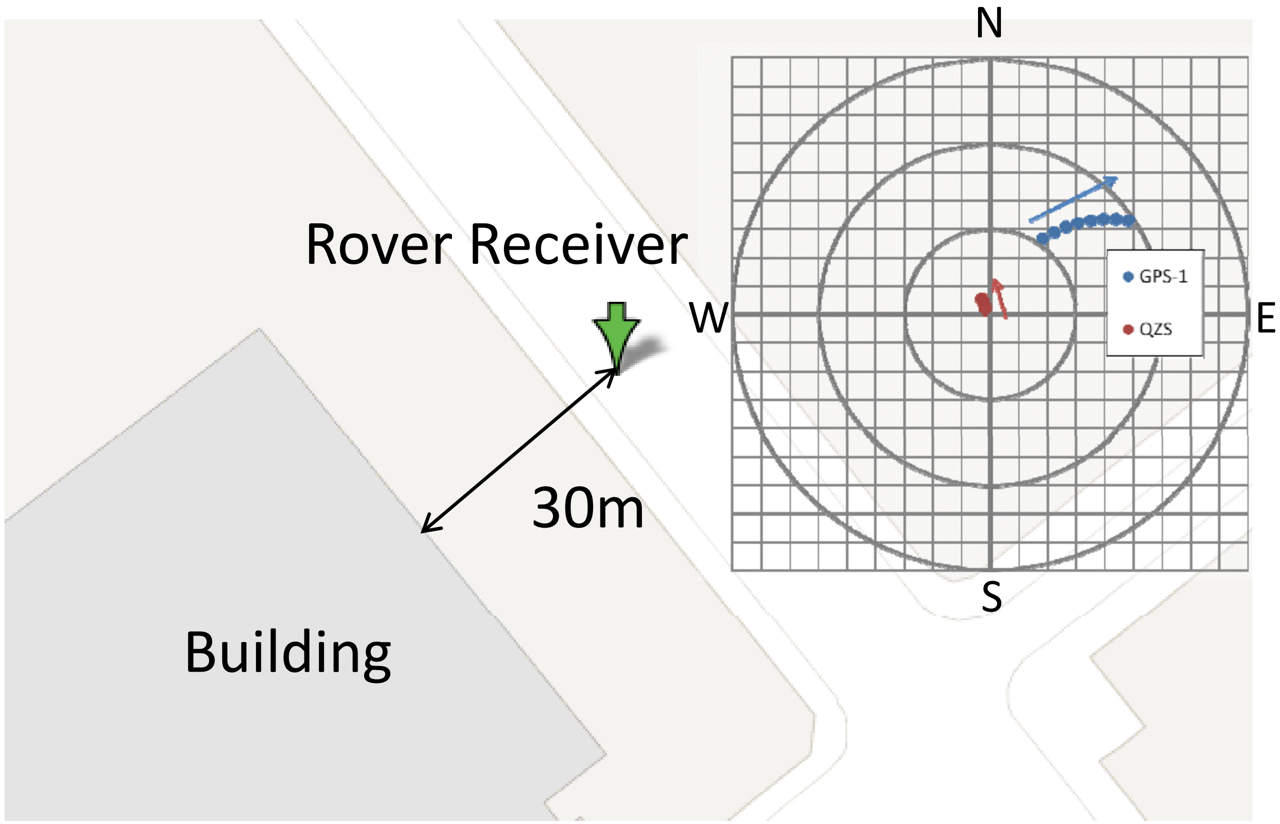
3. Kinematic Test 1 (*tukishima, Tokyo*)
4. Kinematic Test 2 (*edagawa, Tokyo*)

Validation for proposed method

Estimate multipath error using proposed method
Target : GPS-PRN1 (transmitting both L1 and L5)

Static Test 1 (*Toyosu,Tokyo*)

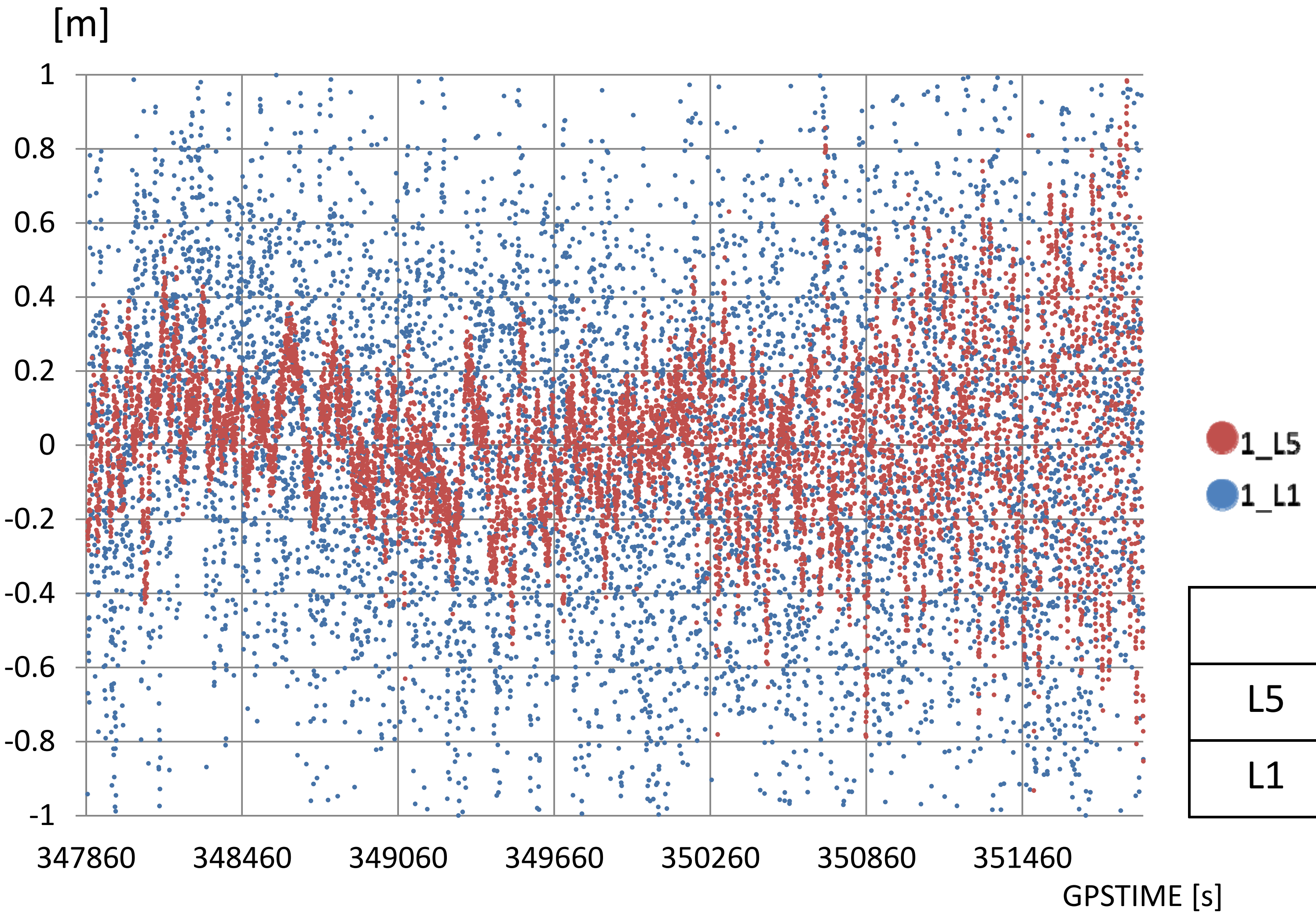
12/13/ 2012 (GPSTIME) 0:30~
Geodetic Receiver
60 min 2 Hz
5-8 satellites in view over 15 degrees elevation
Target SV : GPS-PRN-1 (L1,L5) Reference SV : QZS-1 (L1,L5)
Precise position was computed by post processing



Long delay multipath

using proposed method
to extraction the PRN-1 multipath

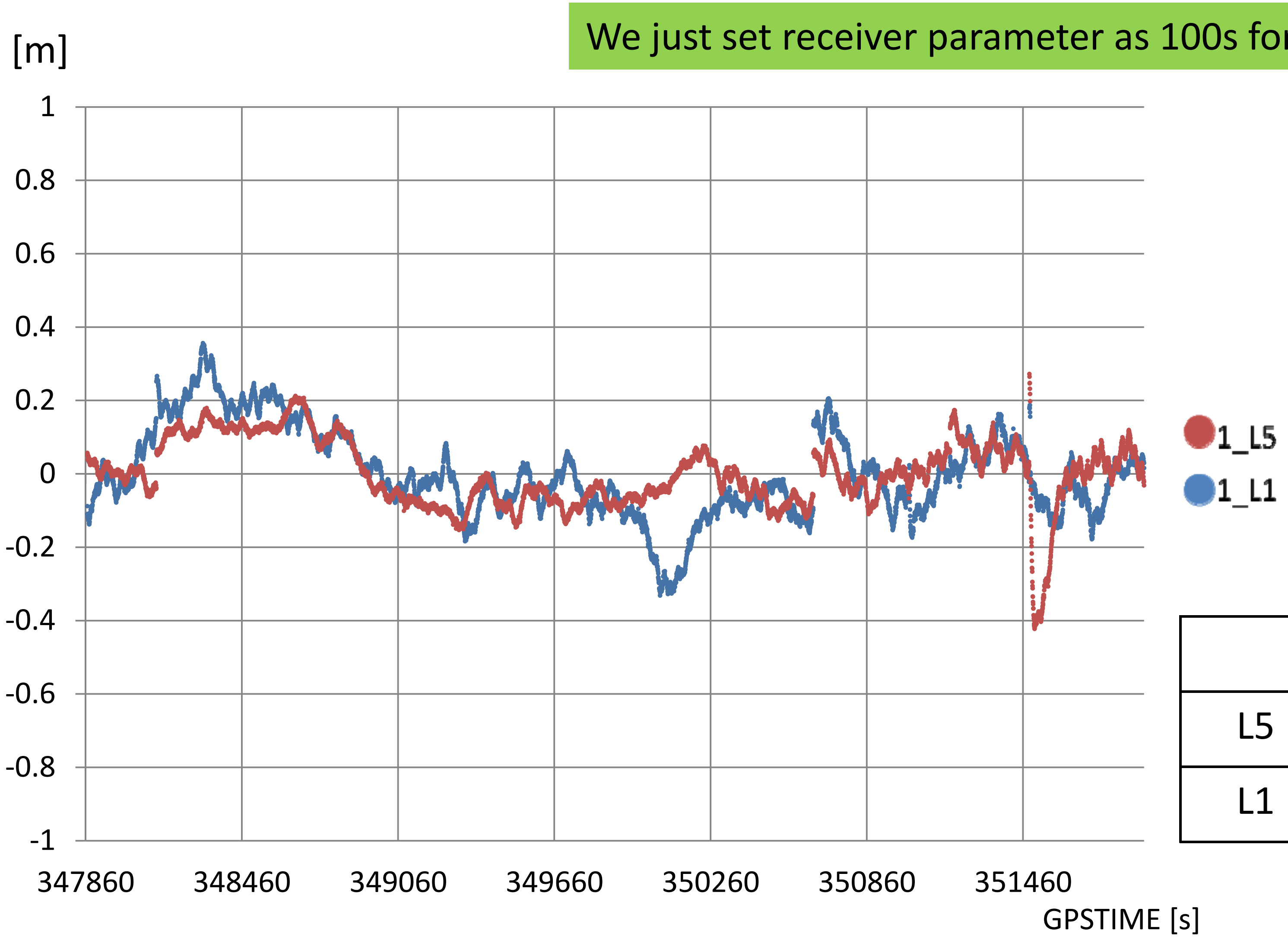
Static Test 1 Multipath Errors (no smoothing)



	σ [m]
L5	0.37
L1	0.52

Static Test 1 Multipath Errors (100s smoothing)

We just set receiver parameter as 100s for smoothing



	σ [m]
L5	0.09
L1	0.12

Static Test 2 (*campas,Tokyo*)

12/14/ 2012
(GPSTIME) 0:30~

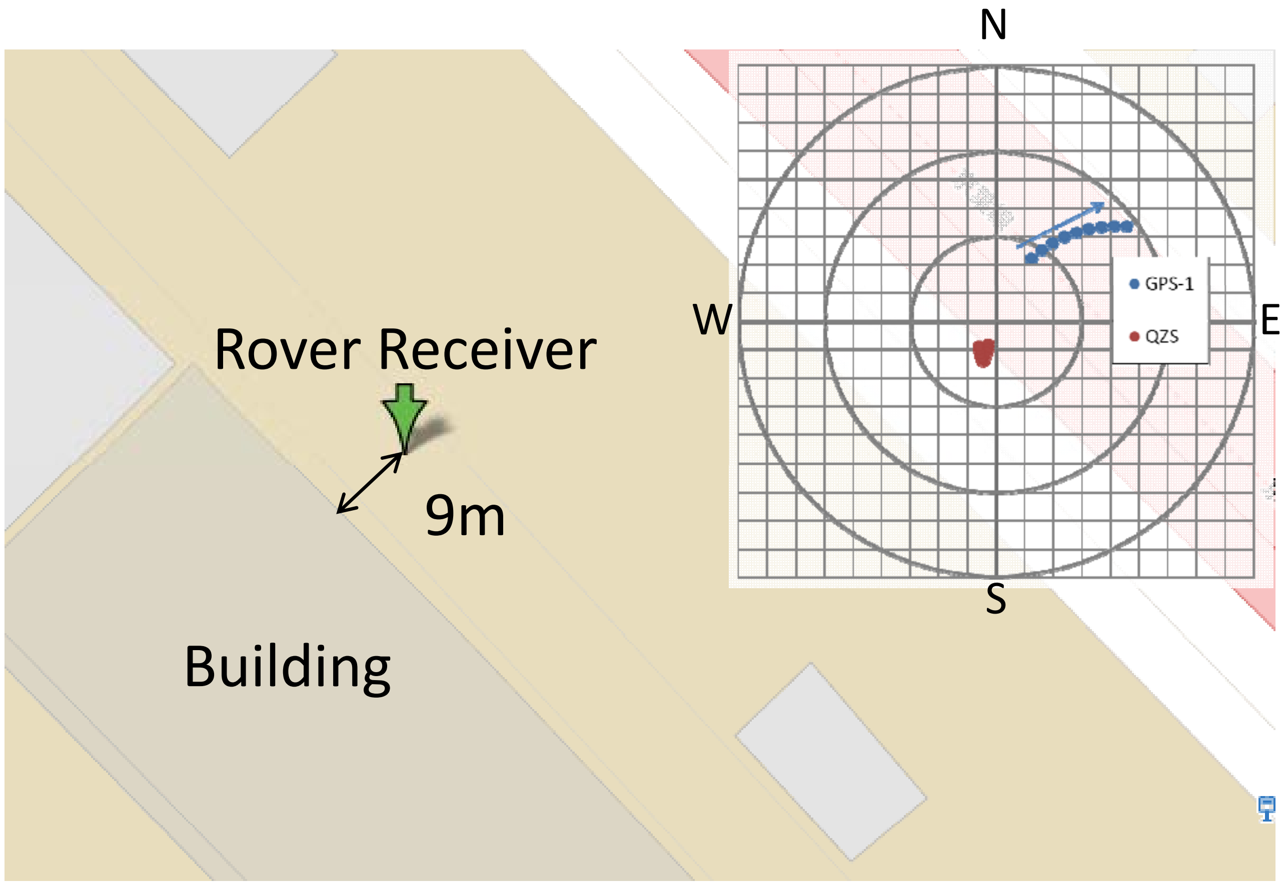
Geodetic Receiver

60 min 2 Hz

5-9 satellites in view
over 15 degrees
elevation

Target SV
: GPS-PRN-1 (L1,L5)
Reference SV
: QZS-1 (L1,L5)

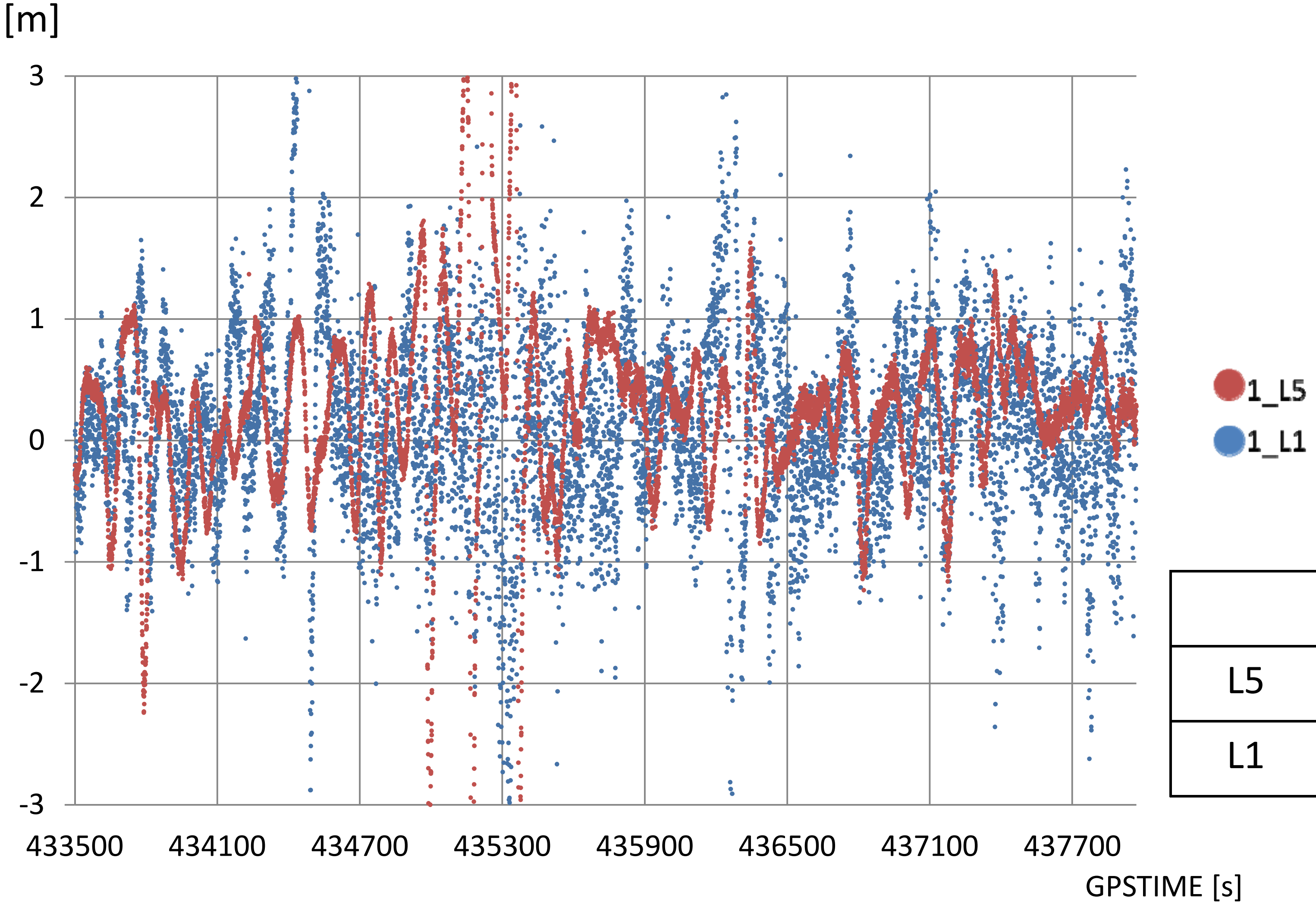
Precise position was
computed by
post processing



Short delay multipath

using proposed method
to extraction the PRN-1 multipath

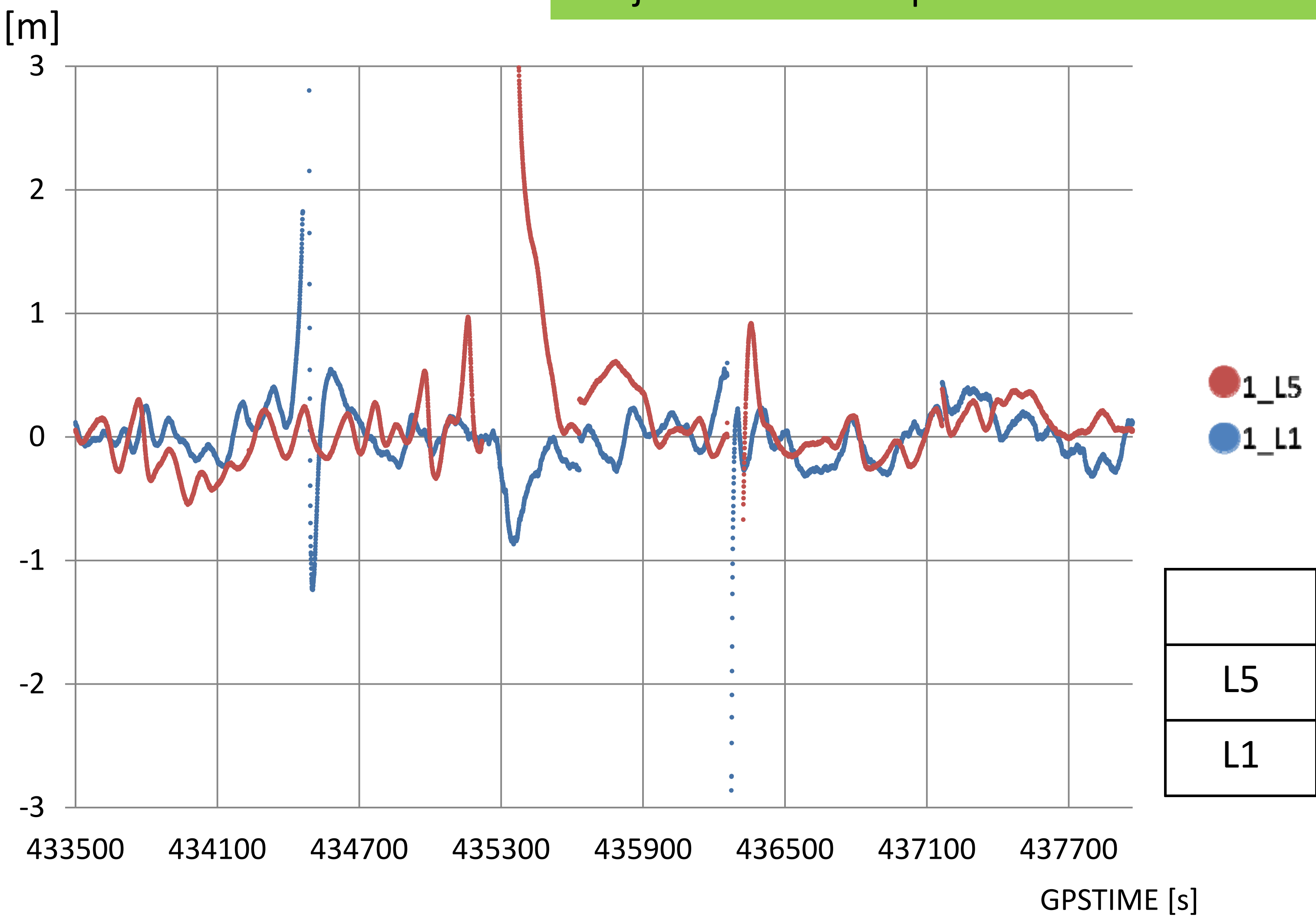
Static Test 2 Multipath Errors (no smoothing)



	σ [m]
L5	1.40
L1	1.74

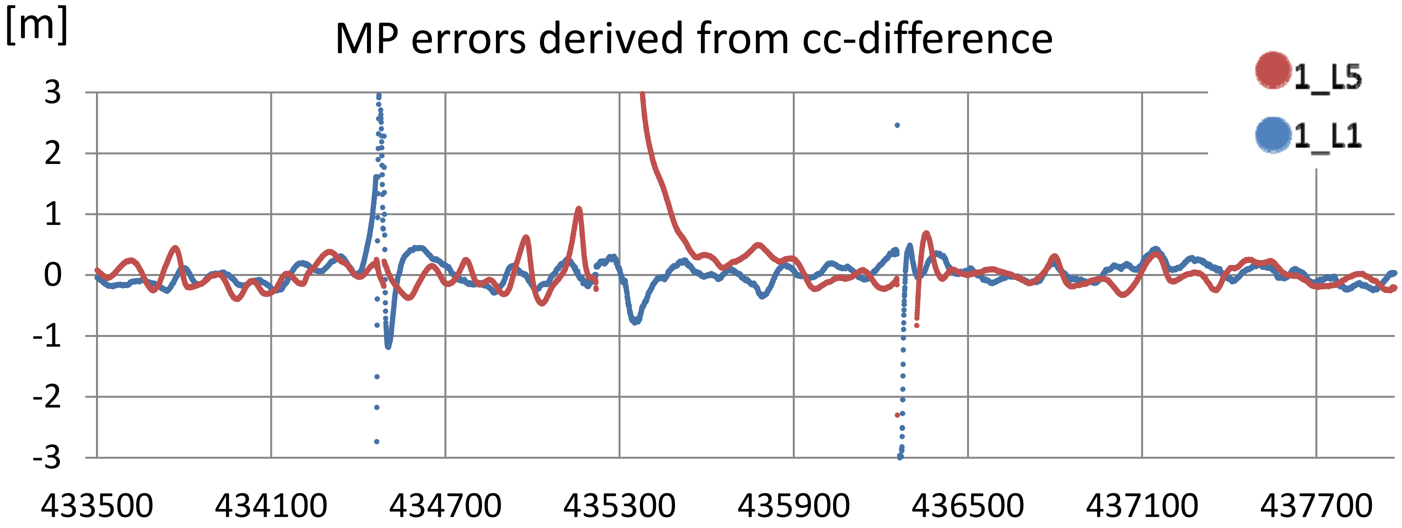
Static Test 2 Multipath Errors (100s smoothing)

We just set receiver parameter as 100s for smoothing



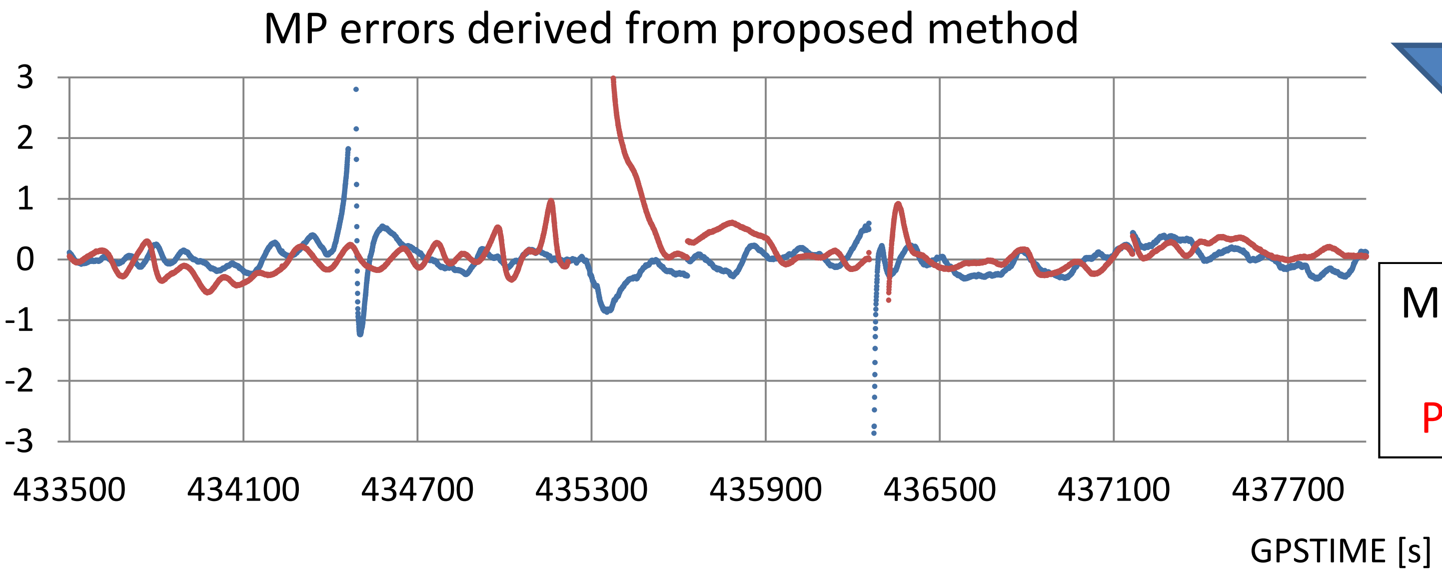
	σ [m]
L5	1.69
L1	1.56

Validation of Our Proposed Method


MP errors derived from cc-difference

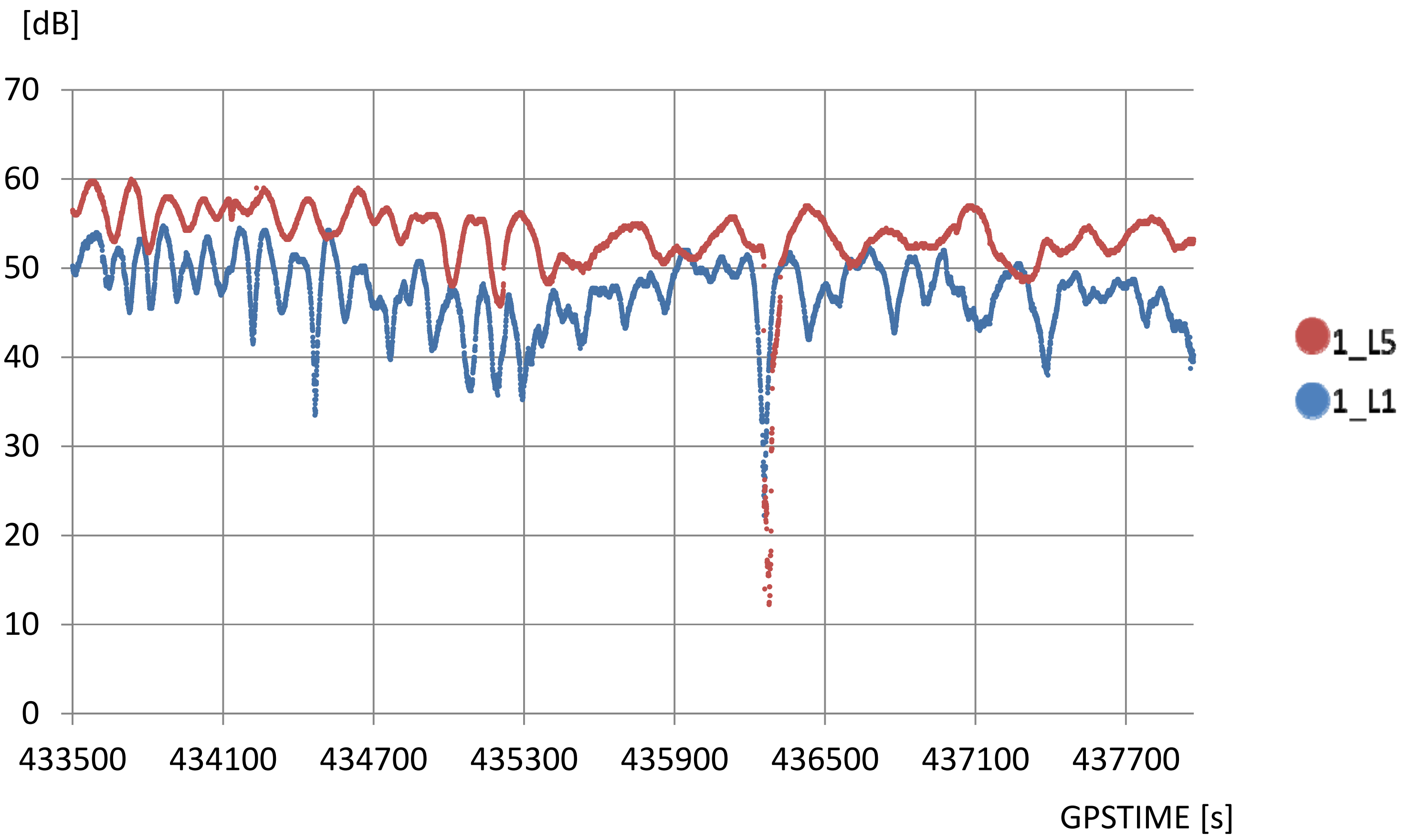
Multipath for PRN-1
derived from
cc-difference

match


MP errors derived from proposed method

Multipath for PRN-1
derived from
Proposed Method

Temporal Carrier to Noise Ratio

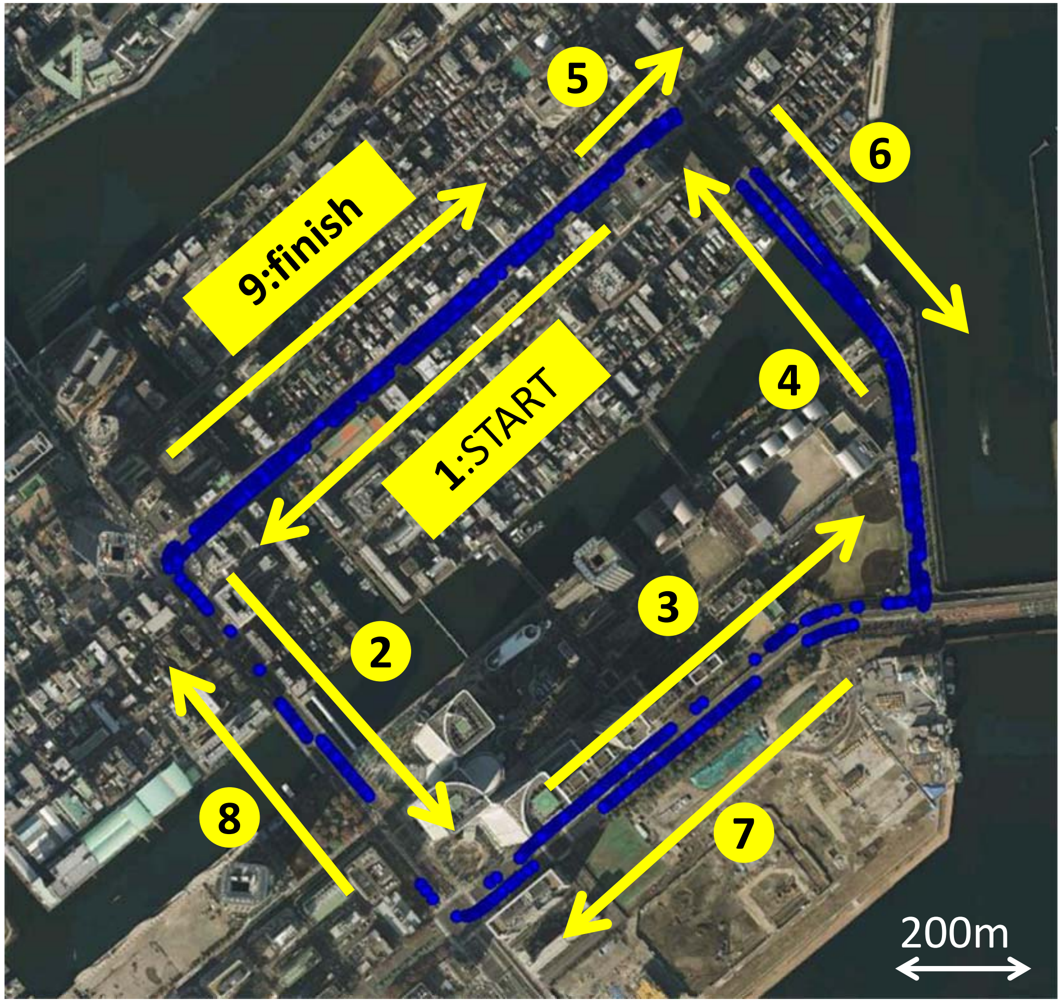


•Another type of geodetic receiver shows almost same difference level (4-5dB) between L1 and L5 although the maximum level was different.

Kinematic Test 1 (*tukishima, Tokyo*)

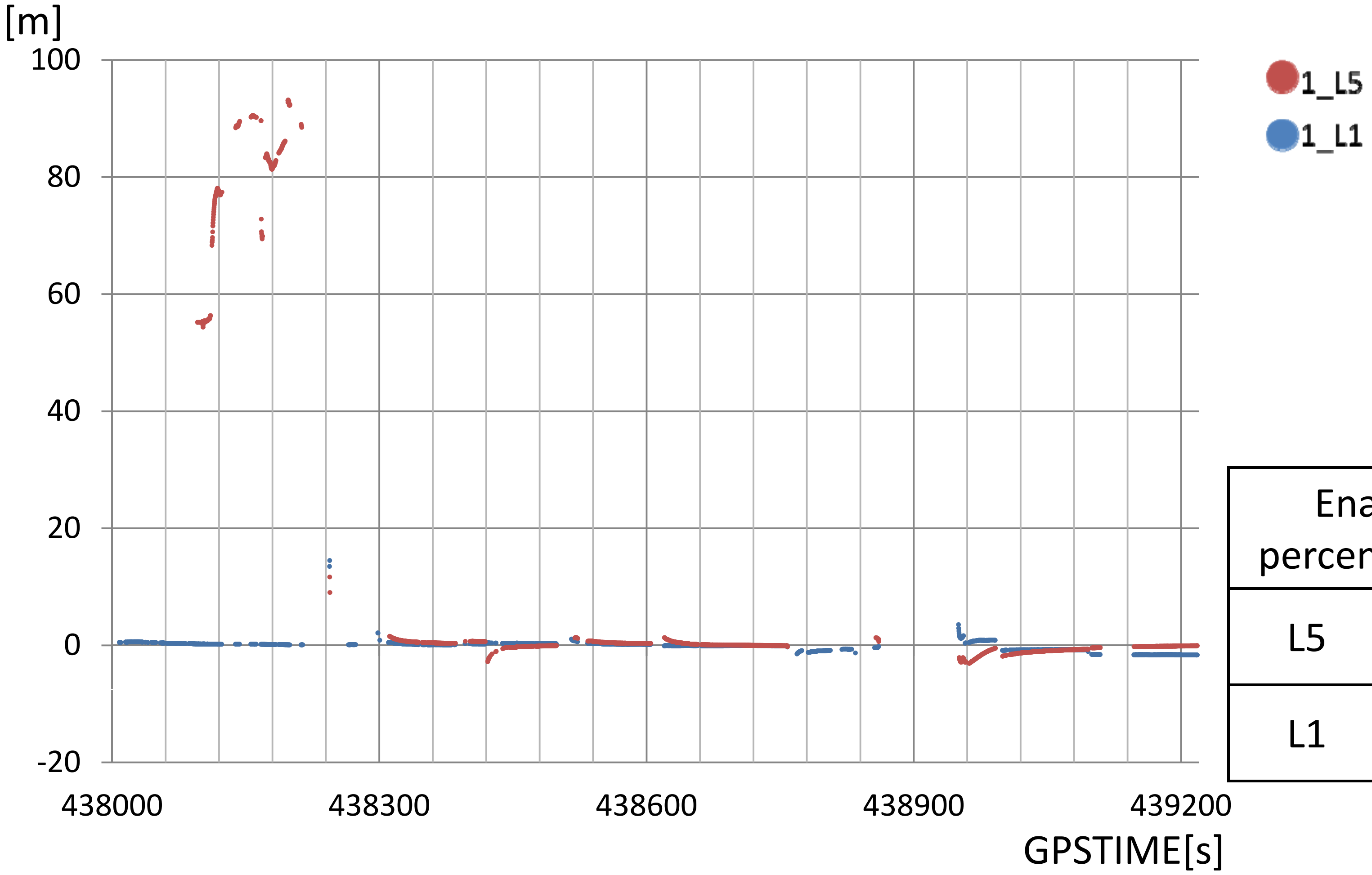
11/23/ 2012
Geodetic Receiver
20 min 5 Hz
4-8 satellites in view over 15 degrees elevation
Target SV : GPS-PRN-1 (L1,L5) Reference SV : QZS-1 (L1,L5)
Precise position was computed by post processing
100s smoothing

Fix rate[%]	
RTK	74.0



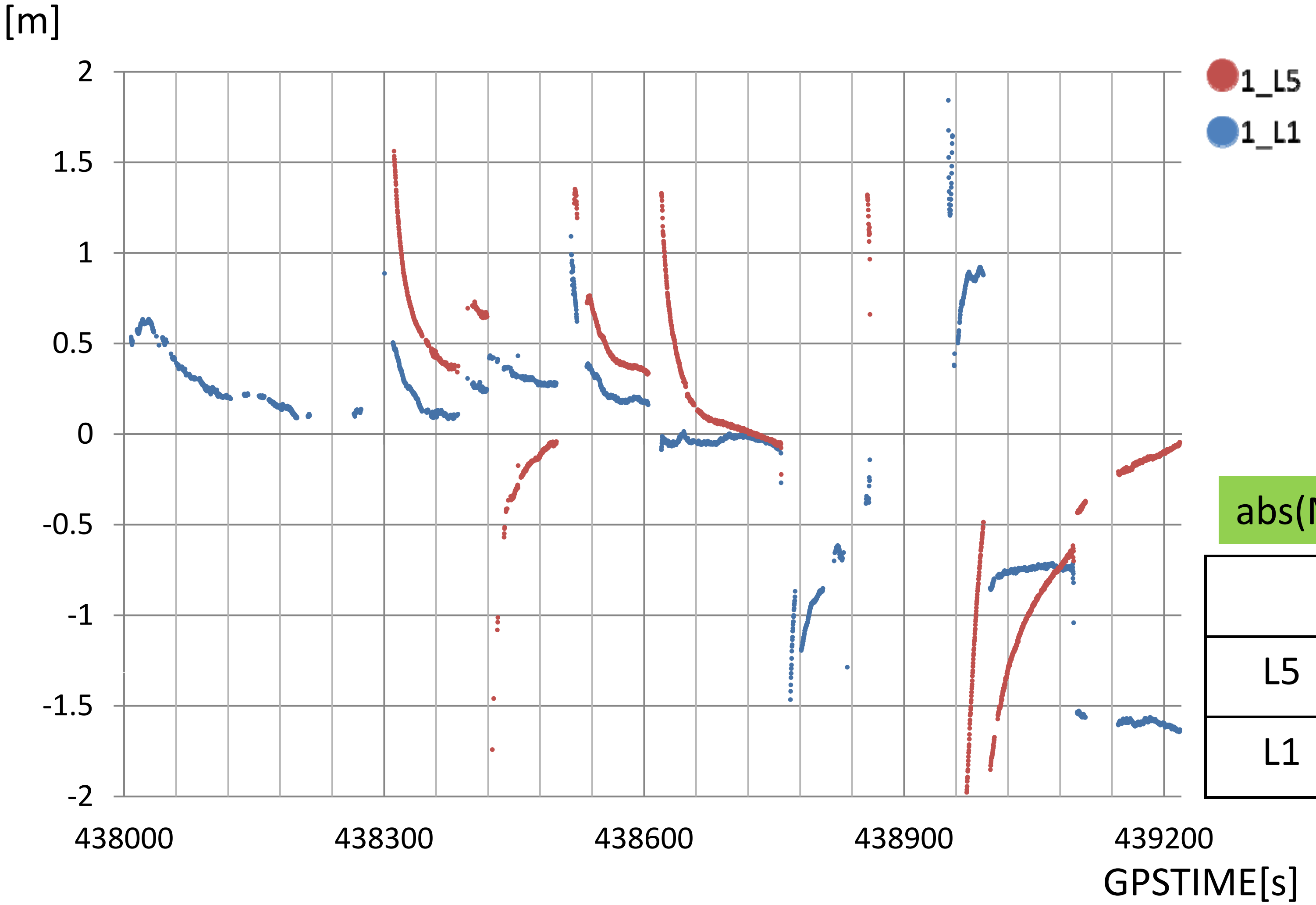
(Post-Processed RTK Plots)

Kinematic Test 1   Multipath Errors



Enabled percentage[%]	
L5	49.6
L1	59.3

Kinematic Test 1 Multipath Errors



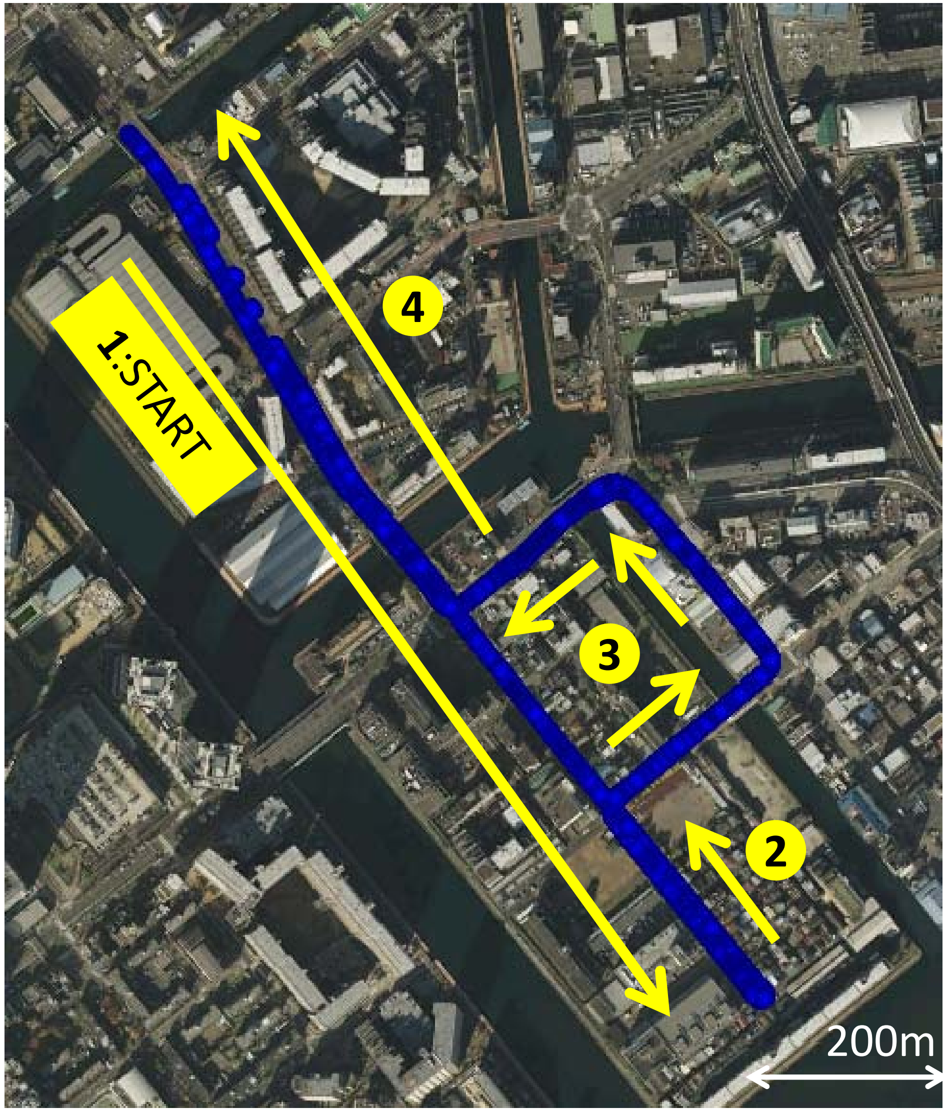
abs(MP) < 25m

	σ [m]
L5	0.82
L1	0.77

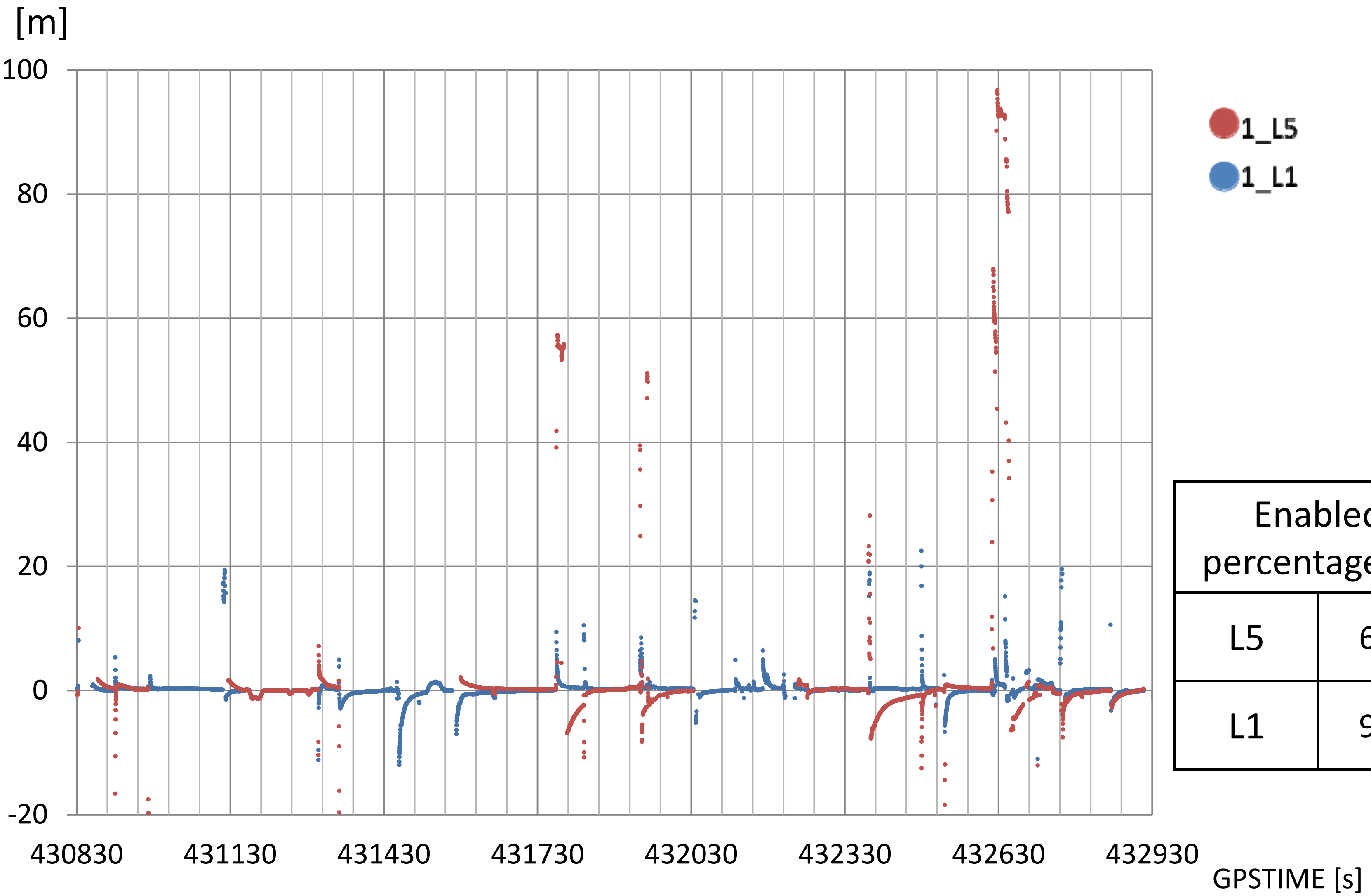
Kinematic Test 2 (*edagawa, Tokyo*)

12/27/2012
Geodetic Receiver
35min 5 Hz
4-9 satellites in view over 15 degrees elevation
Target SV : GPS-PRN-1 (L1,L5) Reference SV : QZS-1 (L1,L5)
Precise position was computed by post processing
100s smoothing

Fix rate[%]	
RTK	94.1

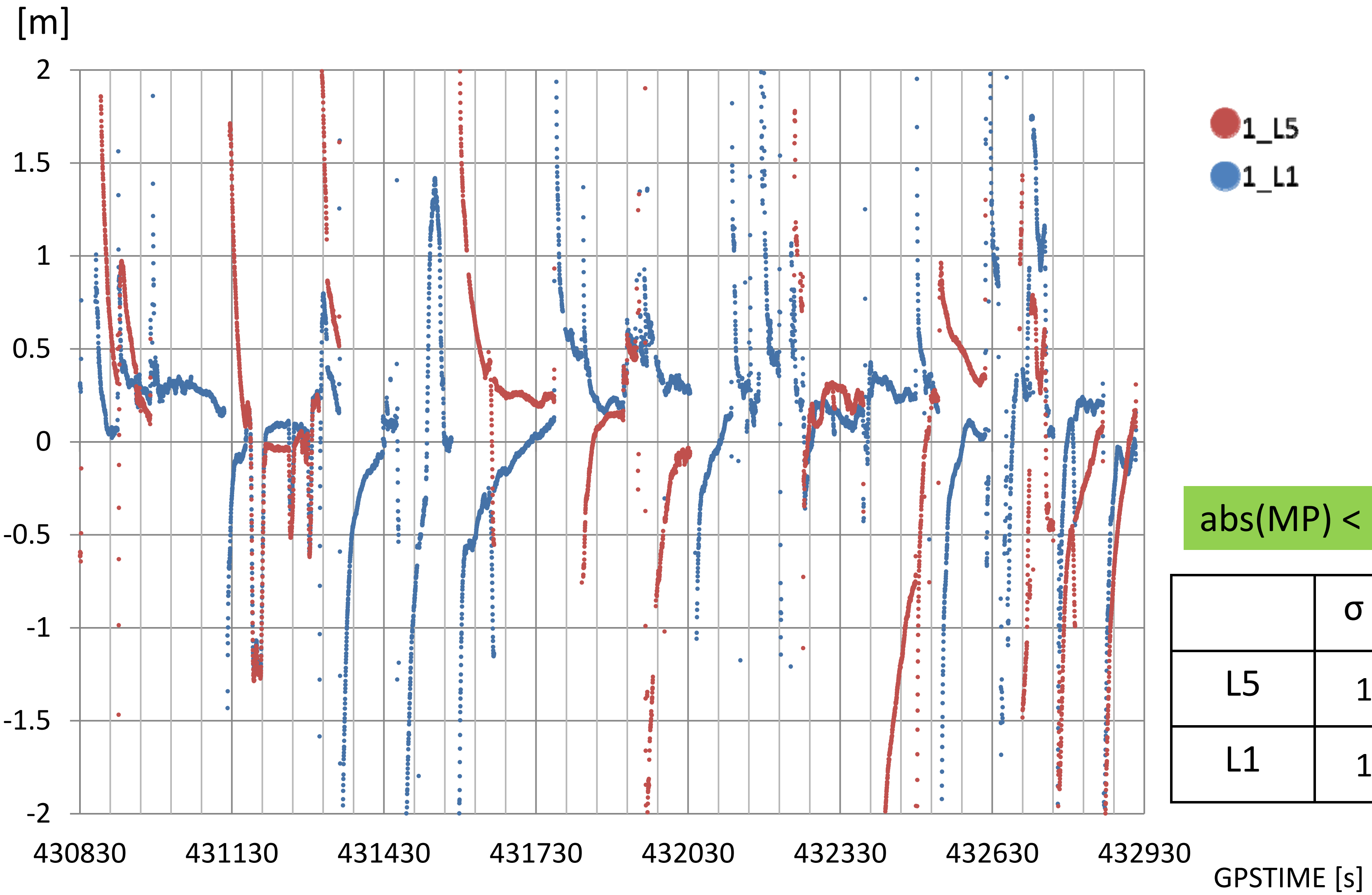


Kinematic Test 2　Multipath Errors



Enabled percentage[%]	
L5	64.9
L1	91.5

Kinematic Test 2　Multipath Errors



abs(MP) < 25m

	σ [m]
L5	1.93
L1	1.55

Conclusion

- Pseudo-range observables from L5 are basically robust against multipath.
- We were able to estimate multipath errors for moving targets by using the proposed method.
- The multipath mitigation performance between L1 and L5 was not so different at present.
- Using L5 instead of L1 will be practical in the future without special correlator.

Future work

- Further investigation for L5 signal is required because manufactures are still developing the tracking technique for new L5 signal.
- Software defined GNSS receiver can be used to evaluate it.

Thank you very much

for your kind attention!