The study of fast re-tracking using theoretical Doppler frequency on GNSS

Shungo SHINOHARA*
Nobuaki KUBO
Tokyo University of
Marine Science and Technology

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1. **Motivation**
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CSAC (chip scale atomic clock)

2004 : scientists demonstrated

2011 : became commercially available

✓ **Low Cost**

✓ **Low power consumption**

✓ **Small size and volume**

✗ **Accuracy is inferior to that of rubidium clock**

It is suitable for GNSS receivers on vehicles.

Objectives

Old

Use the CSAC with an SDR (software defined receiver)
and focus on determining the robustness of the carrier phase,
while attempting to realize fast re-tracking.

↓

<u>But, the effect is slight.</u>

- Also written that in the "GPS World" article* that shows the result by using NSL front end and CSAC.
- However, there are other advantages of using CSAC with receiver or front end. (for example, three satellite positioning)

* "Innovation : Reducing the Jitter"
http://gpsworld.com/innovation-reducing-the-jitters/

New

Use the CSAC with commercial receivers
on the car and run around semi-urban areas.

Try to **check the quality of Doppler Frequency**
and **detect the wrong fix on RTK positioning.**

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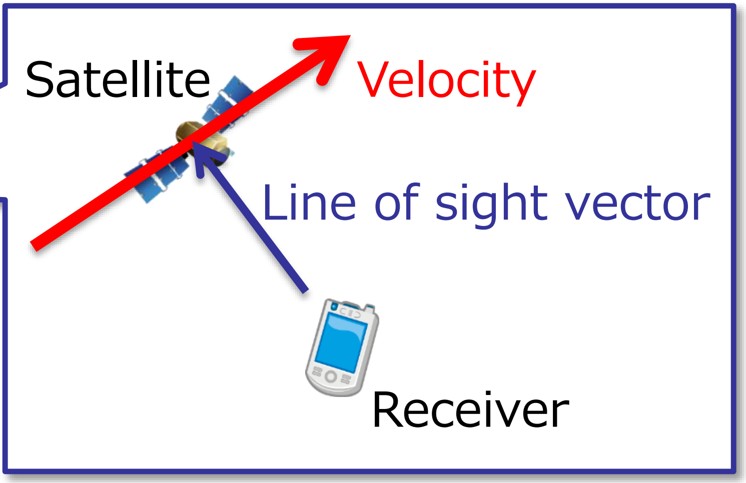
Observation & Theoretical Doppler Frequency

Observation Doppler

$$D_{obs} = D_{dynamics} + D_{sv} + D_{off} + noise$$

Theoretical Doppler

$$D_{th} = D_{dynamics} + D_{sv}$$



Where:

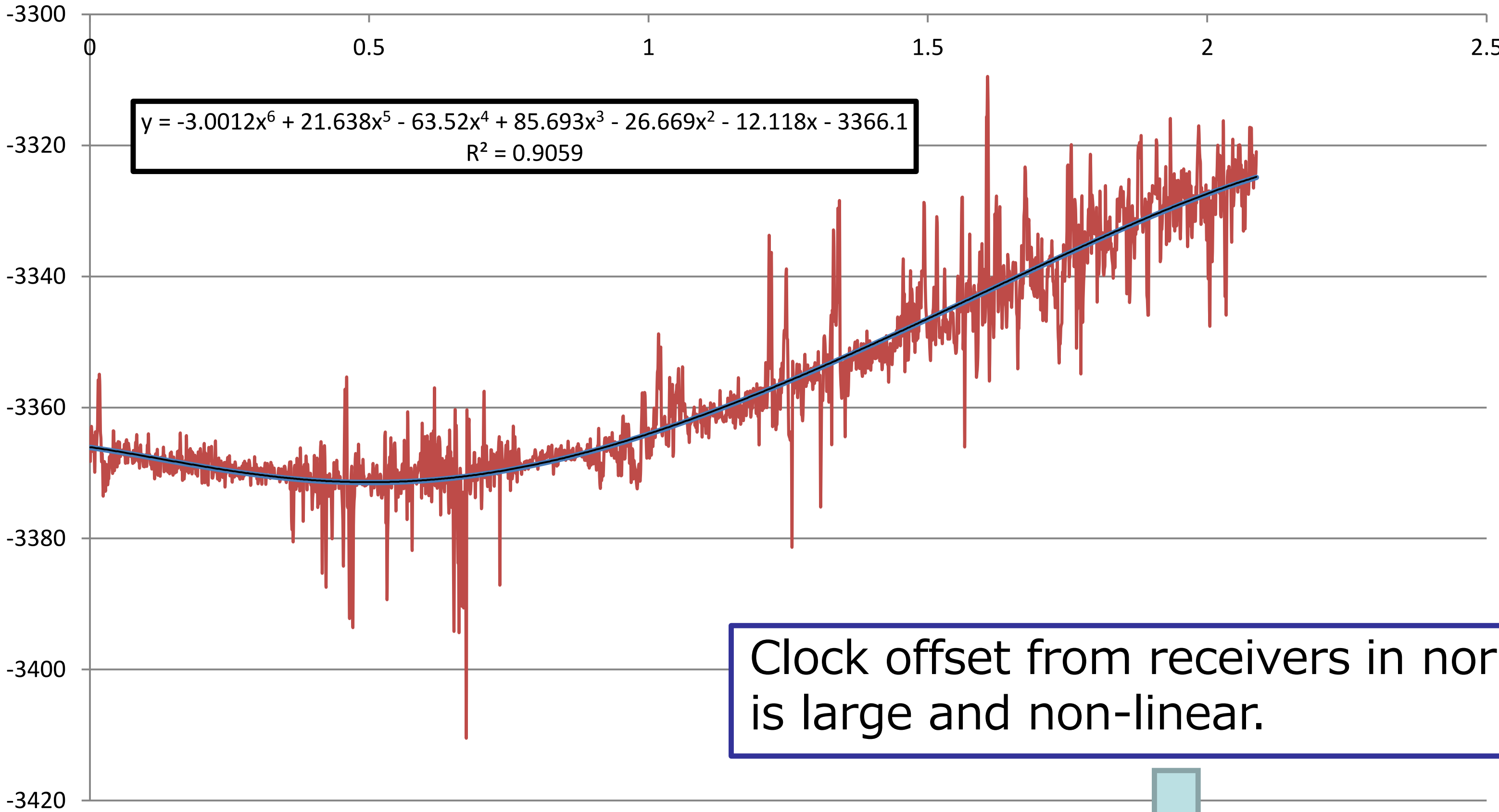
- $D_{dynamics}$: Doppler Frequency by dynamics [Hz]
- D_{sv} : Doppler Frequency by satellites [Hz]
- D_{off} : Clock offsets [Hz] (calculated from speed calculation)

If the very accurate clock such as CSAC is used, clock offset could be almost zero.

→ D_{off} is canceled.

observation Doppler and theoretical Doppler should be the same value.

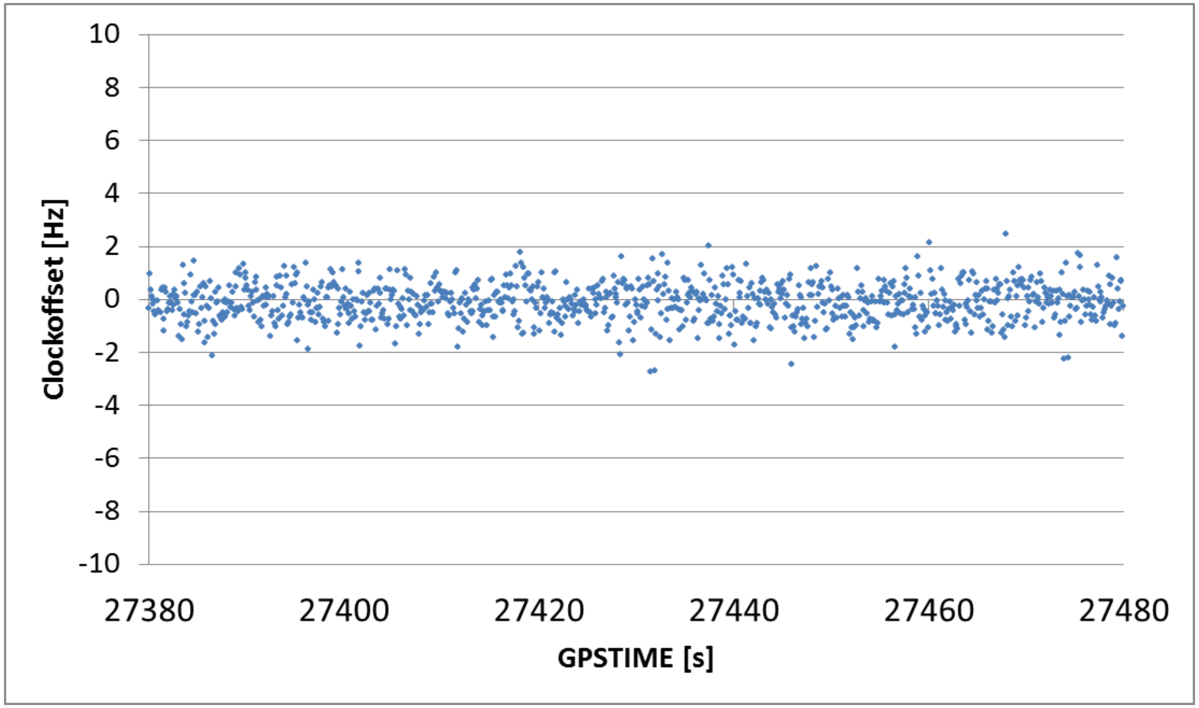
Estimate clock offset



Clock offset from receivers in normal is large and non-linear.

Estimating theoretical Doppler is troublesome.

clock offset when CSAC is used



- 100 seconds data
- static and open sky

Standard Deviation : 0.69 [Hz]

The clock offset is small and almost within a few Hz.

It could be said that clock offset can be assumed to be zero.

Become easy to compare between observation and theoretical Doppler.

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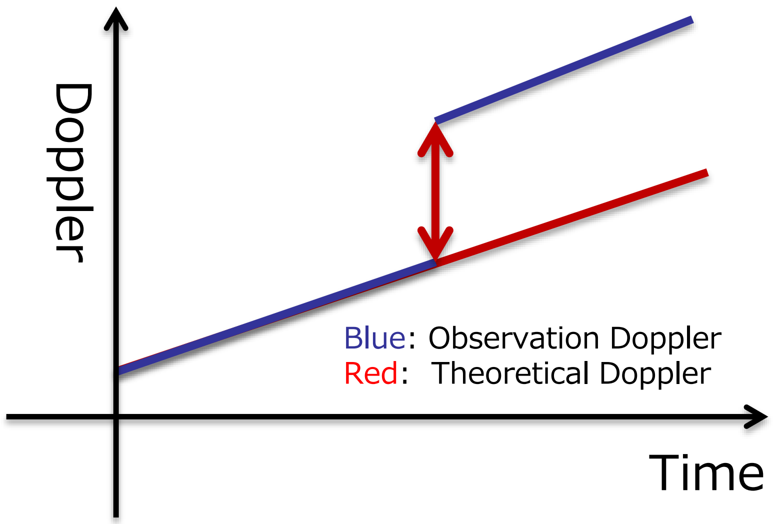
Proposed method

If the Doppler is bad, the carrier phase is also bad.
It means, wrong fix is likely to occur when the Doppler is bad.

If a wrong fix has occurred, there should be a **difference** between observation Doppler and theoretical Doppler.

If the difference is larger than the threshold*, the satellite is rejected from positioning calculation.



* Value is depending on accuracy of theoretical Doppler

Points of the proposed method

- Usually, RTK solutions which is included only over 3 in ratio test, are reliable values. But unexpected solutions are still remained.
- The purpose of the proposed method is to remove the only such solutions, and don’t remove the solution of the others.
- Clock offset is substantially zero by using CSAC, performing proposed method can be easily. (Especially in Real-time processing.)

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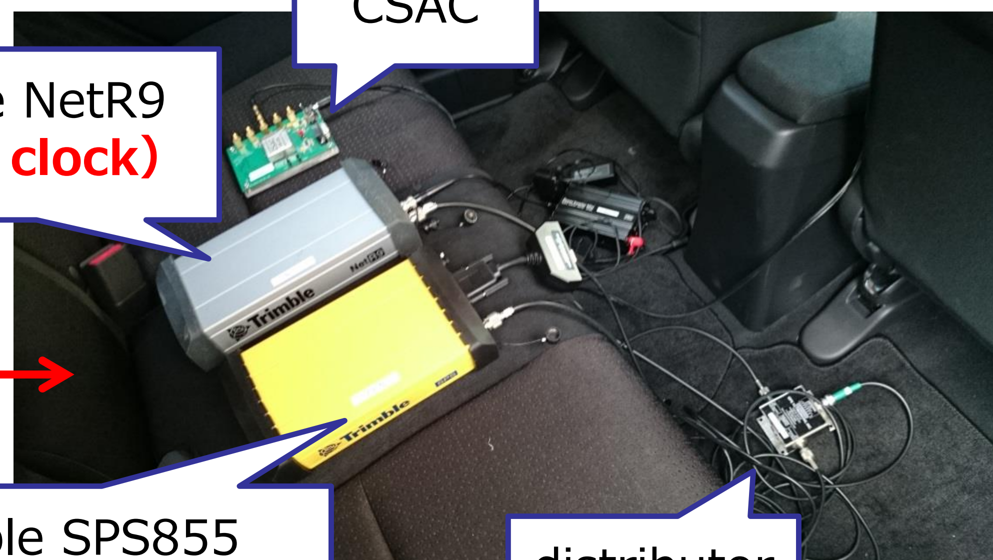
Test

The car was running
in the semi-urban areas.

Antenna

CSAC

Trimble NetR9
(CSAC clock)



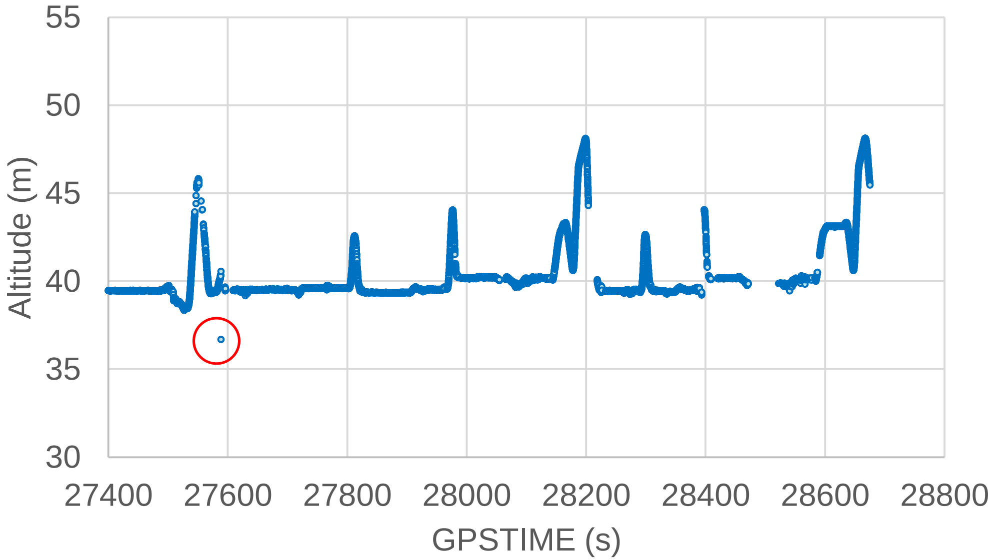
Trimble SPS855
(internal clock)

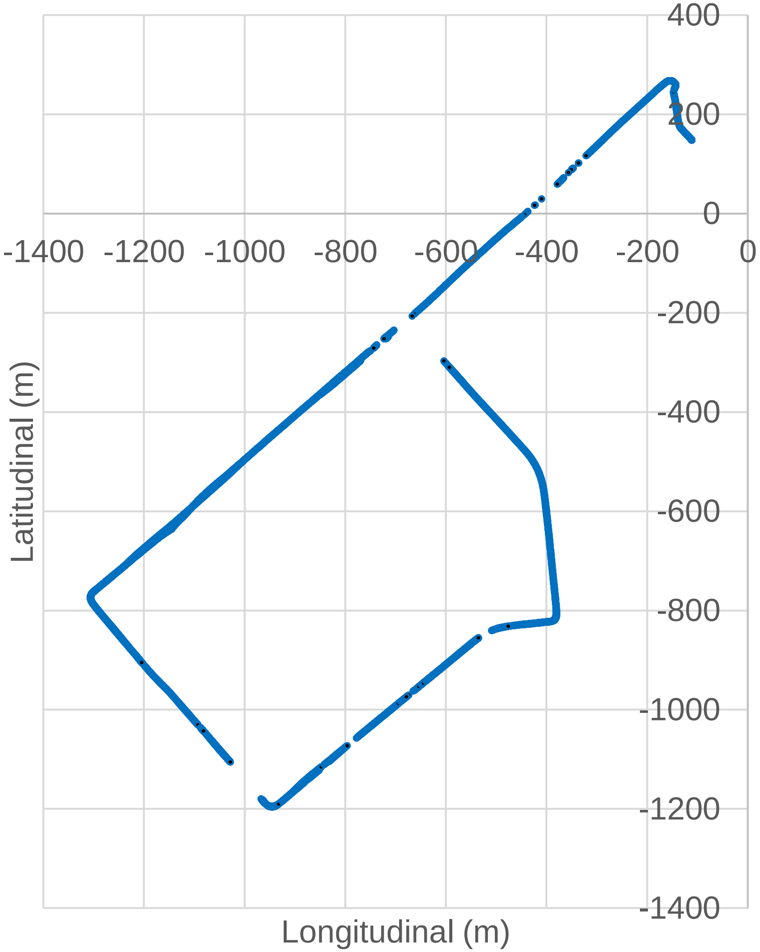
distributor

Environment of the route

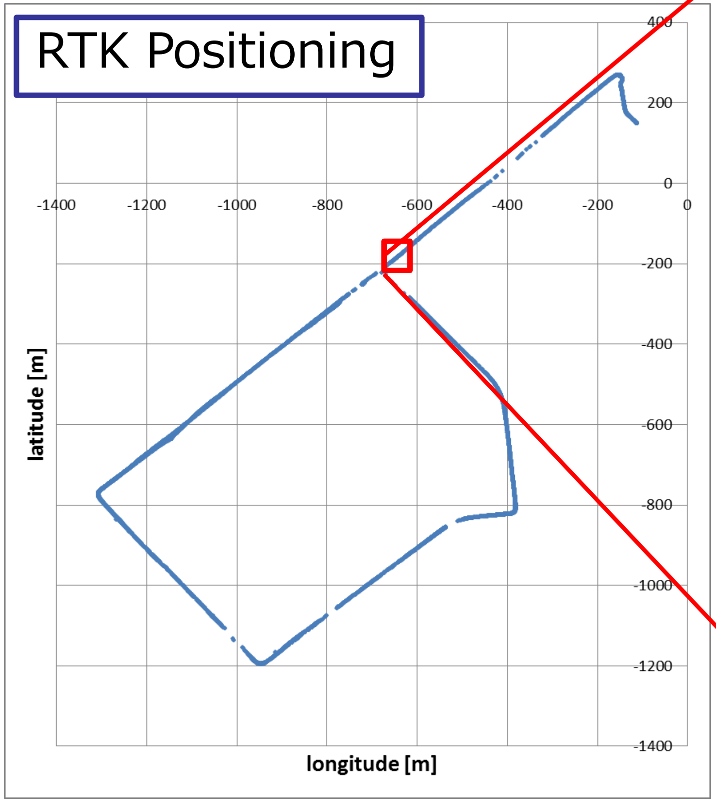
RTK Positioning Result under Semi-urban Areas

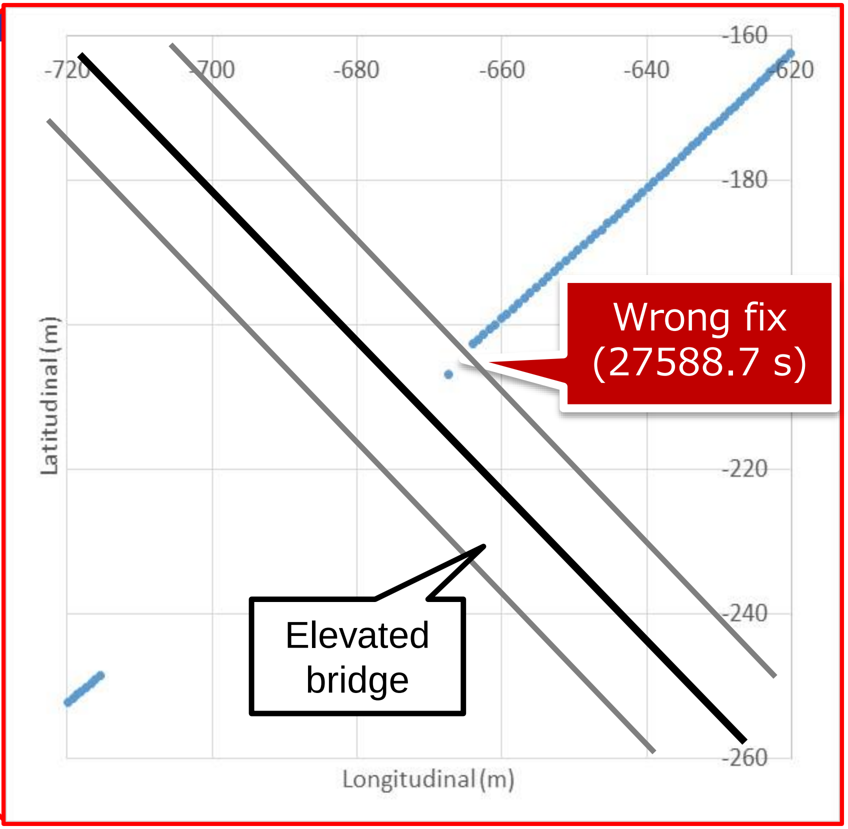
Date : Oct. 5, 2014
About 23 min. (10 Hz)
LAMBDA + ratio test>3
Fix Rate : 84.8%
Multi-GNSS :GPS/QZS/GLO/BEI





Large errors due to wrong integer ambiguities





Of all fixed epochs,
only one large wrong fix was found.

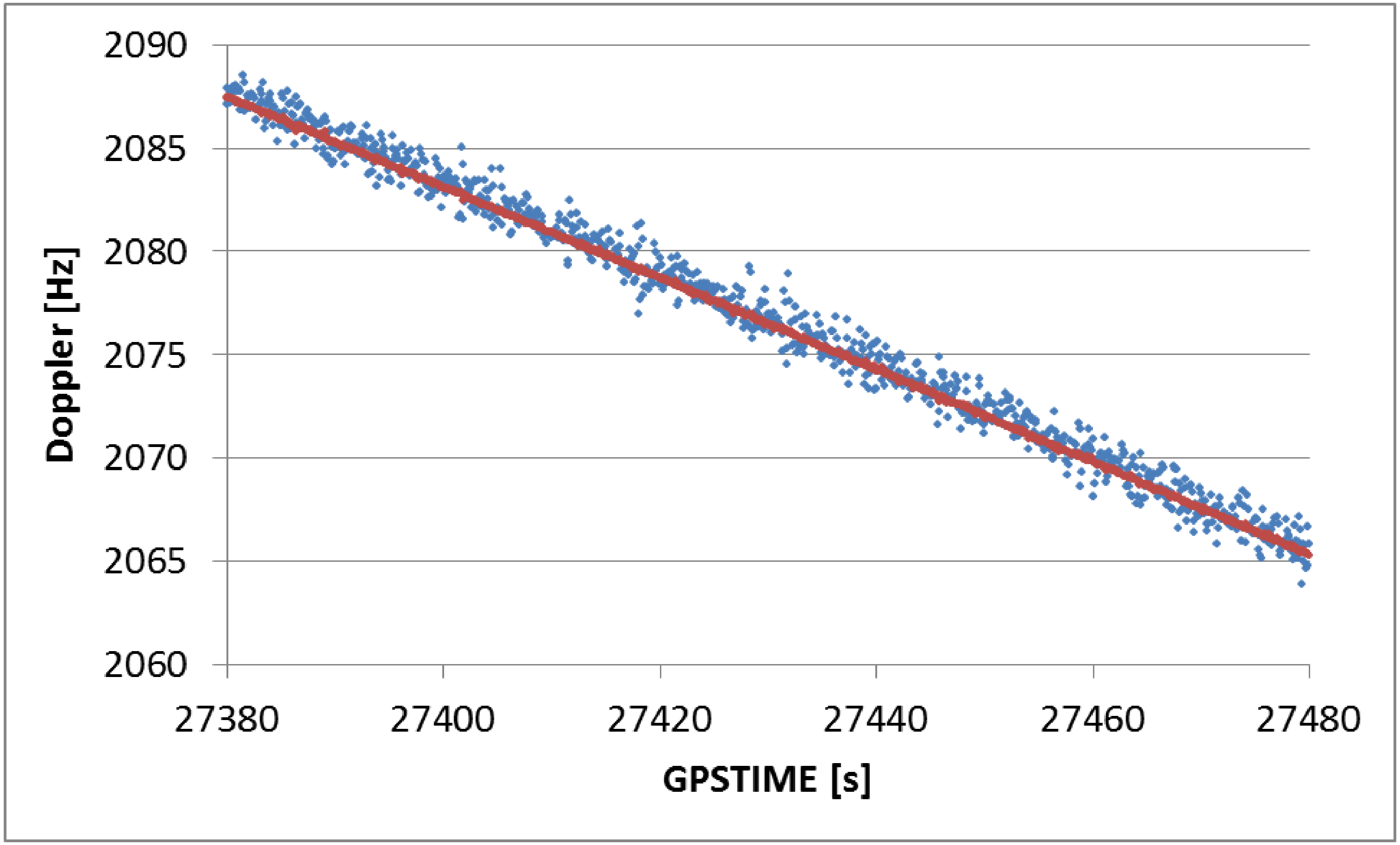
time series of ratio & satellites

GPSTIME	Ratio	number of satellites	satellites that are used for RTK positionig													
27586	14.04	13	73	78	2	5	6	9	10	13	23	33	101	108	124	
27586.1	19.07	13	73	78	2	5	6	9	10	13	23	33	101	108	124	
27586.2	15.27	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.3	5.85	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.4	16.88	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.5	14.85	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.6	28.43	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.7	17.08	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.8	16.16	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27586.9	34.28	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27587	9.69	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27587.1	26.50	14	73	78	81	2	5	6	9	10	13	23	33	101	108	124
27587.2	4.84	13	78	81	2	5	6	9	10	13	23	33	101	108	124	
27587.3	10.35	13	78	81	2	5	6	9	10	13	23	33	101	108	124	
27587.4	17.97	13	78	81	2	5	6	9	10	13	23	33	101	108	124	
27587.5	22.64	13	78	81	2	5	6	9	10	13	23	33	101	108	124	
27587.6	29.70	12	78	81	2	6	9	10	13	23	33	101	108	124		
27587.7	18.68	12	78	81	2	6	9	10	13	23	33	101	108	124		
27587.8	8.09	12	78	81	2	6	9	10	13	23	33	101	108	124		
27587.9	9.09	12	78	81	2	6	9	10	13	23	33	101	108	124		
27588	39.72	7	2	6	9	10	13	23	33							
27588.1	21.90	7	2	6	9	10	13	23	33							
27588.2	19.01	7	2	6	9	10	13	23	33							
27588.3	16.63	7	2	6	9	10	13	23	33							
27588.4	3.64	7	2	6	9	10	13	23	33							
27588.5	2.16	7	2	6	9	10	13	23	33							
27588.6	2.02	5	6	9	10	13	23									
27588.7	4.65	5	6	9	10	13	23									

Wrong fix

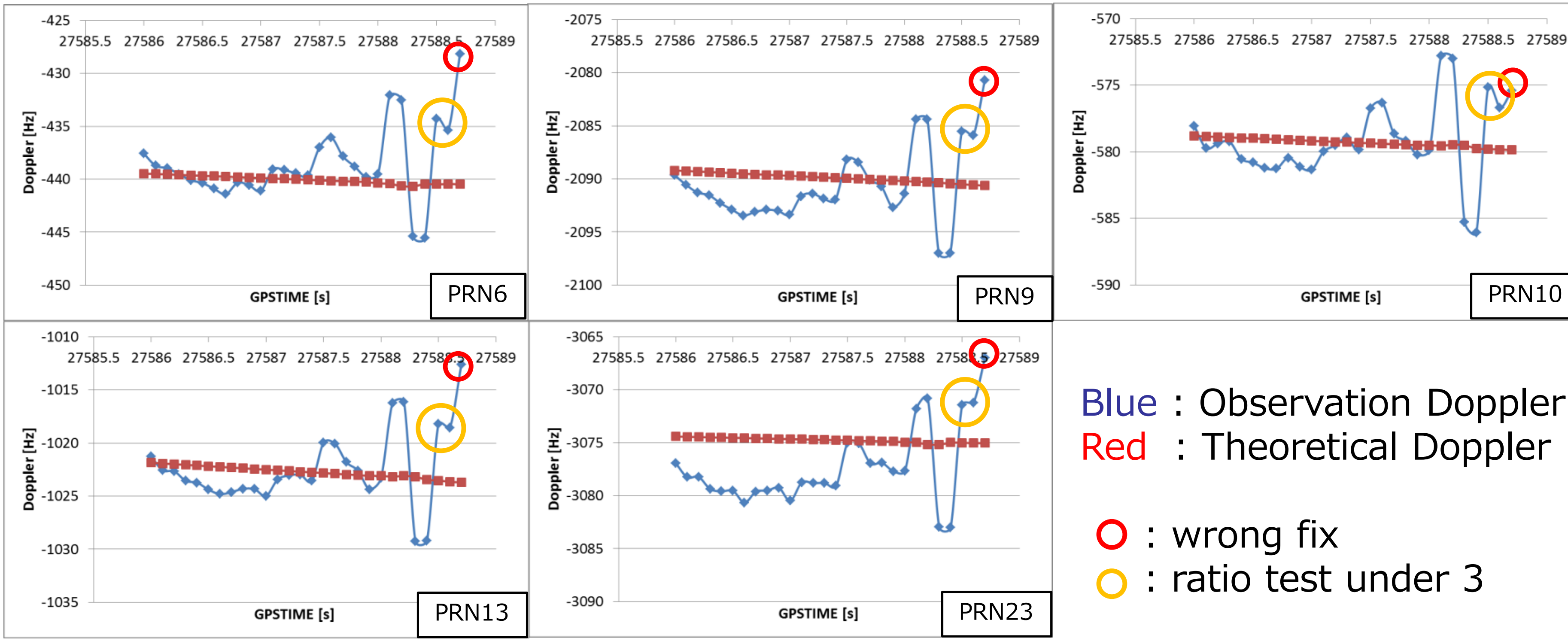
Ratio are under 3
(rejected from the solutions)

Compare the two Doppler in static



Blue : Observation Doppler
Red : Theoretical Doppler

Compare the two Doppler

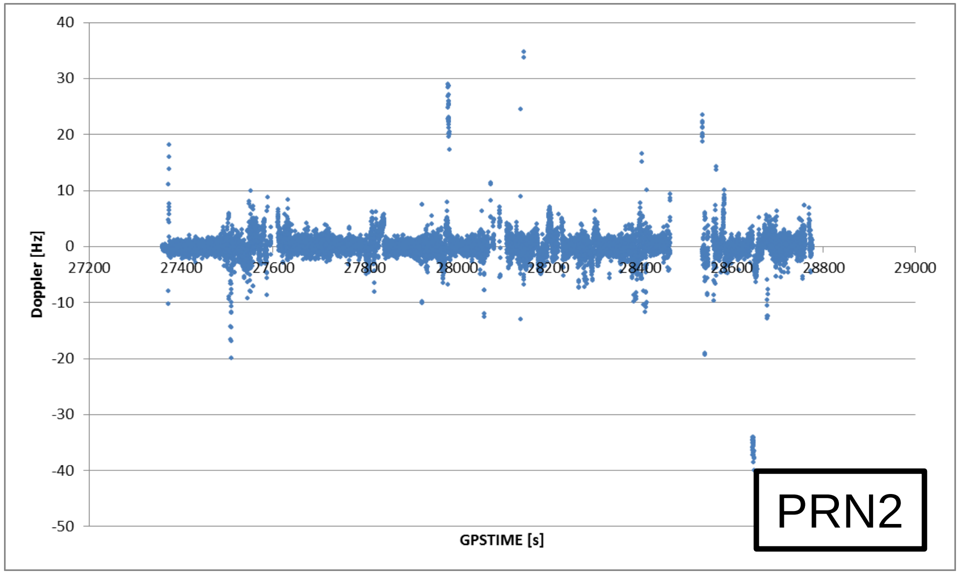


Blue : Observation Doppler
Red : Theoretical Doppler

○ : wrong fix
○ : ratio test under 3

When the wrong fix occur,
the differences of these Doppler is over 10 Hz.

Difference between the two Doppler



Date : Oct. 5, 2014
About 23 min. (10 Hz)

Standard Deviation : 2.89 [Hz]
Maximum : 34.8 [Hz]
Minimum : -39.9 [Hz]

Speed and direction data for calculating theoretical Doppler are **from GNSS**.

→

The accuracy of theoretical Doppler is not good and the noise is larger.

If speed pulse sensor and MEMS gyro are used for Doppler estimation, the theoretical Doppler is very accurate and the error about a few Hz.

A item that need to be checked

Proposed method

$$|D_{obs} - D_{th}| > threshold$$

→ Reject the satellite

It might be also remove good solutions.

The ratio is over 3 and There is no problem in the positioning

We want to avoid that.

Now checking about it.

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Conclusions

- If we use CSAC with the GNSS receivers,
  it is convenient to calculate theoretical Doppler frequency
  because clock offset of the receivers is canceled.
  (within a few Hz in normal)

- When wrong fix occur on RTK positioning,
  there are large differences between Observation Doppler
  and Theoretical Doppler and it can be possible to reject
  the satellites that have bad Doppler
  with the proposed method.

- In the test, there is only one wrong fix and
  fix fate should be fallen a few percent
  with the proposed method.

Future plans

- Conduct the same test using the high accuracy theoretical Doppler which is calculated by speed pulse sensor and gyro.
- Check more data whether there is not reducing the correct fix solutions with the proposed method.

Thank you
for your attention