Using pressure sensors for altitude aiding with a multi-constellation GNSS in urban environments

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Outline

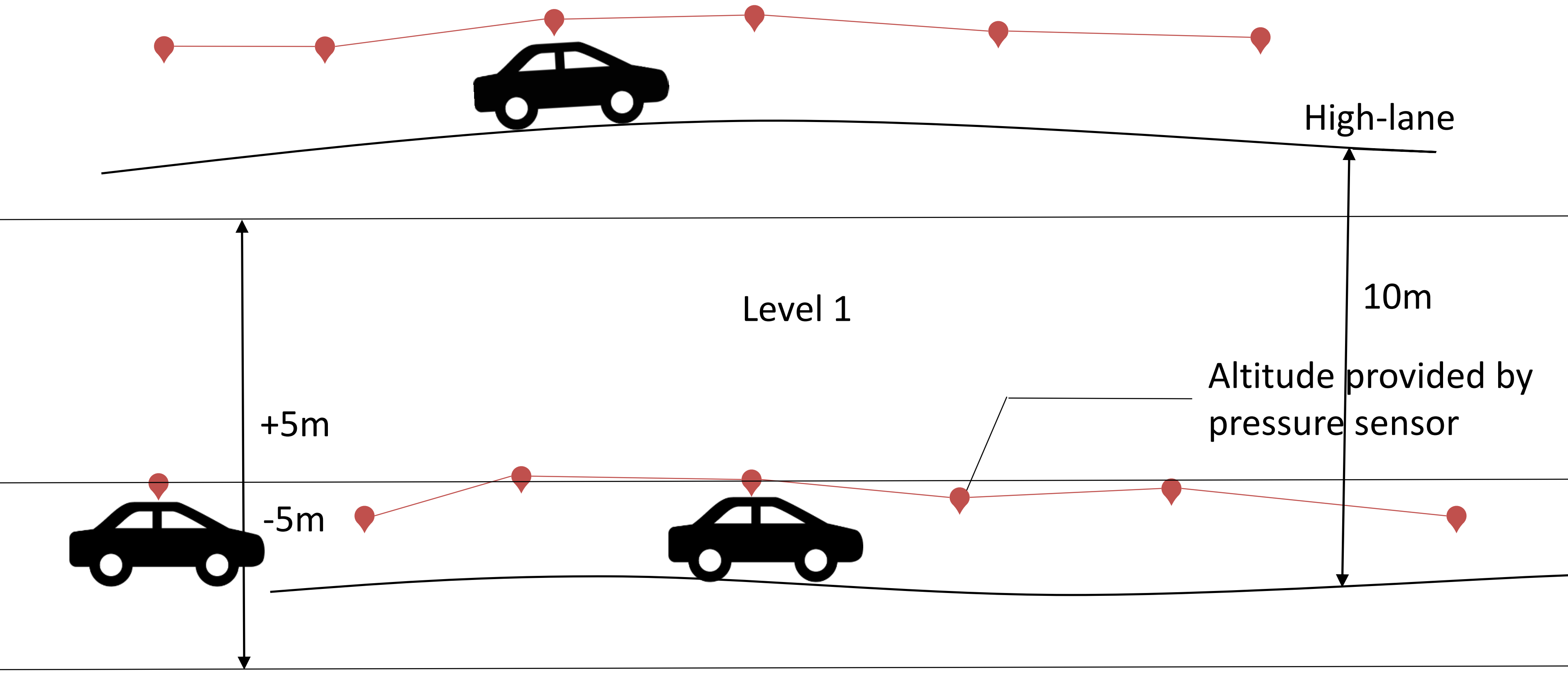
- Background and Objective
- Performance of barometric pressure sensor
- Altitude information provided by pressure sensor and calibration algorism
- Testing and Results
- Possibility of calibration using absolute altitude by single frequency RTK FIX solution
- Conclusions

Background

- Future ITS services will focus on technologies for vehicle autonomous navigation and assist for vehicles safety driving.
- Currently, many sensors can be integrated into vehicles as they become smaller and cheaper.
- Our target is avoid collisions by using barometric pressure sensors and consumer GNSS receiver to detect vehicles when they are on a complex multi-lane highway.

Objective

Accuracy requirement for Detecting high-lane



Altitude information precision demand is ±5m

Characteristics of altitude information by Sensor and GNSS receiver

Improving altitude information by Barometric pressure sensor + GNSS receiver

- Consumer GNSS receiver
  - ✓Can provide absolute 3D position
  - × Affected by obstructs
  - × Vertical accuracy is not reliable to compare horizontal accuracy

- Barometric pressure sensor
  - ✓Can provide altitude information continuously
  - ✓Vertical accuracy is stable
  - × Fluctuate with atmospheric conditions in vehicle
  - × Need calibration by weather information

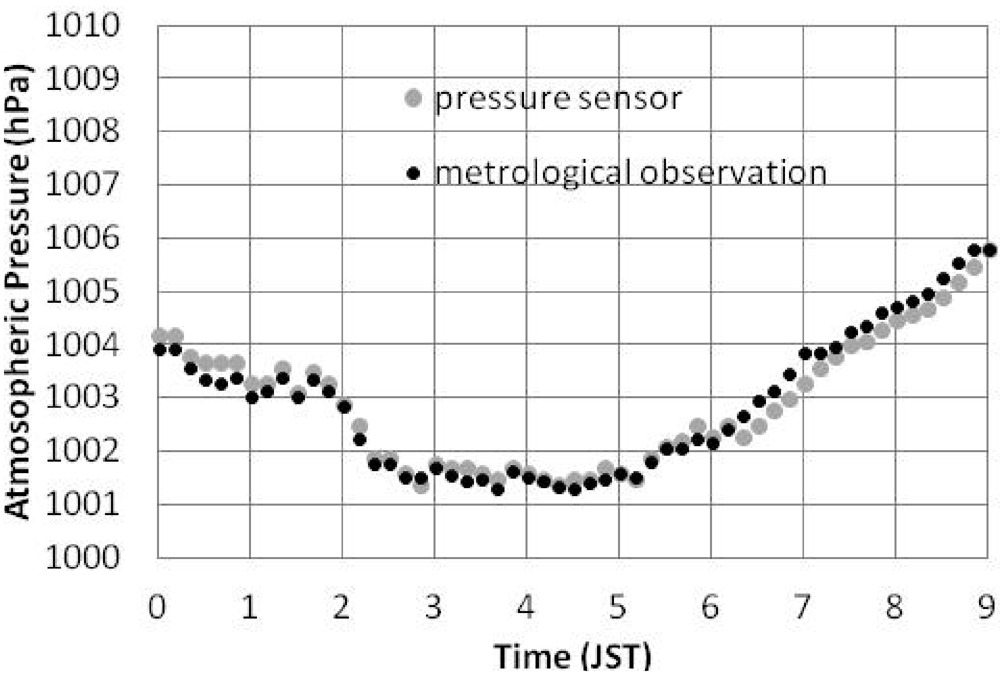
→ Evaluate altitude information by Barometric pressure sensor

Related Studies on Barometric Pressure sensor and GNSS

- Height Measurement Error of Barometric Altimeter and Its Correction (Sakai, T. et al., 2005)
  - Describe characteristics and collecting of both GNSS altimeter and barometric altimeter for aircraft. Estimate magnitude of error and correcting altitude by atmospheric observation.
- Barometric and GPS Altitude Sensor Fusion (Zaliva, V. et al., 2014)
  - Improves accuracy and provides tighter confidence bounds of altitude from a sensors. Optimizing estimated altitude by altimeter for the GNSS altitude.
- Barometric Height Estimation Combined with Map-Matching in a Loosely-Coupled Kalman-Filter(Bevermeire, M. et al., 2010)
  - Sensor fusion algorithm based on IMU, GNSS and pressure sensor for vehicle.
- Enhancing Altitude Accuracy in Automotive Navigation using MEMS Barometric Sensor with GPS (Lionel, J. et al., 2008)
  - Details of the pressure sensor calibration and altitude filtering techniques. Several techniques to ciliolate altitude for barometric pressures sensor.

Performance of Barometric pressure sensor at static conditions

Meteorological observations vs. Pressure sensor data (Static)



- ✓ Barometric pressure Sensor shows same tendency with metrological observation
- ✓ Atmospheric pressure changes effected have to be calibrated for altitude

Barometric pressure sensor	
Date	8/1/2014
Period / Interval	9Hours / 10minuits
Environments / Data provided	Static / Japan meteorological agency vs. Pressure sensor at build. Distance 4km
Conditions	Calibration at start time

Results	
1σ	0.24hPa
Convert for altitude	About 2m

Altitude provided by Barometric pressure sensor

- Transform to Altitude by Barometric pressure
- Altitude difference based calibration
  - ✓ Reference atmospheric barometric pressure provided by Japan meteorological agency by each 10 minuets
  - ✓ Reference absolute altitude source (RTK FIX solution)

$$ALT(0) - ALT(obs) = -8.3 \cdot ((P(0) - \Delta P(JMA)) - P(obs))$$

$ALT(0)$: Absolute altitude provided by RTK Fix solution

$P(0)$: Atmospheric pressure obsarvation at start time

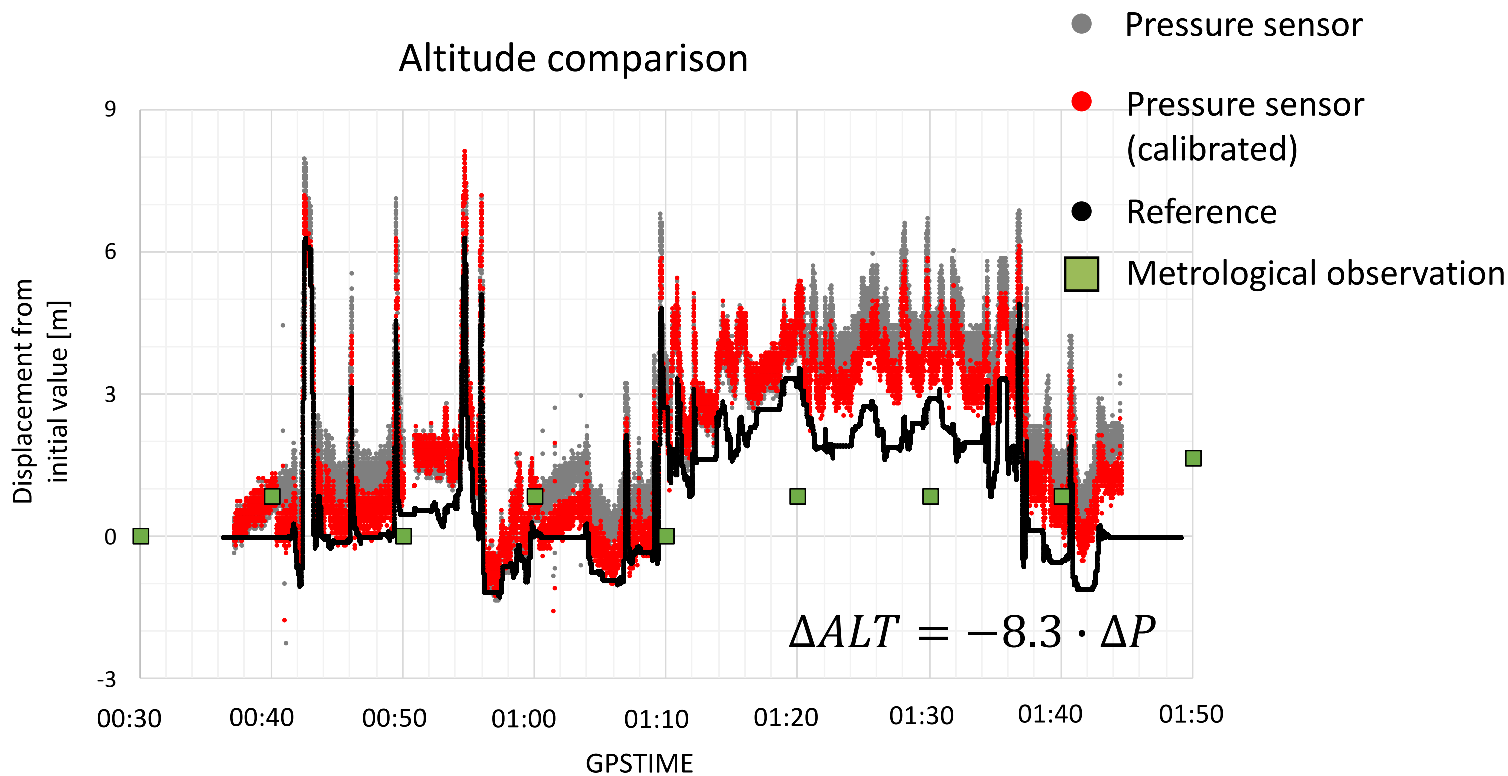
$\Delta P(JMA)$: Atmosheric barometric pressure obsarvation provided by Japan meteorological agency by each 10 minuets

$$\Delta ALT = -8.3 \cdot \Delta P$$

Altitude provided by Barometric pressure sensor

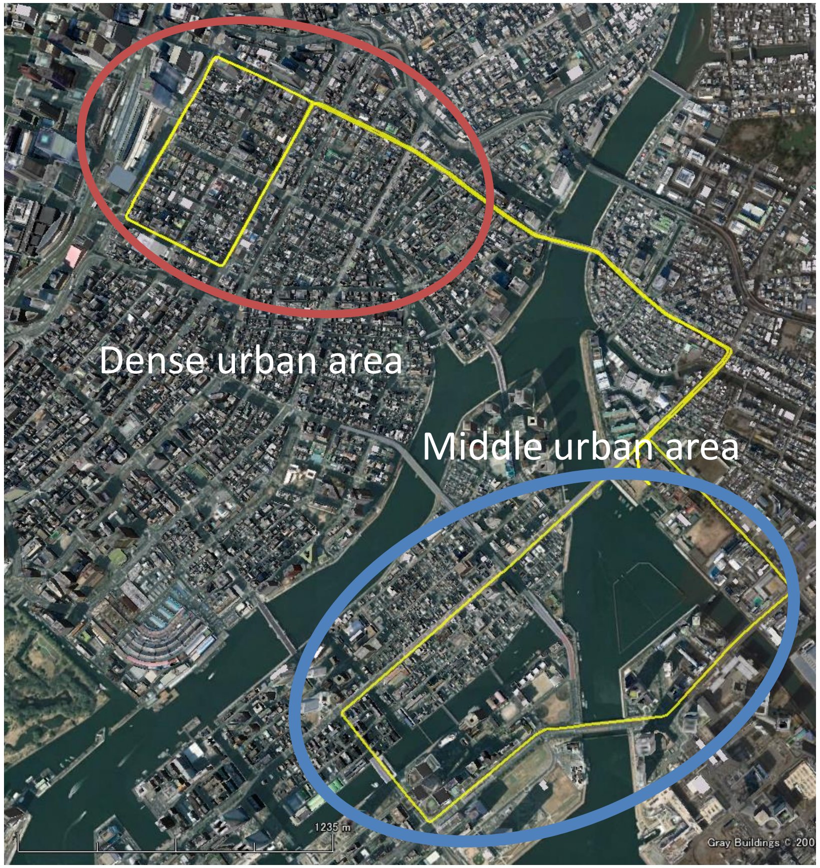
TIME (UTC)	Metrological observation at sea level [hPa]
0:30	1013.3
0:40	1013.2
0:50	1013.3
1:00	1013.2
1:10	1013.3
1:20	1013.2
1:30	1013.2
1:40	1013.2
1:50	1013.1

19/8/2015 (TOKYO)



- Pressure sensor observations drifted
- Calibration with metrological observation is valid

Testing and results
3 trials conditions



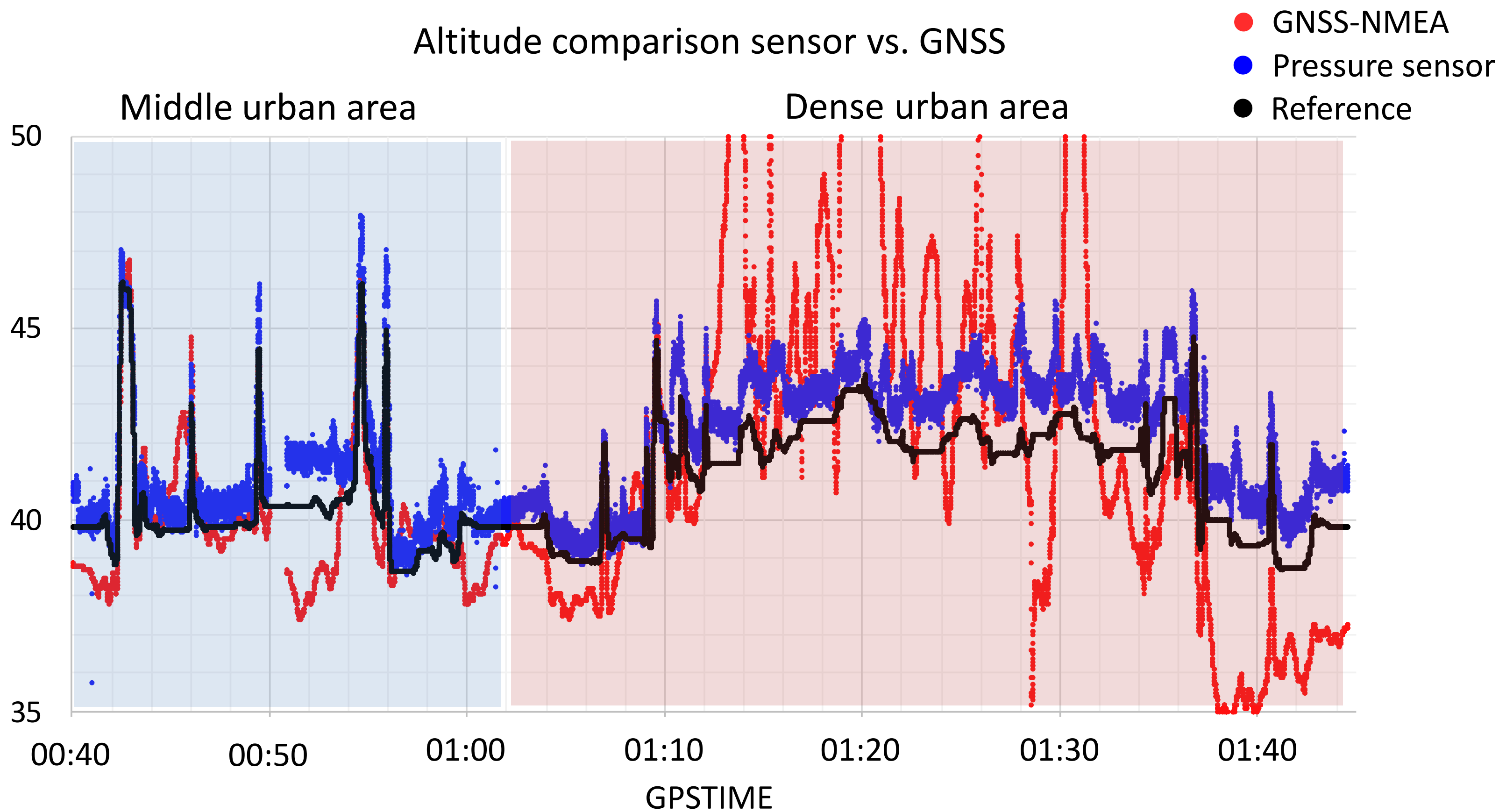
Course

- ✓ Start - round Middle urban area - go back to start point (about 20 minute) - round Dense urban area - go back to start point (about 40 minute)

- ✓ 3 Trials with Sensor and Consumer GNSS receiver
  - ✓ GNSS Receiver
    - ✓ Single frequency
    - ✓ GPS/QZSS/BaiDou
    - ✓ Output Rawdata and NMEA
  - ✓ Barometric pressure sensor
  - ✓ Reference position was taken by POS LV (Sensor integrated high-grade post-processing system)
  - ✓ comparison objective
    - ✓ Standard deviation
    - ✓ Reliability

    (the percentage of number that of within absolute 5merters)

Altitude comparison sensor vs. GNSS
Trial 1

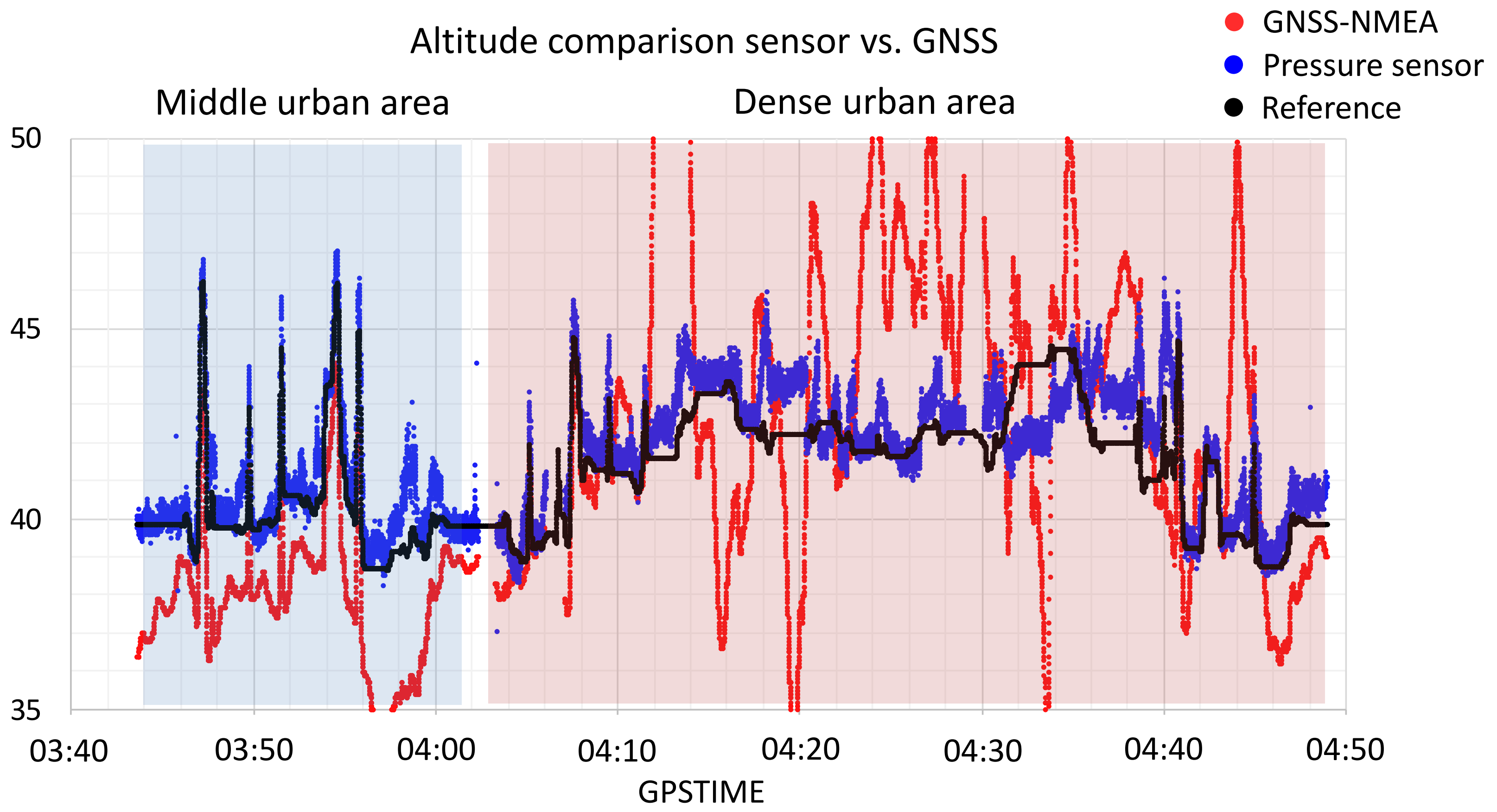


Sensor : 1σ = 0.49
Reliability : 100%
NMEA : 1σ = 1.59
Reliability : 100%

Sensor : 1σ = 0.59
Reliability : 100%
NMEA : 1σ = 6.58
Reliability : 83.8%

Altitude comparison sensor vs. GNSS

Trial 2

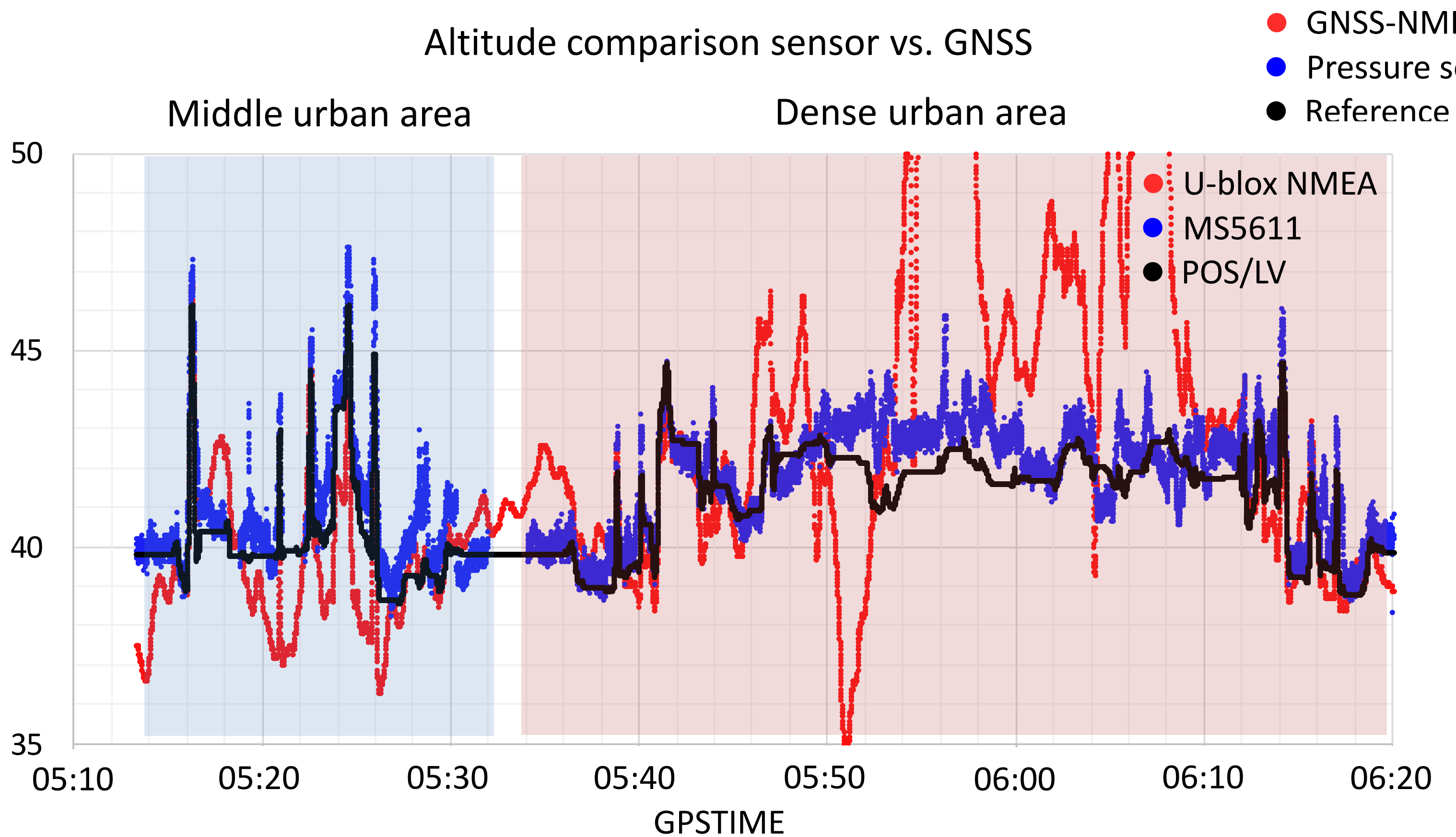


Sensor : 1σ = 0.58
Reliability : 100%
NMEA : 1σ = 0.94
Reliability : 100%

Sensor : 1σ = 0.96
Reliability : 100%
NMEA : 1σ = 4.88
Reliability : 80.9%

Altitude comparison sensor vs. GNSS

Trial 3



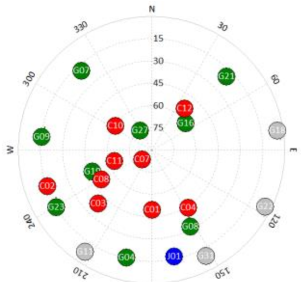
Sensor : 1σ = 0.74
Reliability : 100%
NMEA : 1σ = 1.38
Reliability : 100%

Sensor : 1σ = 0.71
Reliability : 100%
NMEA : 1σ = 5.01
Reliability : 80.4%

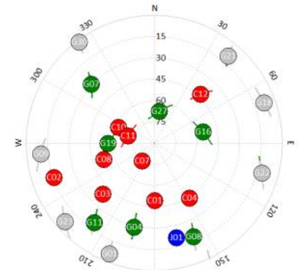
Summery of Altitude comparison sensor vs. GNSS

Sky plot and altitude error

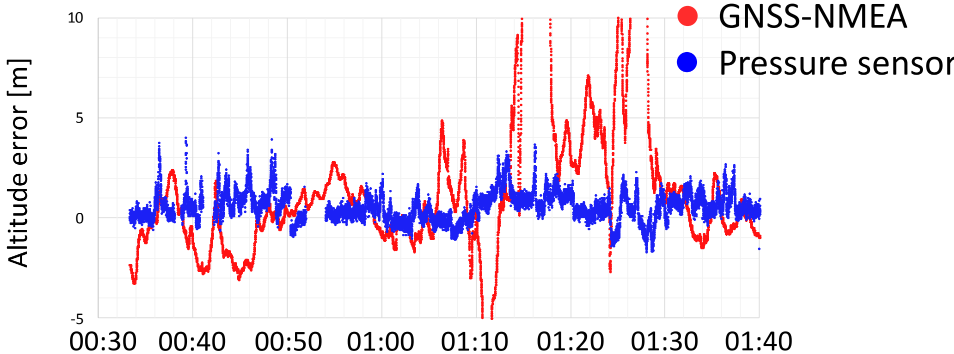
Middle urban area | Dense urban area

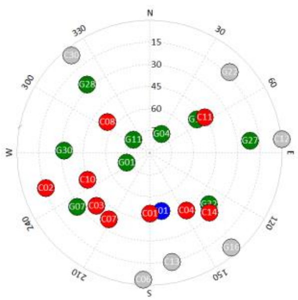


26minutits

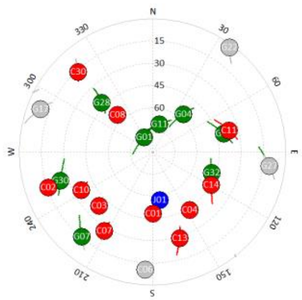


41minutits

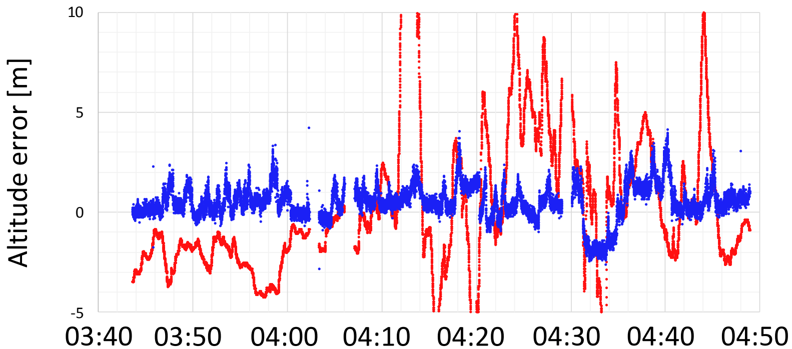


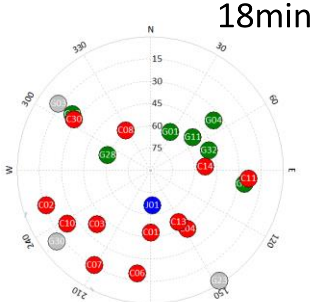


18minutits

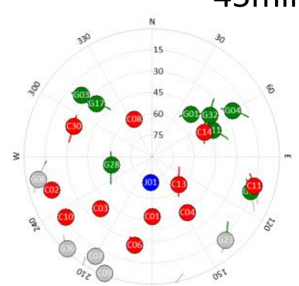


45minutits

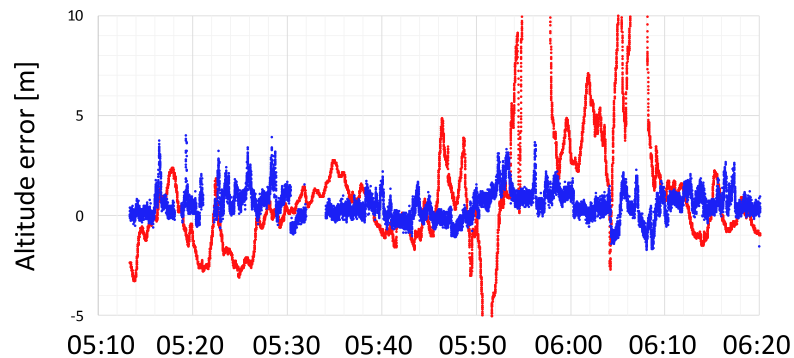




19minutits



43minutits



Summery of Altitude comparison sensor vs. GNSS

Environment			Sensor		NMEA	
Trial		minuits	1σ [m]	Reliability [%]	1σ [m]	Reliability [%]
1	Middle	26	0.49	100.0%	1.59	100.0%
	Dense	41	0.59	100.0%	6.58	83.8%
2	Middle	18	0.58	100.0%	0.94	100.0%
	Dense	45	0.96	100.0%	4.88	80.9%
3	Middle	19	0.74	100.0%	1.38	100.0%
	Dense	43	0.71	100.0%	5.01	80.4%

- ✓ Altitude provide by GNSS is difficult to detect highway
- ✓ Altitude provide by Pressure sensor is stable than GNSS
- ✓ Reliability of Altitude provide by GNSS depends on there environment
- ✓ There are drifts in Barometric pressure fluctuates by atomosperic factor

Algorithms for calibration

Calibration using absolute altitude by RTK FIX solution

- Barometric pressure fluctuates with atmospheric conditions in vehicle
  - Pressure changes by atmospheric pressure and in the vehicle conditions such as air-conditioner and opening or closing the car doors.
- In the case of real-time positioning at moving vehicle, altitude information provide by sensor have to be frequently calibrated

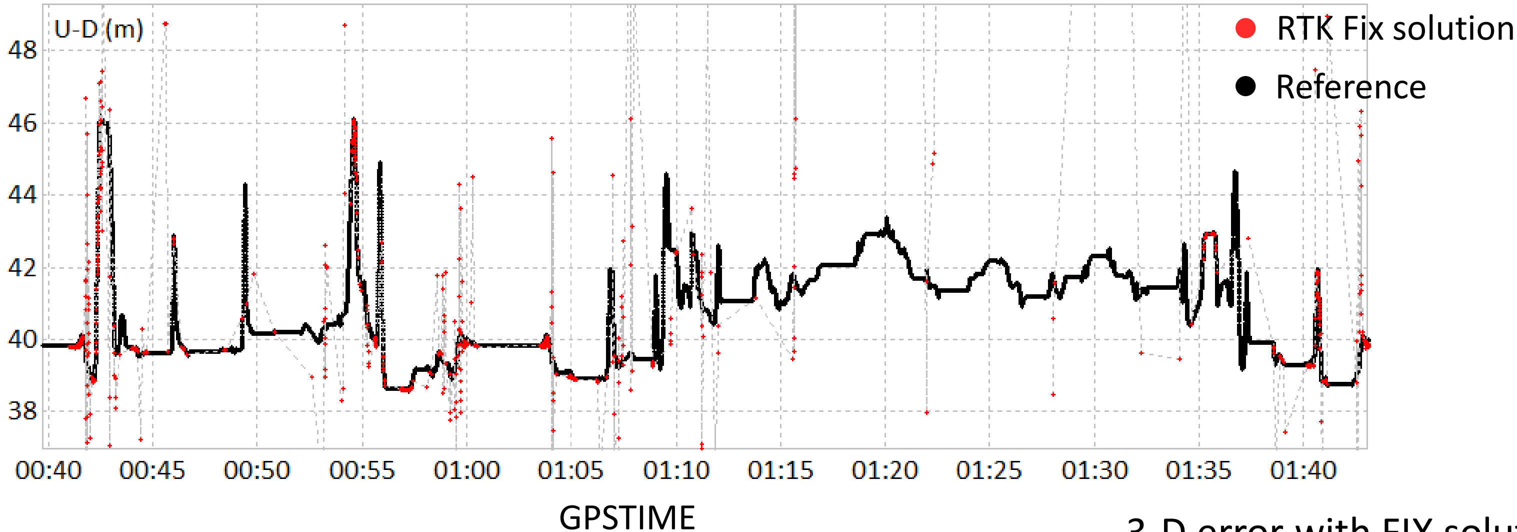
→if the finite intervals of reliable absolute altitude information are obtained, these are valid for calibrate pressure sensor

- Evaluation of the possibility in RTK FIX solution for calibration

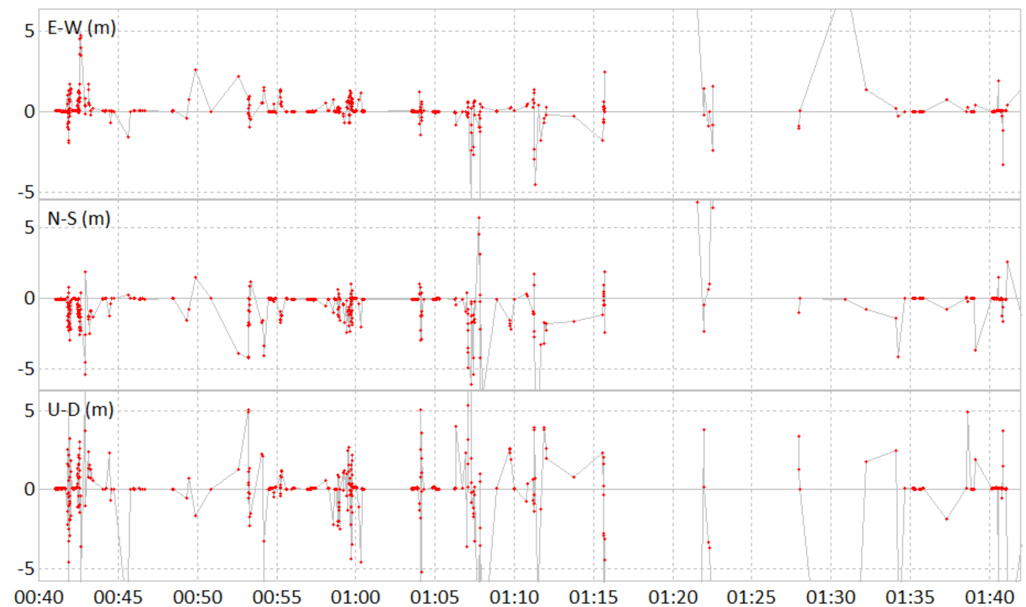
→How available and reliable is the FIX solution?

Single frequency RTK-Fix solution Trial 1

Altitude comparison GNSS VS. POSLV



3-D error with FIX solution



- Instantaneous AR by Lambda
- Minimum Ratio threshold value for ratio test = 3.0
- Fix rate = 6.9%
- Reliability = 79.5% (Ratio of Fix solution 2D-error within 0.5m and altitude error within absolute 1m for Number of Fix)

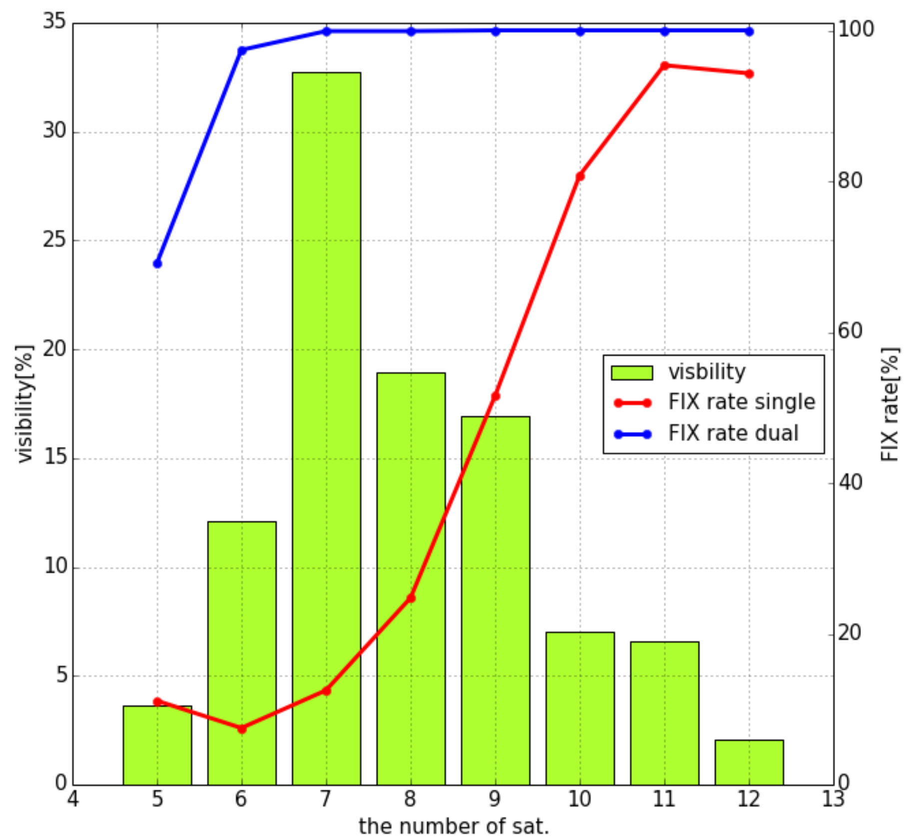
How to detect reliable solution automatically ?

Availability of Single frequency RTK Static 24houres data

Static test at open sky
GPS 24hours 1Hz

Number of Sat	Epoch	FIX(%)
5	3128	11.13
6	10455	7.51
7	28275	12.50
8	16357	24.75
9	14657	51.55
10	6062	80.77
11	5695	95.38
12	1772	94.30

- ✓ In the point of FIX rate, Dual frequency RKT is enough to 6or more satellites.
- ✓ For Single frequency RTK, 10 or more satellites are required.



Average of the number of sat:7.9

Reliability of Single frequency RTK
Static 24houres data

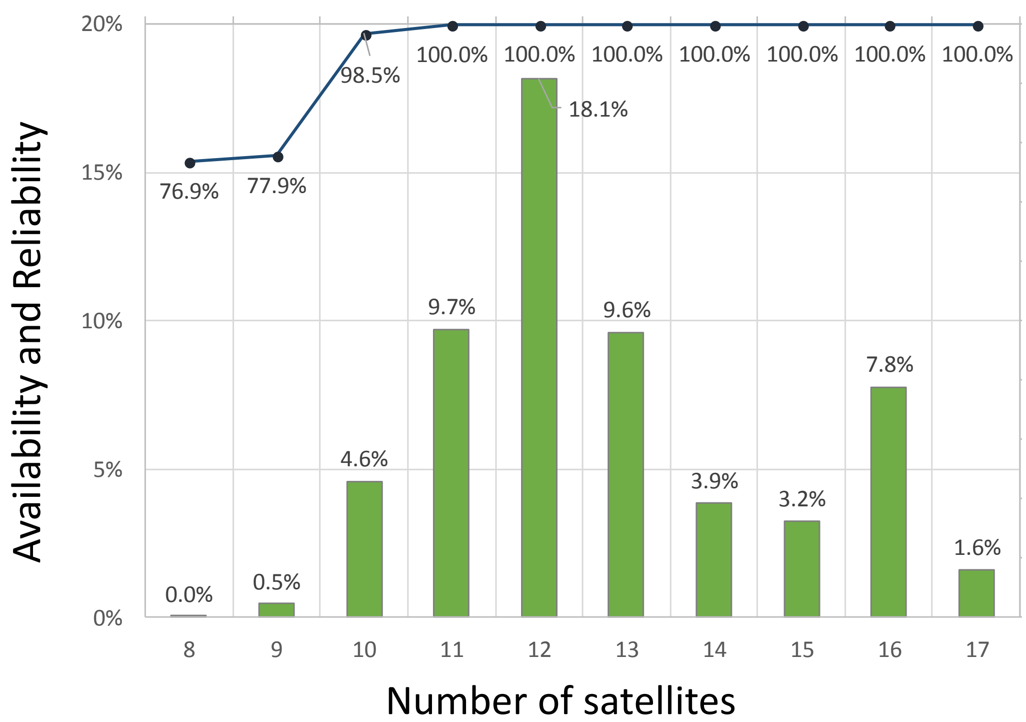
Static test at open sky with **30deg mask angle**

GPS/BeiDou/QZSS 24hours 1Hz

Number of Sat	Number of Fix solution	Number of Reliable solution	Average of Ratio factor
8	13	10	3.6
9	389	303	4.7
10	3961	3903	4.9
11	8396	8392	5.4
12	15680	15680	5.4
13	8304	8304	6.8
14	3327	3327	8.6
15	2803	2803	11.3
16	6711	6711	13.0
17	1381	1381	12.9
total	50965	50814	7.7

● Reliability
(Ratio of Fix solution 3D-error within 0.5m for Number of Fix)

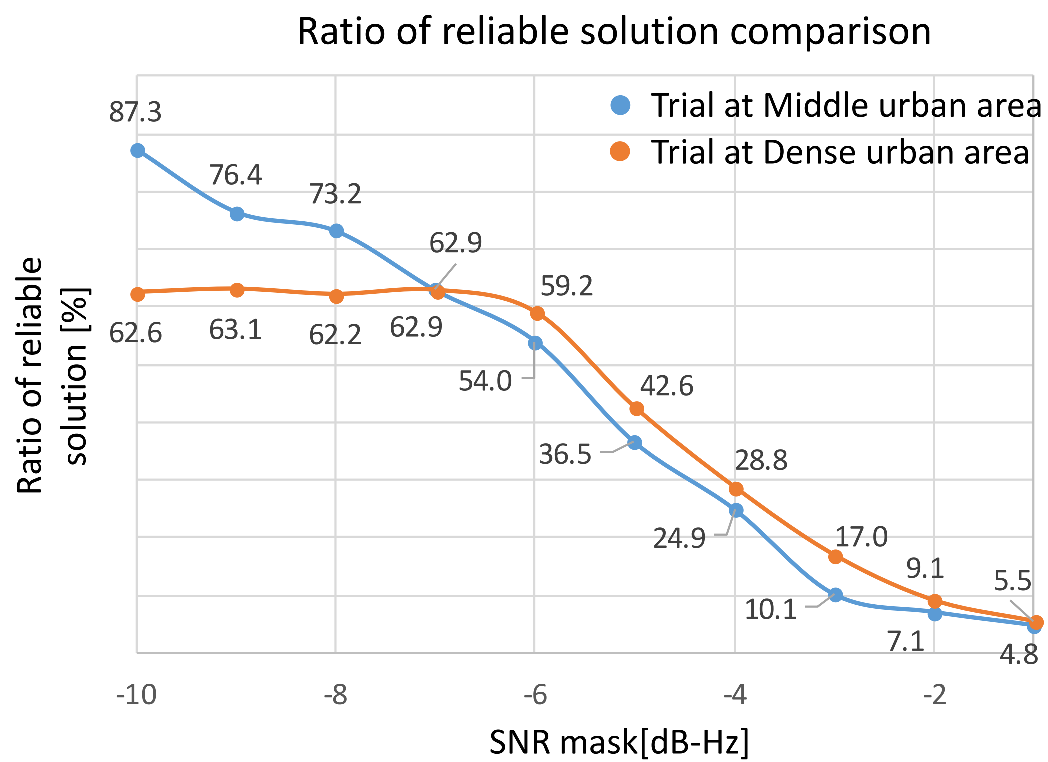
■ Availability
(Fix rate)



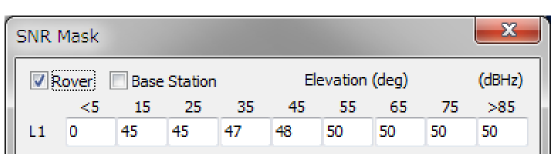
Performance of single frequency RTK

Moving Vehicle data -Trial 1 –SNR MASK

Threshold	Middle urban Fix rate [%]	Dense urban Fix rate [%]
-1	7.44	2.11
-2	11.87	4.09
-3	13.72	4.93
-4	13.7	7.88
-5	13.65	9.44
-6	13.78	12.8
-7	16.1	14.91
-8	19	15.14
-9	19	15
-10	18.86	14.19
Normal	14.8	4.2



- Changing the SNR mask to reduce the multipath errors
- Minus -8 to -1 with the standard SNR mask (Elevation dependent)



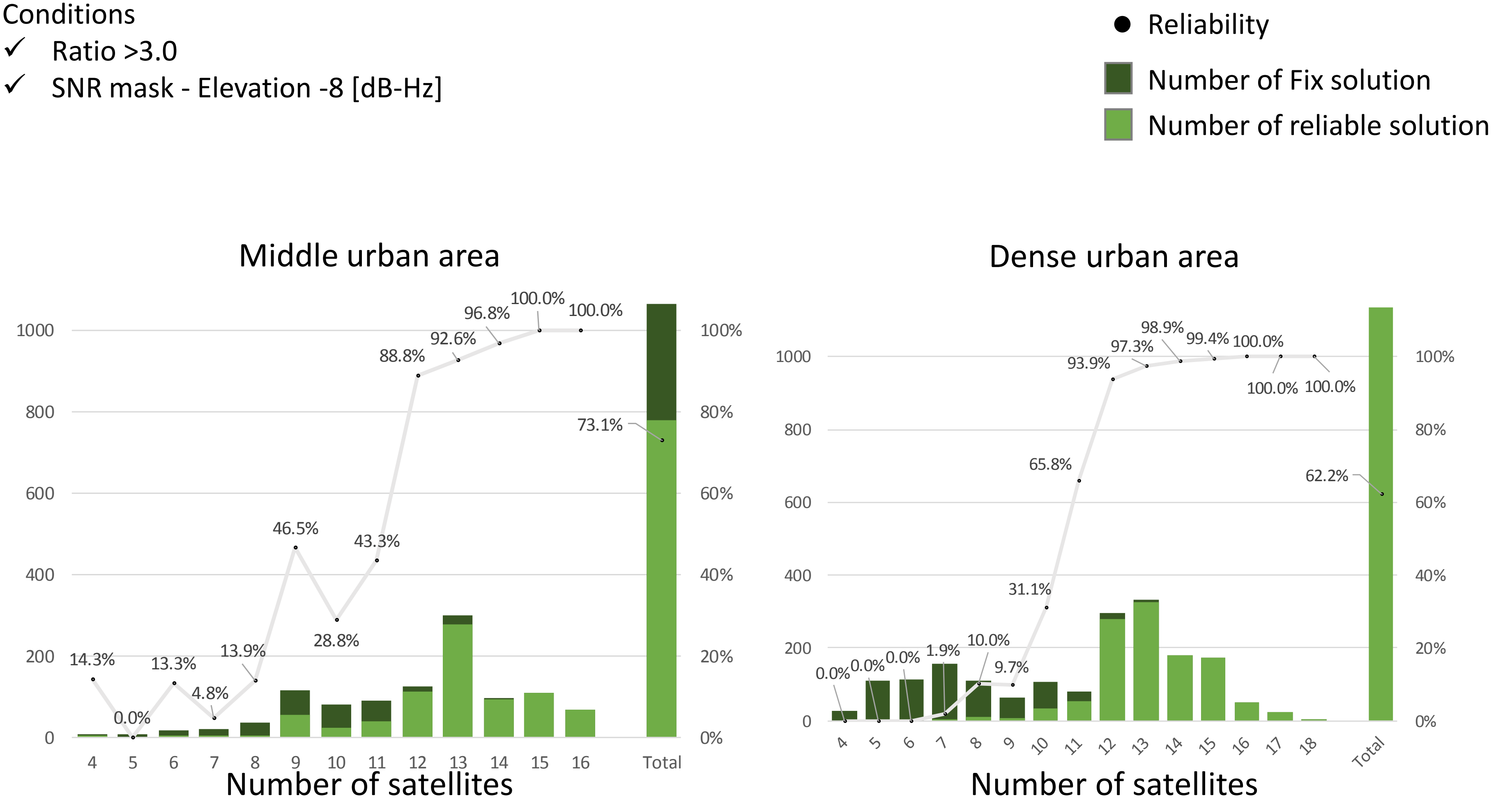
Standard for SNR mask

*Reliable solution
2D-error within 0.5m and altitude error within 1m

Performance of single frequency RTK

Moving Vehicle data -Trial 1 –SNR MASK

Conditions
- ✓ Ratio >3.0
- ✓ SNR mask - Elevation -8 [dB-Hz]



*Reliable solution
2D-error within 0.5m and altitude error within 1m

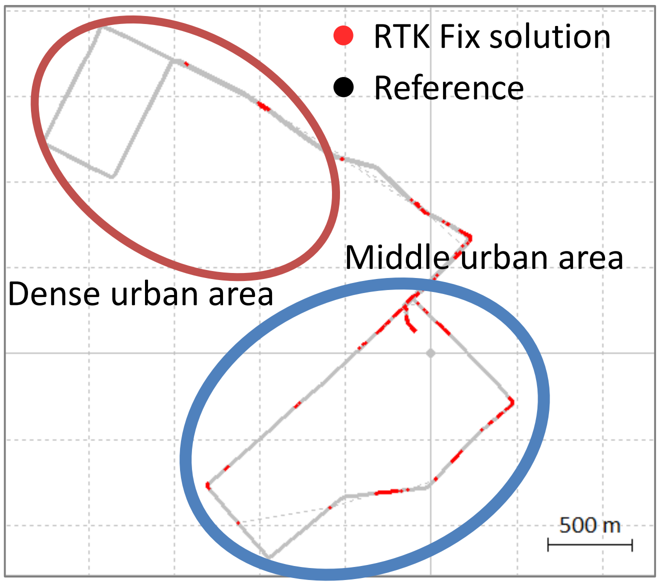
Performance of single frequency RTK

Time intervals of reliable absolute solution

Conditions

- ✓ Ratio >3.0
- ✓ SNR mask - Elevation -8 [dB-Hz]
- ✓ Over 12satellites

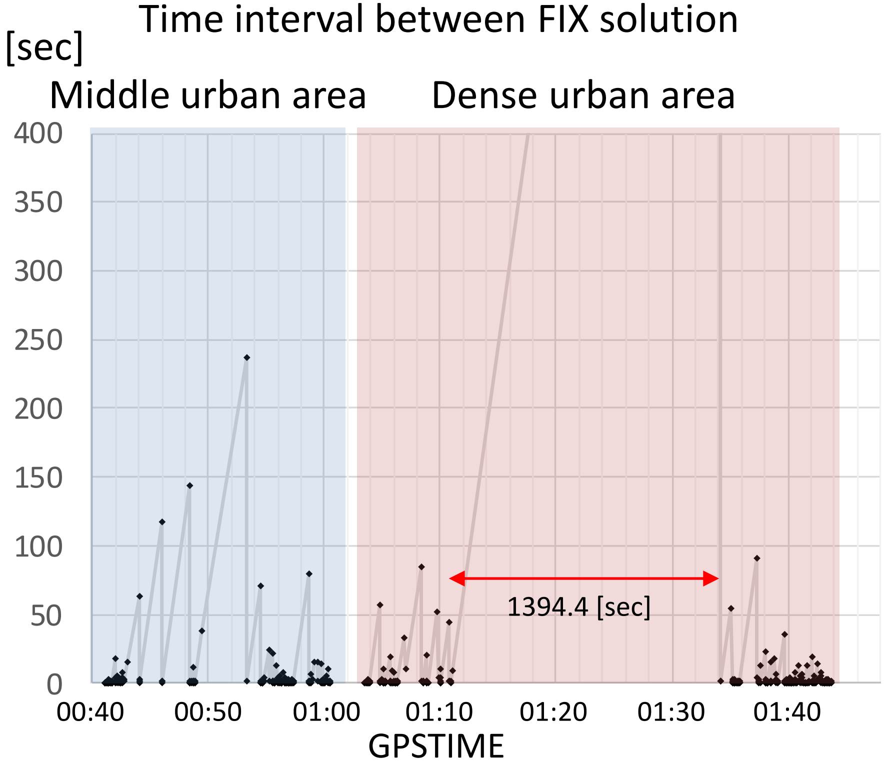
Horizontal plot



Middle urban area
Availability : 12.4%
Reliability : 94.4%

Dense urban area
Availability : 8.8%
Reliability : 97.2%

Time interval between FIX solution



Maximum time intervals =1394.4sec

Standard deviations of time intervals = 34.4sec

Conclusion

- Altitude information is calculated by Barometric pressure sensor calibrate by metrological observation data and RTK solution
- Altitude information by sensor is more stable than GNSS data with high availability in the short period
- Reliability of single frequency RTK solution is strictly affected by number of satellites
- Limited of the high reliable solutions are valid for calibrate barometric pressure sensor