Fast Ambiguity Resolution in RTK-GPS Positioning for Marine Navigation

Falin Wu, Nobuaki Kubo and Akio Yasuda

Tokyo University of Mercantile Marine, Japan

Contents

- **Introduction**
- **Fast Ambiguity Resolution Algorithm**
  - Wide-lane Ambiguity Resolution **<u>with altitude aiding</u>**
  - L1 Ambiguity Resolution
- **Test Results**
- **Summary**

RTK-GPS Positioning in Marine Environment

- **Marine Navigation Requirement**

  Several meters level (usual)

  several cm level (specific)

- **Marine Environment**

  Bridges and large buildings

- **Ambiguity Resolution**

  Not easy

Observation Models

Double Difference:

$$P_1 = \rho + e_I + e_T + e_{m_{p1}} + e_1$$

$$P_2 = \rho + \left(\lambda_2 / \lambda_1\right)^2 e_I + e_T + e_{m_{p2}} + e_2$$

$$\Phi_1 = \rho - e_I + e_T + e_{m_{\phi 1}} + \lambda_1 N_1 + \varepsilon_1$$

$$\Phi_2 = \rho - \left(\lambda_2 / \lambda_1\right)^2 e_I + e_T + e_{m_{\phi 2}} + \lambda_2 N_2 + \varepsilon_2$$

Linear Combinations of Observables

- Wide-lane:

$$\Phi_W = \left(\frac{\Phi_1}{\lambda_1} - \frac{\Phi_2}{\lambda_2} \right) \lambda_W = \rho + (\lambda_2 / \lambda_1) e_I + e_T + e_{m_{\phi W}} + \lambda_W N_W + \varepsilon_W$$

- Narrow-lane:

$$\Phi_N = \left(\frac{\Phi_1}{\lambda_1} + \frac{\Phi_2}{\lambda_2} \right) \lambda_N = \rho - (\lambda_2 / \lambda_1) e_I + e_T + e_{m_{\phi N}} + \lambda_N N_N + \varepsilon_N$$

- Ionospheric-free:

$$\Phi_{ion} = (\Phi_W + \Phi_N)/2 = \rho + (\lambda_N N_N + \lambda_W N_W)/2 + e_T + e_{m_{\phi ion}} + \varepsilon_{ion}$$

- Ionospheric:

$$\Phi_I = \Phi_N - \Phi_W = -2(\lambda_2 / \lambda_1) e_I + \lambda_N N_N - \lambda_W N_W + \left(e_{m_{\phi N}} - e_{m_{\phi W}} \right) + (\varepsilon_N - \varepsilon_W)$$

Ambiguity Resolution On-The-Fly

- Estimate position using carrier smoothed pseudorange
- All satellites divide in two groups (primary 4 satellites and secondary satellites)
- Detect cycle-slip
- Resolve the wide-lane ambiguity (test)
- Resolve the L1 ambiguity (test)
- Calculate the position

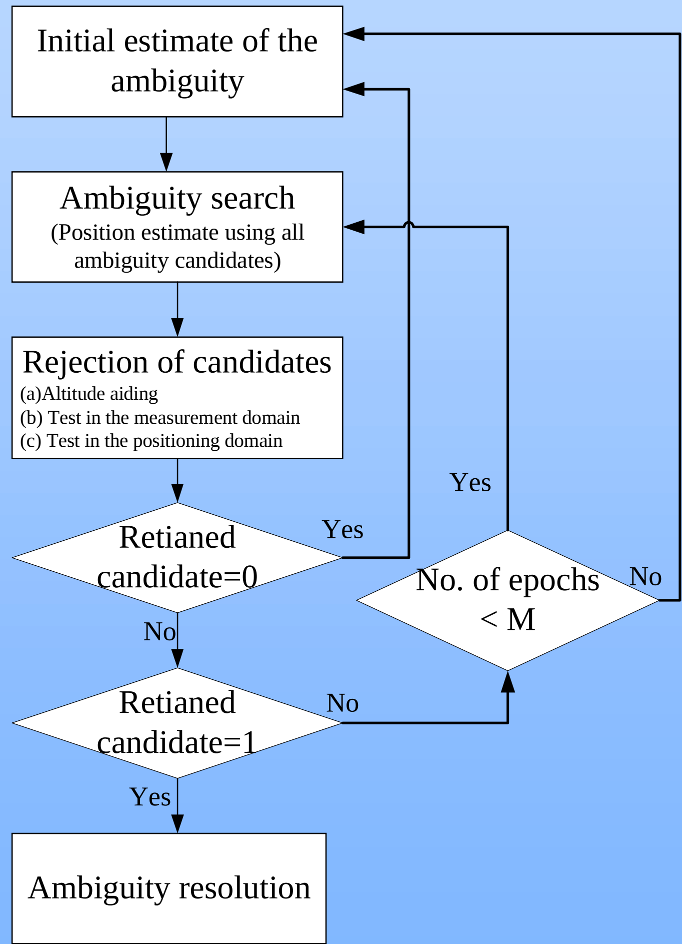
Cycle-slip Detection

Time difference of ionospheric combination

$$\begin{aligned}\Delta\Phi &= \Phi_I(t_n) - \Phi_I(t_{n-1}) \\ &= -2(\lambda_2/\lambda_1)\{e_I(t_n) - e_I(t_{n-1})\} \\ &\quad + (\lambda_N - \lambda_W)\delta N_1 + (\lambda_N + \lambda_W)\delta N_2 \\ &\cong -2(\lambda_2/\lambda_1)\{e_I(t_n) - e_I(t_{n-1})\} \\ &\quad - 75.5\cdot\delta N_1 + 96.9\cdot\delta N_2\,(cm)\end{aligned}$$

Wide-lane Ambiguity Resolution

- Define search grid
- Ambiguities search
  - **Altitude aiding**
  - **Test in the measurement domain**
  - **Test in the positioning domain**
- Determine ambiguities



Procedure 1: Define Search Grid

- Estimates initial wide-lane ambiguities

$$\hat{N}_W = \left[\frac{\phi_W - \rho}{\lambda_W} \right]_{roundoff} \qquad \sigma_N^W = \sqrt{\sigma^{PR2} + \sigma^{W2}}$$

- Define search grid:

$$\hat{N}_w^i - k\sigma_N^W \le N_W^i \le \hat{N}_w^i + k\sigma_N^W \quad (i = 1, 2, \cdots, nsv - 1)$$

K=2 corresponds to 125 search grids (5*5*5)

Procedure 2: Ambiguities Search

- Test in the measurement domain
- Test in the positioning domain
- Candidate rejection using altitude aiding

Statistical test in the measurement domain

- Criterion:

$$\frac{v^T C_W^{-1} v}{df} > \frac{\chi^2_{df,\,1-a}}{df} k_1^W$$

v - residual vector

a - significant level

df - degree of freedom

k_1^W - an empirical parameter (1-2)

C_W - measurement error covariance matrix of wide-lane

Statistical test in the positioning domain (horizontal)

- Criterion:

$$\left| r^{PR} - r^{W} \right|_{H} > k_2^W \sigma_H^{PR-W}$$

$$\sigma_H^{PR-W} = RHDOP \sqrt{\left(\sigma_m^{PR}\right)^2 + \left(\sigma_m^{W}\right)^2}$$
$$= RHDOP \sqrt{65^2 + 4^2}$$
$$\cong 65.1 \cdot RHDOP \quad (cm)$$

Candidate rejection using altitude aiding

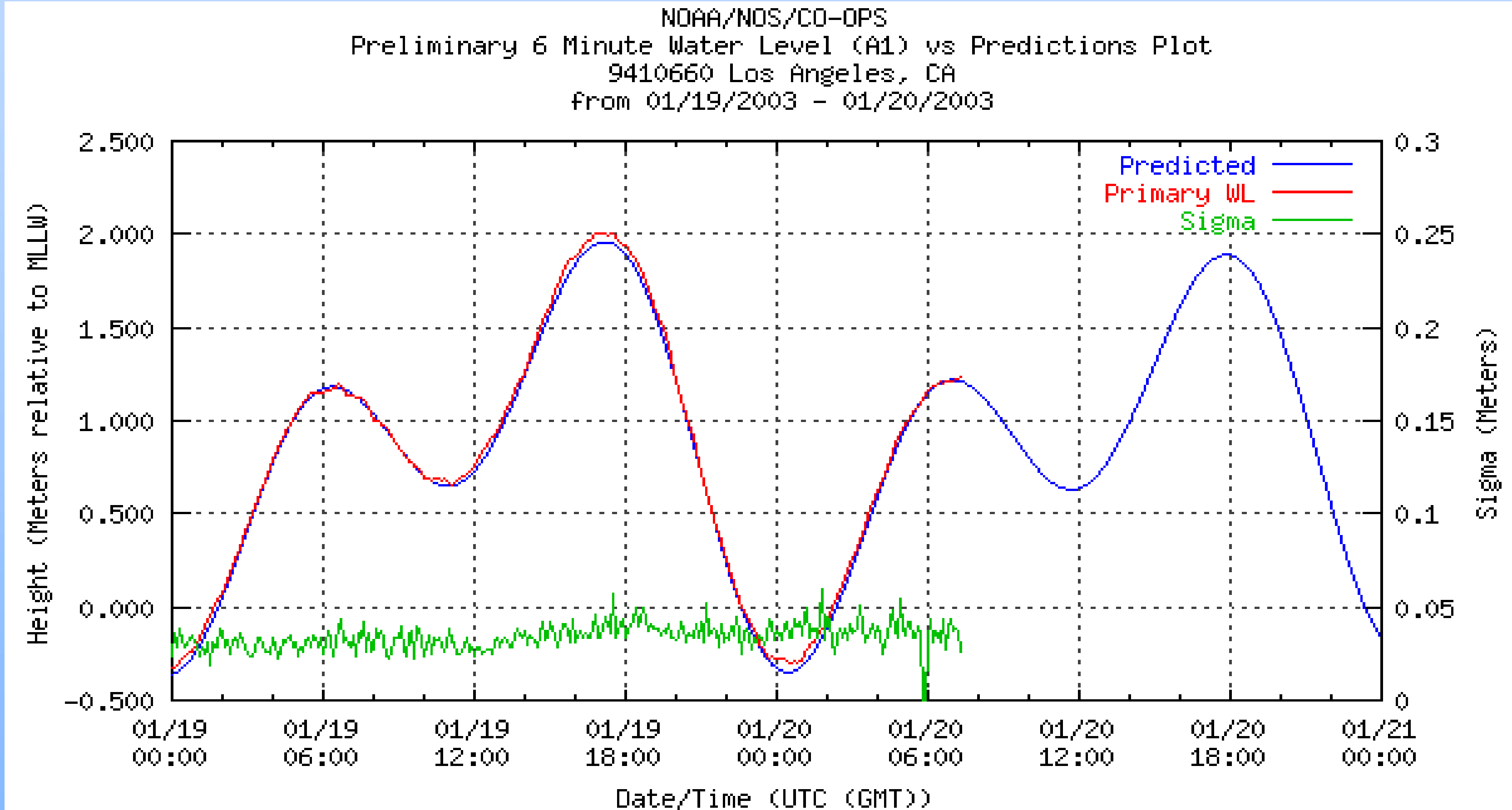
- Rejection criterion:

$$A^W > A_{\max} \quad or \quad A^W < A_{\min}$$

- A_{min} and A_{max}
  - **Water level information**
  - **Other information(dynamics, ship size)**

In case of usual sea condition, antenna altitude is enough limited within ±1.0m from water level.

Water level information



http://co-ops.nos.noaa.gov/data_res.html

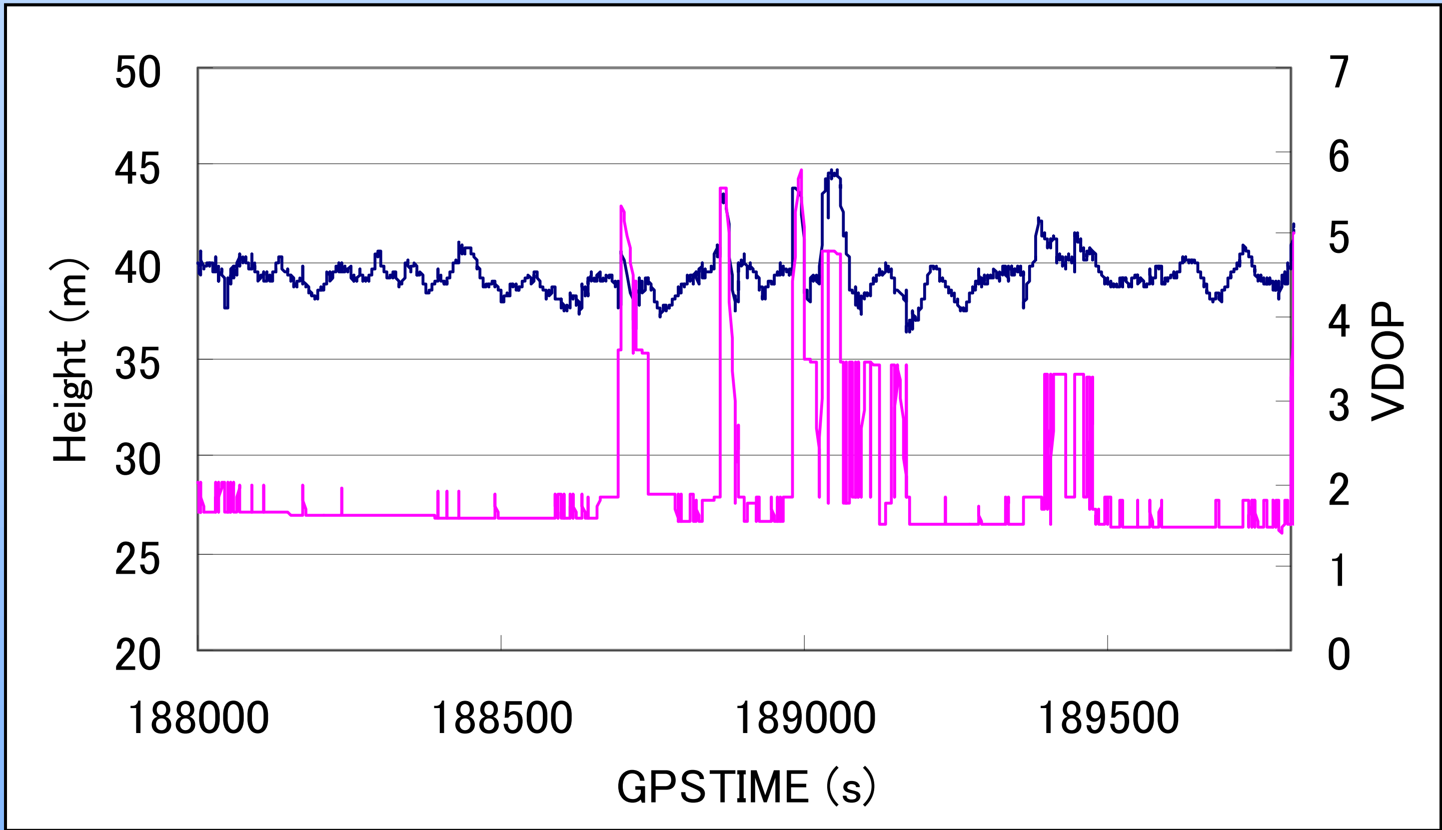
Why don’t we use vertical position domain test?

- Mask angle is usually set above 10-15 degrees in RTK.
- Multipath deteriorates the DGPS accuracy immediately after the ship pass through the bridges.

DGPS altitude accuracy is not good.
VDOP is also not good.

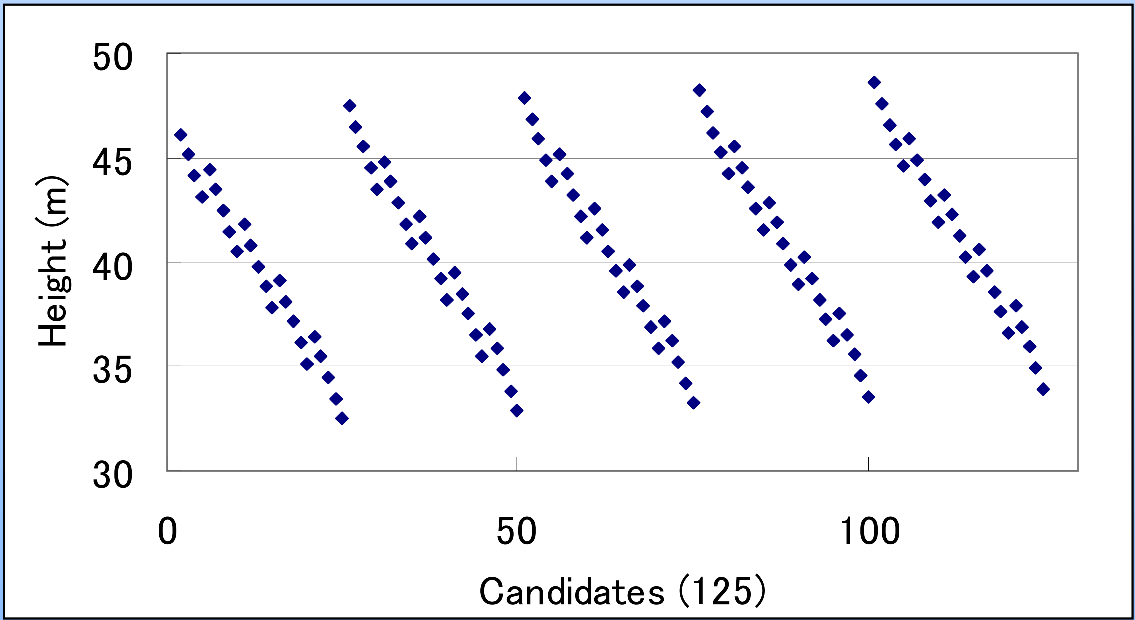
Vertical position test is not useful.

Actual DGPS altitude result and VDOP



True altitude varies from 40.2m to 40.5m.

Wide-lane altitude results in all search grids (GPStime=189000)



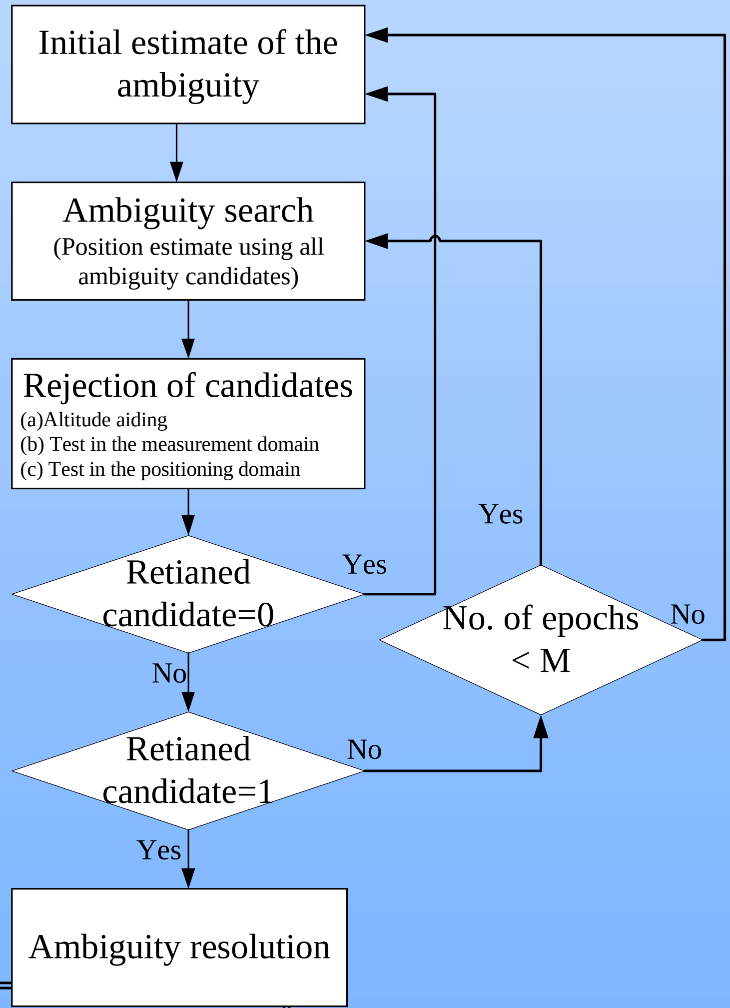
Altitude aiding
±1.0m

Vertical test
±3.0m～ ±10.0m
VDOP*σ*2(95%)

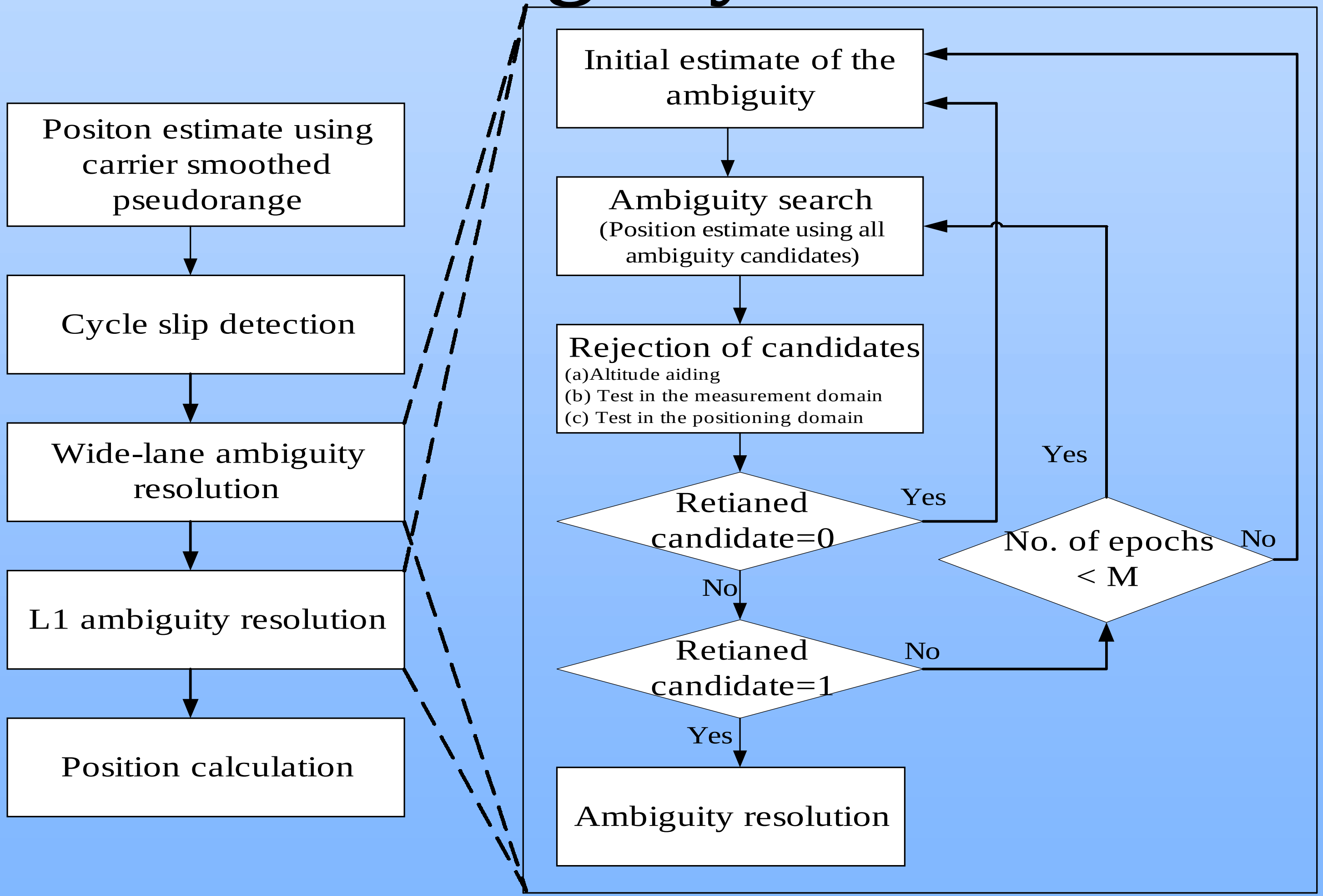
Using altitude aiding is more useful than using vertical test.

Determine Ambiguities

- Candidate = one?
- Number of epochs < M?



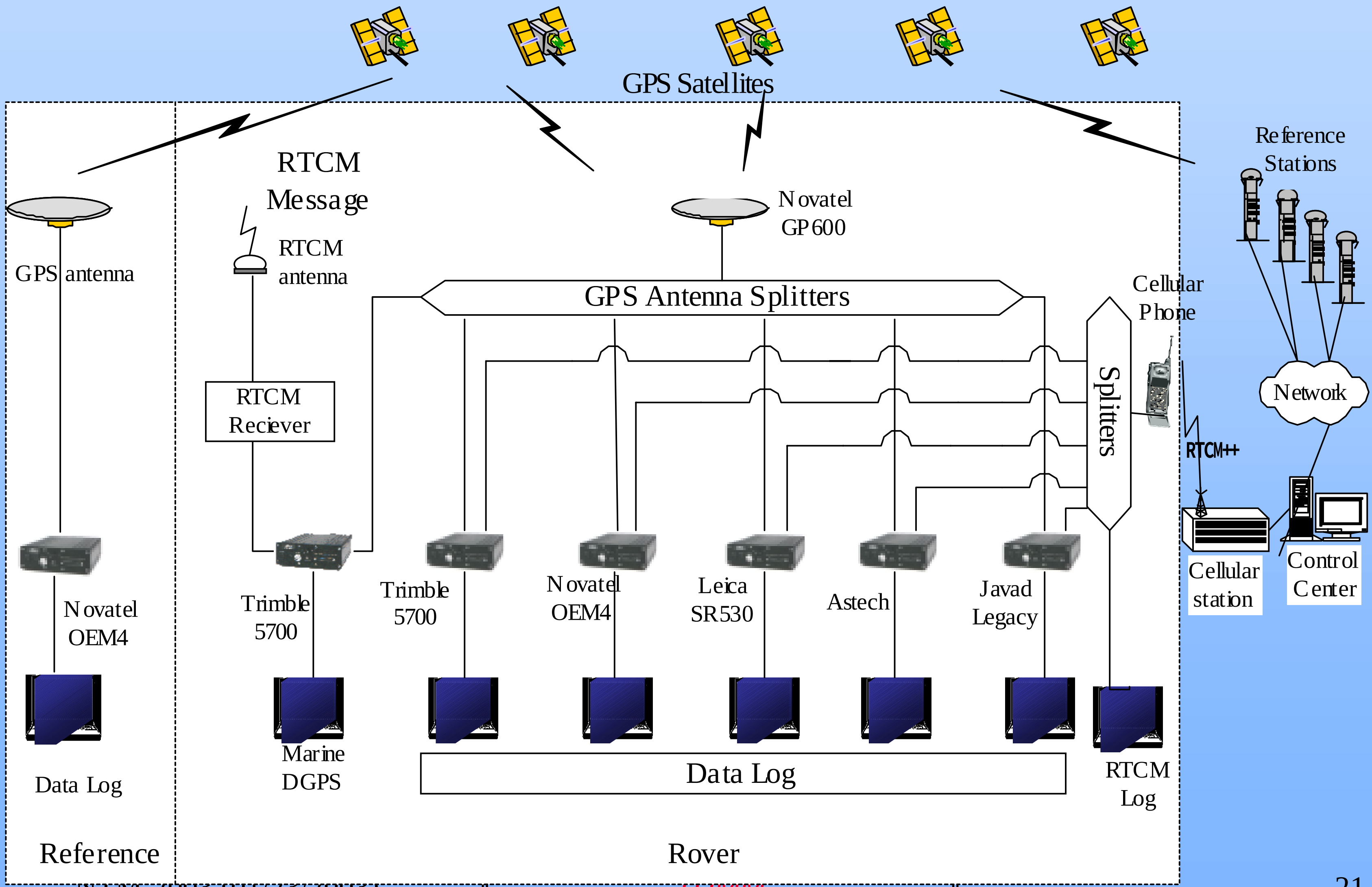
L1 Ambiguity Resolution



Experiment

- Marine-RTK
  - **Use algorithm proposed in this paper**
  - **Marine-RTK has conducted from reference and user data after ship experiment**
- Marine-VRS
  - **Virtual Reference System**
  - **Each stations around user has about 30km**

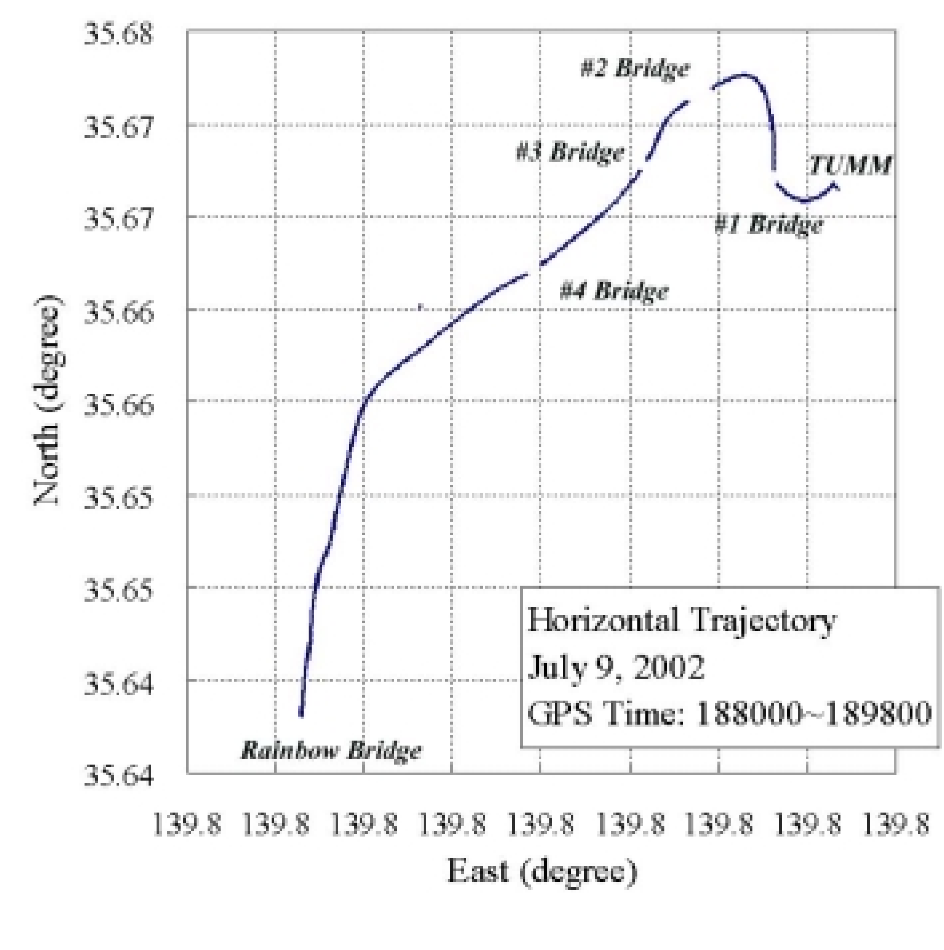
Configuration of Experiment



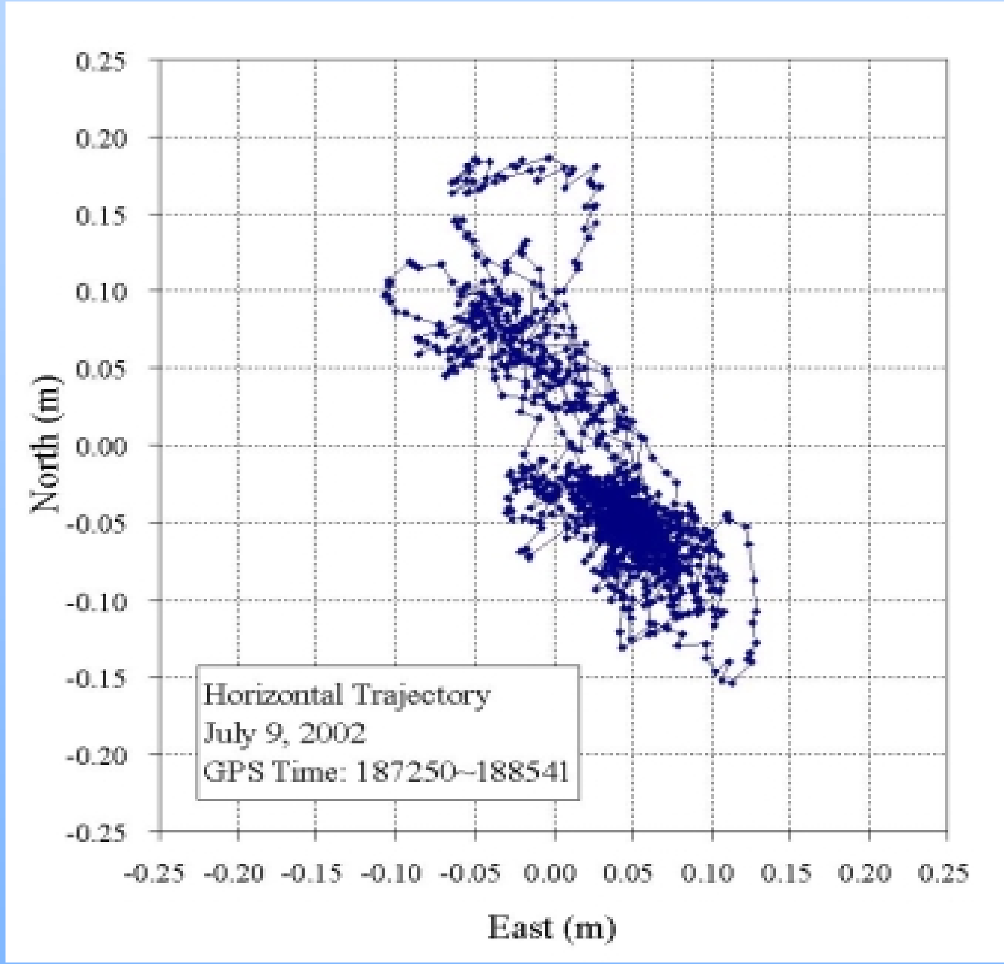
Experiment Stages

- Docked in berth
  - **Baseline: 100m**
  - **30 min**

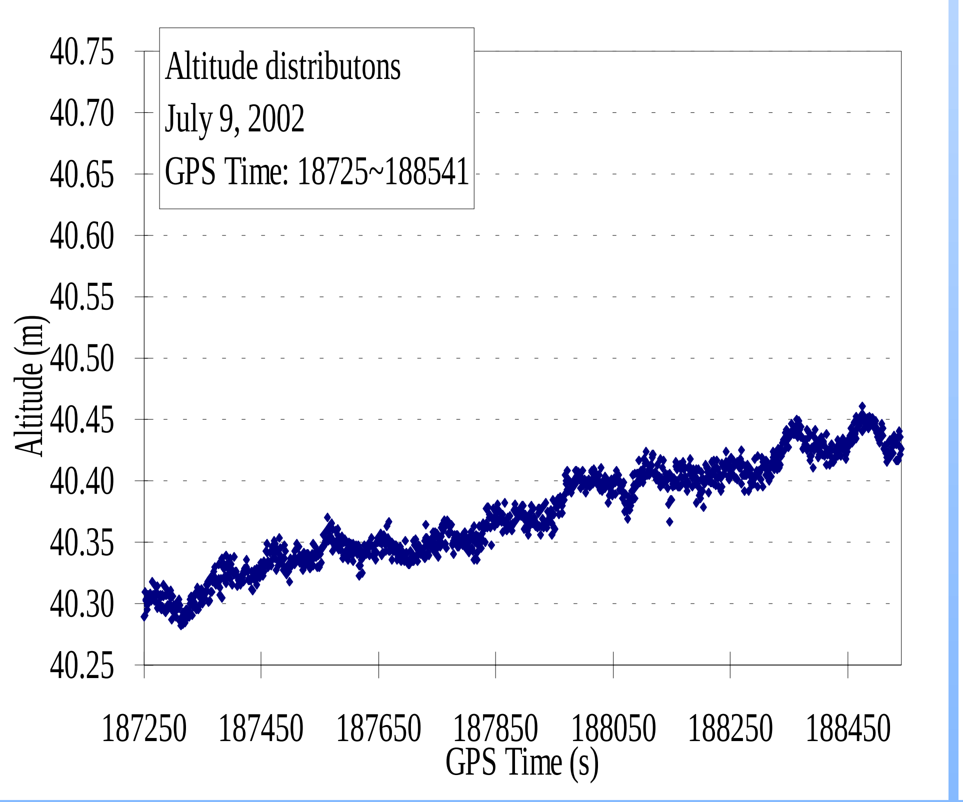
- Sailed from TUMM to Rainbow Bridge
  - **3.5km**
  - **Four bridges**



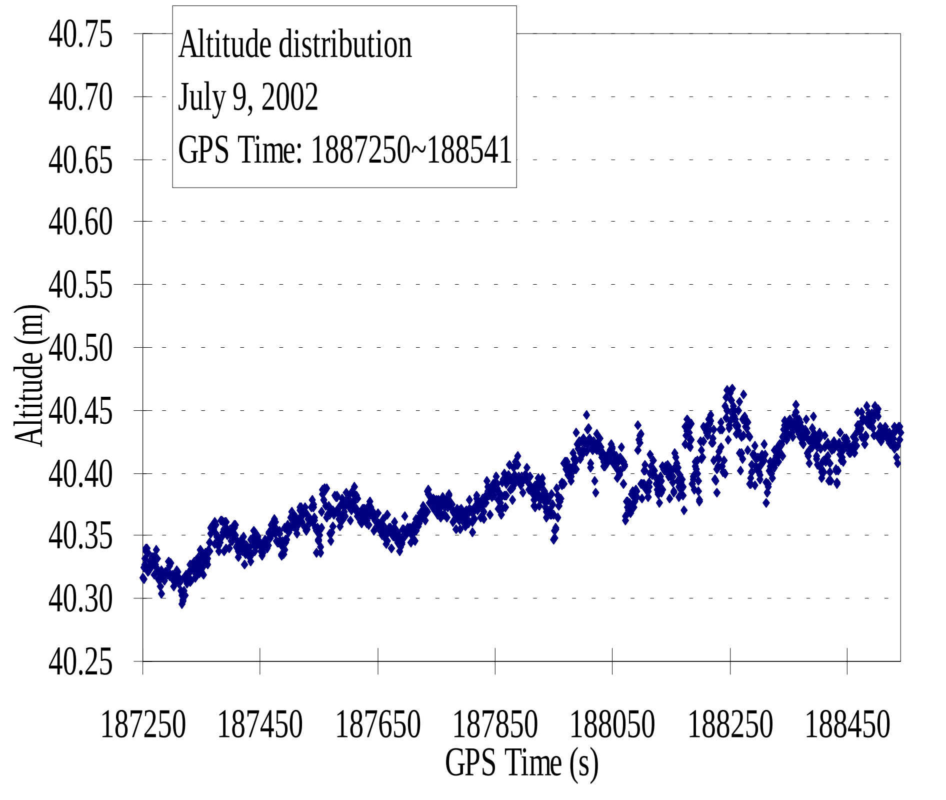
Horizontal Trajectory
(Docked in Berth, Marine-RTK)



Vertical Variation
(Docked in Berth)

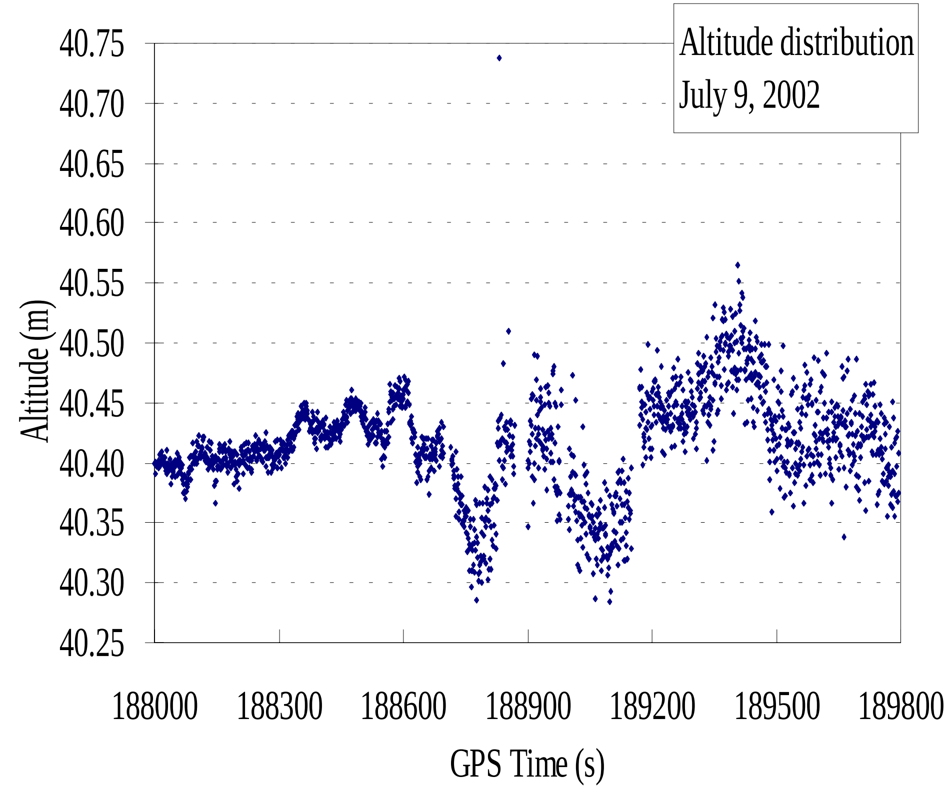


Marine-RTK

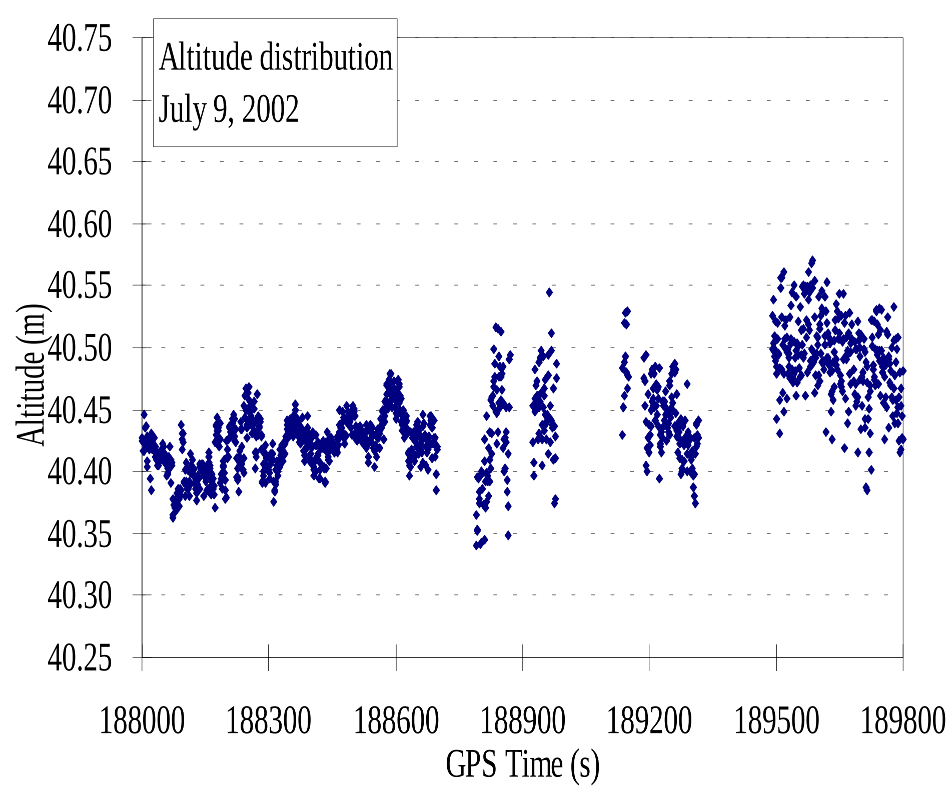


Marine-VRS

Vertical Distribution
(From TUMM to Rainbow Bridge)

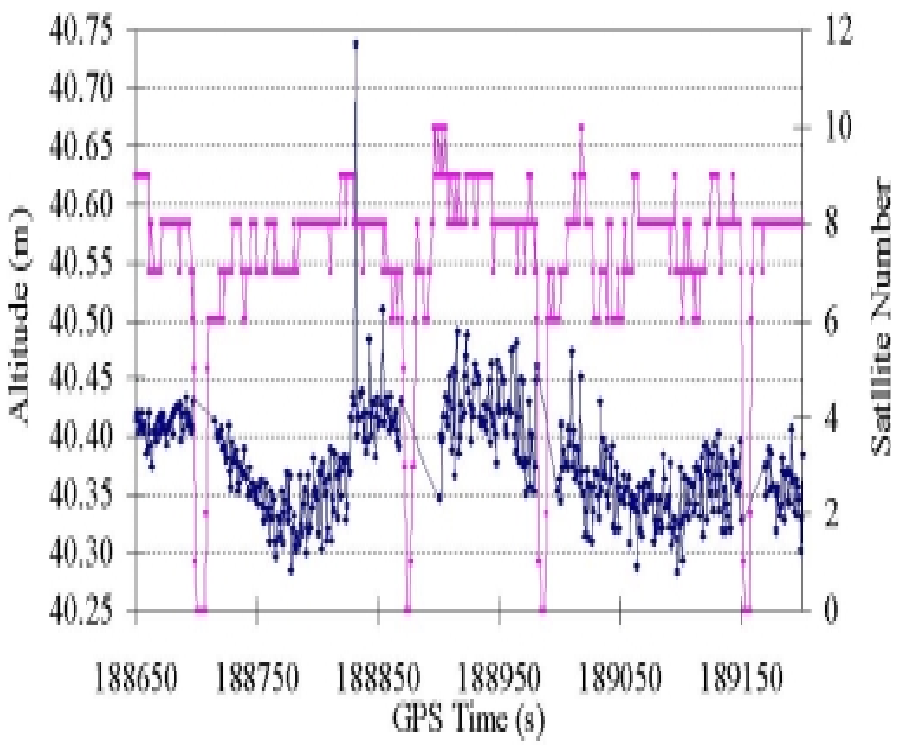


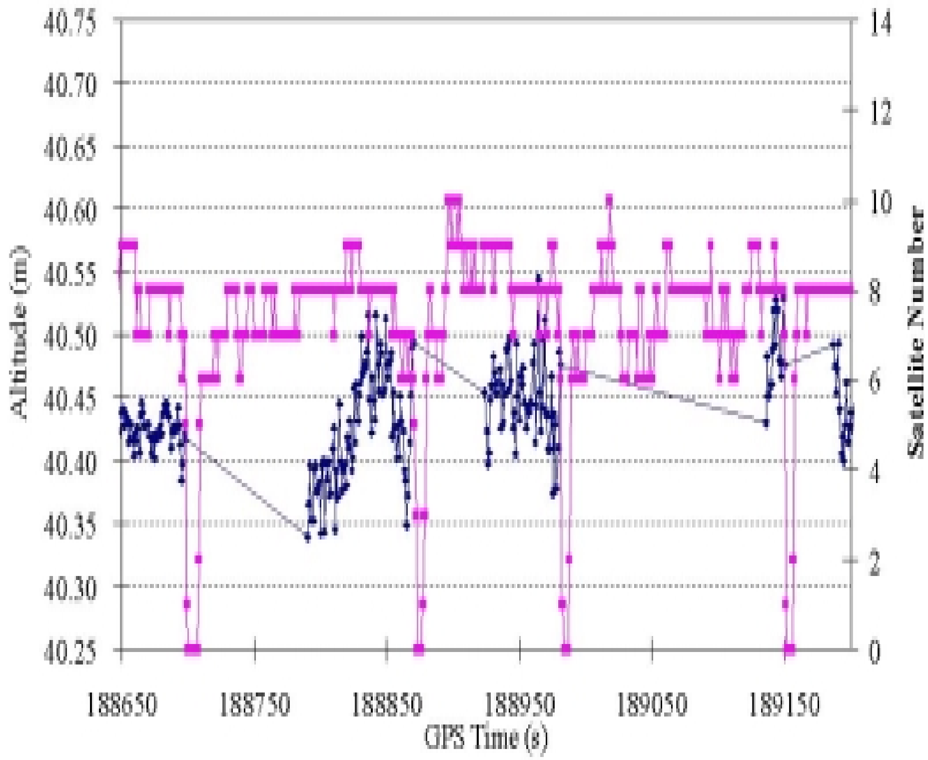
Marine-RTK



Marine-VRS

Altitude Distribution
(Four Bridges, From TUMM to Rainbow Bridge)





Marine-RTK

Marine-VRS

Time to fixed after passed through bridges

	Bridges	1	2	3	4
Marine-RTK	Altitude-aiding	1	6	1	1
	No-Altitude-Aiding	11	11	24	1
Marine-VRS	Novatel	75	35	138	18
	Ashtech	33	16	18	20
	Leica	19	32	23	18

Fixed Percentage

		Fixed Rate (%)
Marine-RTK	Altitude-aiding	97.5
	No-Altitude-Aiding	95.3
Marine-VRS	Novatel (OEM4)	81.2
	Ashtech (Z-12)	90.6
	Leica	92.1

Summary

- Ambiguity Resolution for Marine Navigation

  A new approach using altitude aiding

- Numerical Results

  Good performance

- Future works

  Further test
  Improve robustness of statistical test

Thanks for your attention