Precise point positioning
current state and future perspectives

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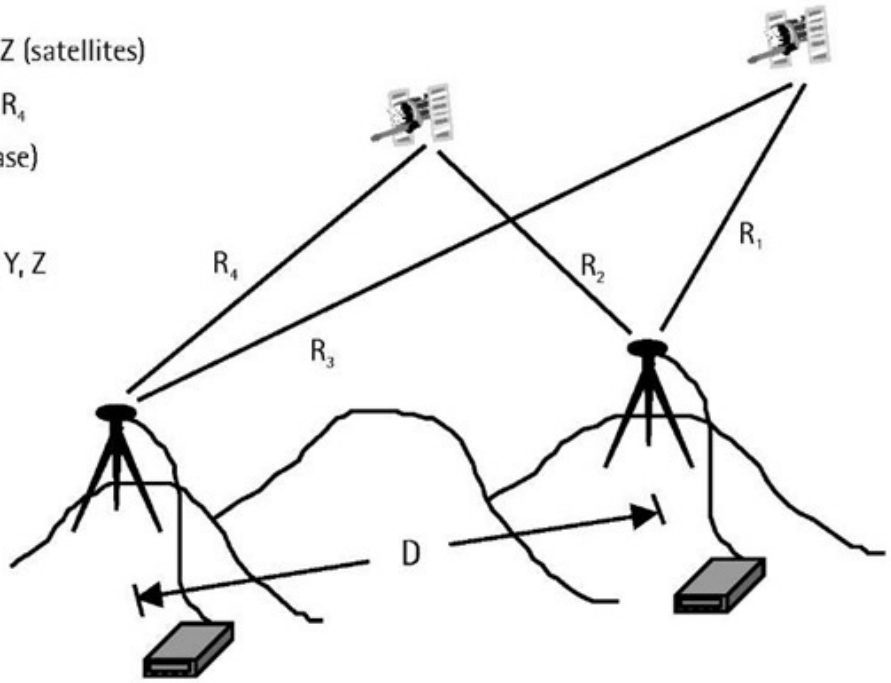
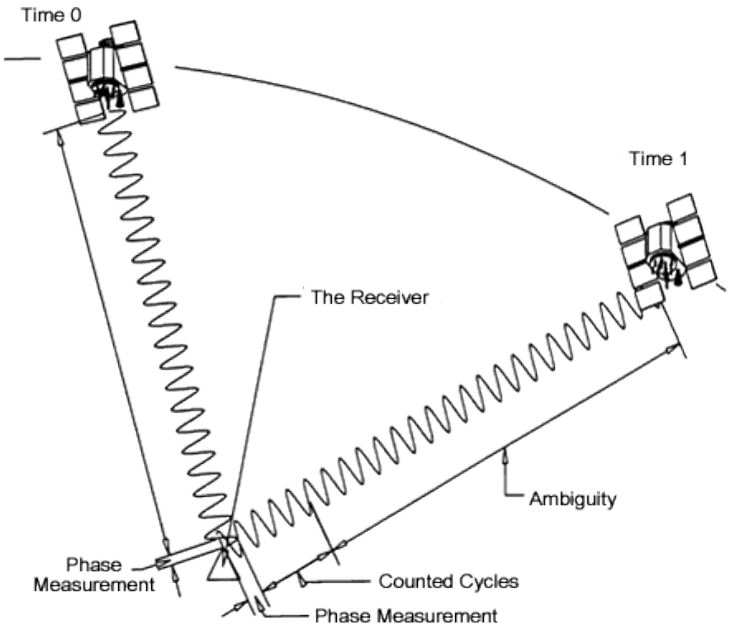
Outline

- Relative positioning
- What is precise point positioning (PPP)
  - Performance of PPP
  - Advantages and disadvantages of PPP
- Rapid ambiguity fixing in PPP
- New signals and PPP
- Virtual Reference Station (VRS) based on PPP

Relative GPS positioning & Integer ambiguity fixing

- Known: X, Y, Z (satellites)
  - \+ R_1, R_2, R_3, R_4
  - \+ X, Y, Z (base)
- Unknown: X, Y, Z (remote)

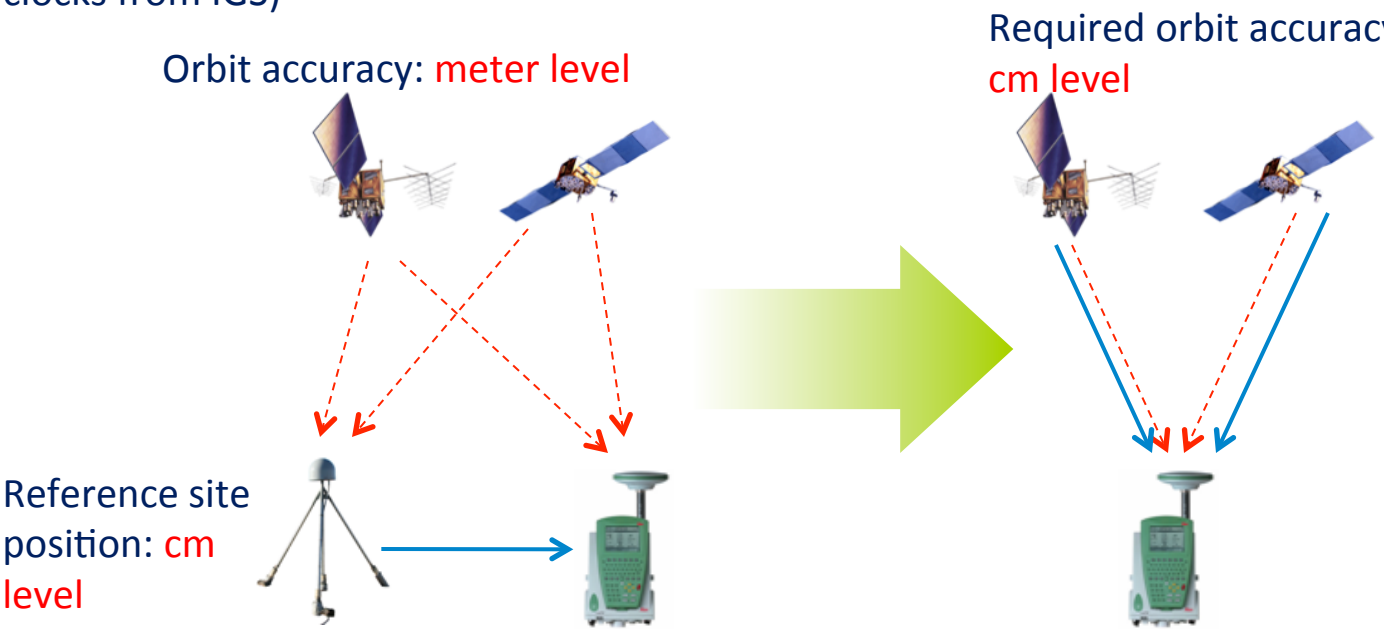




- Pros
  - Common measurement errors can be removed so data reduction is simplified
  - Integer ambiguity fixing is possible and is key to cm/mm positioning accuracy
- Cons
  - Users cannot be too far away from reference sites (preferably < 70 km)
  - Reference site may not be stable, or even unavailable (e.g. oceans, deserts, etc)

Precise point positioning (PPP)

- PPP
  - Using a single site, thus no baseline
  - Using precise satellite orbits and clocks (Free post-processing and real-time cm-level orbits and clocks from IGS)



- PPP ambiguity-fixing is not easy, because hardware biases do not cancel for a single site
- We have to model all types of measurement errors: atmosphere refraction, tidal loading, etc.

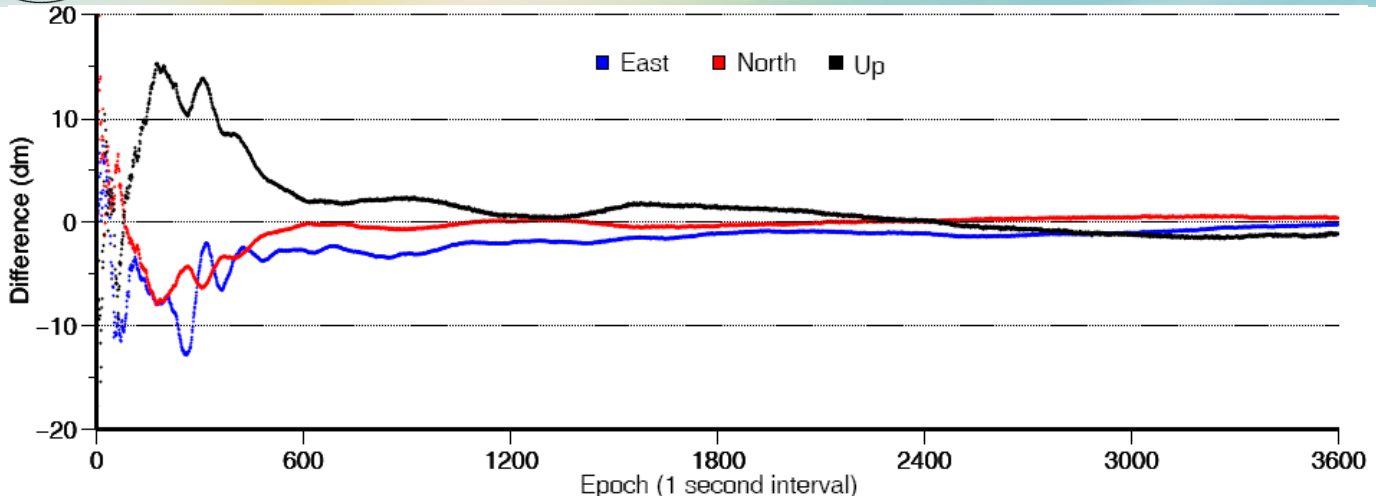
Accuracy achievement of conventional PPP

Mode	Horizontal accuracy (RMS)	Vertical accuracy (RMS)	Range
Standalone	~ 3 m	5 - 10 m	Global
DGPS, WAAS, EGNOS, etc.	0.5 – 1 m	1 – 2 m	National to continental
Precise relative positioning	< 3 cm	< 5 cm	< 100 km from base station

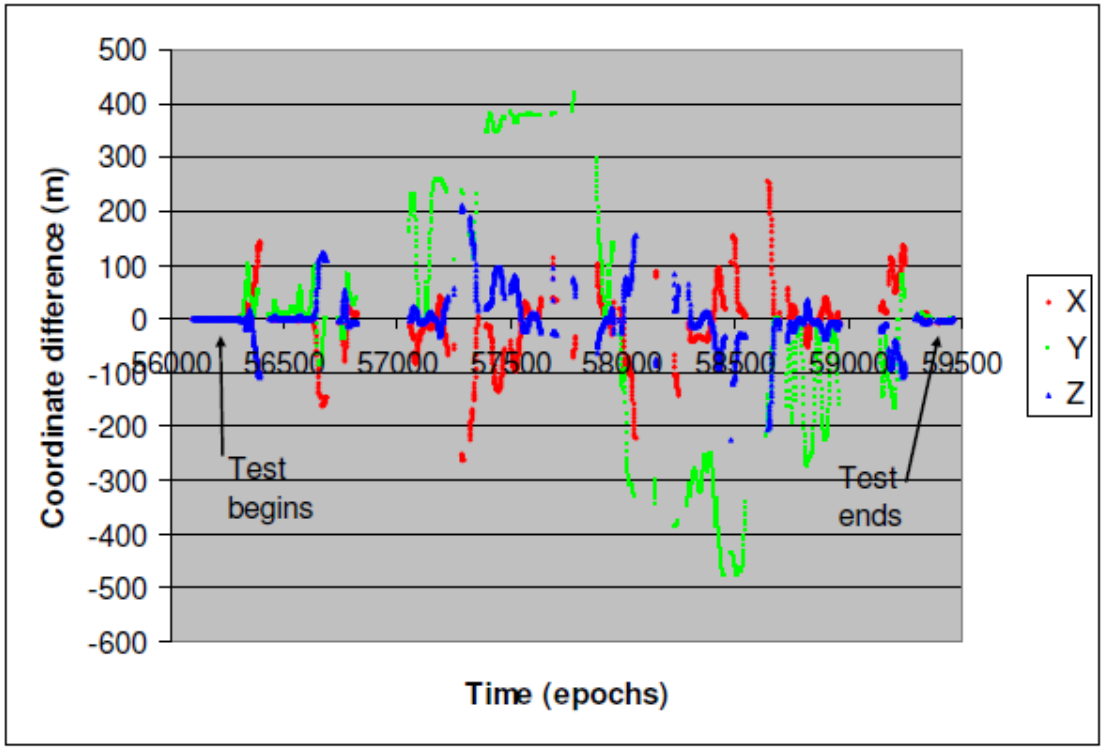
PPP without ambiguity fixing:

Measurements	Mode	RMS (cm)		
		East	North	Up
Dual-frequency	Daily static	<0.5	<0.5	<1.0
	Hourly static	~4.0	~2.0	~3.0
	Post-processing kinematic	~5.0	~4.0	~10.0
	Real-time kinematic	<10.0	<10.0	<20.0
Single-frequency	Post-processing kinematic	~25.0	~25.0	~50.0
	Real-time kinematic	~40.0	~40.0	~50.0

Slow convergence to a good solution: typical cases in conventional PPP

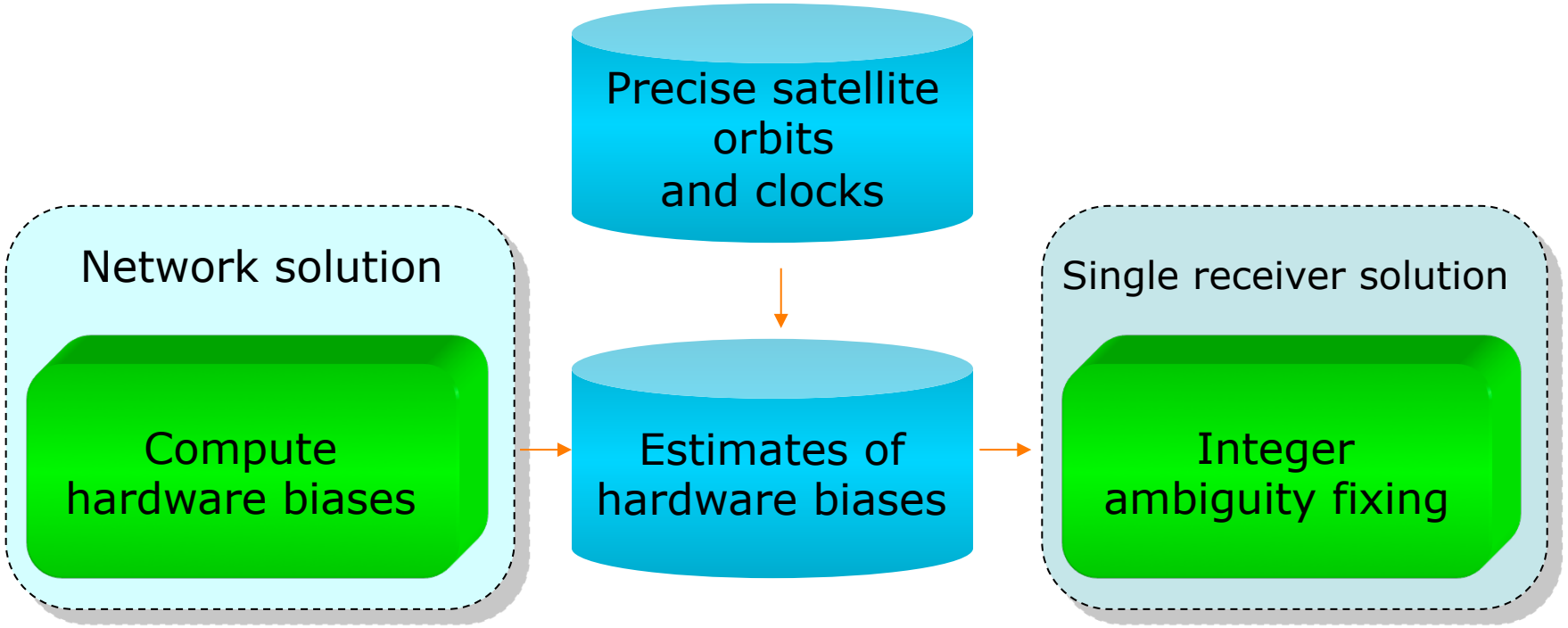


Pseudo kinematic



Real kinematic van-borne receiver

Ambiguity fixing at a single GPS receiver



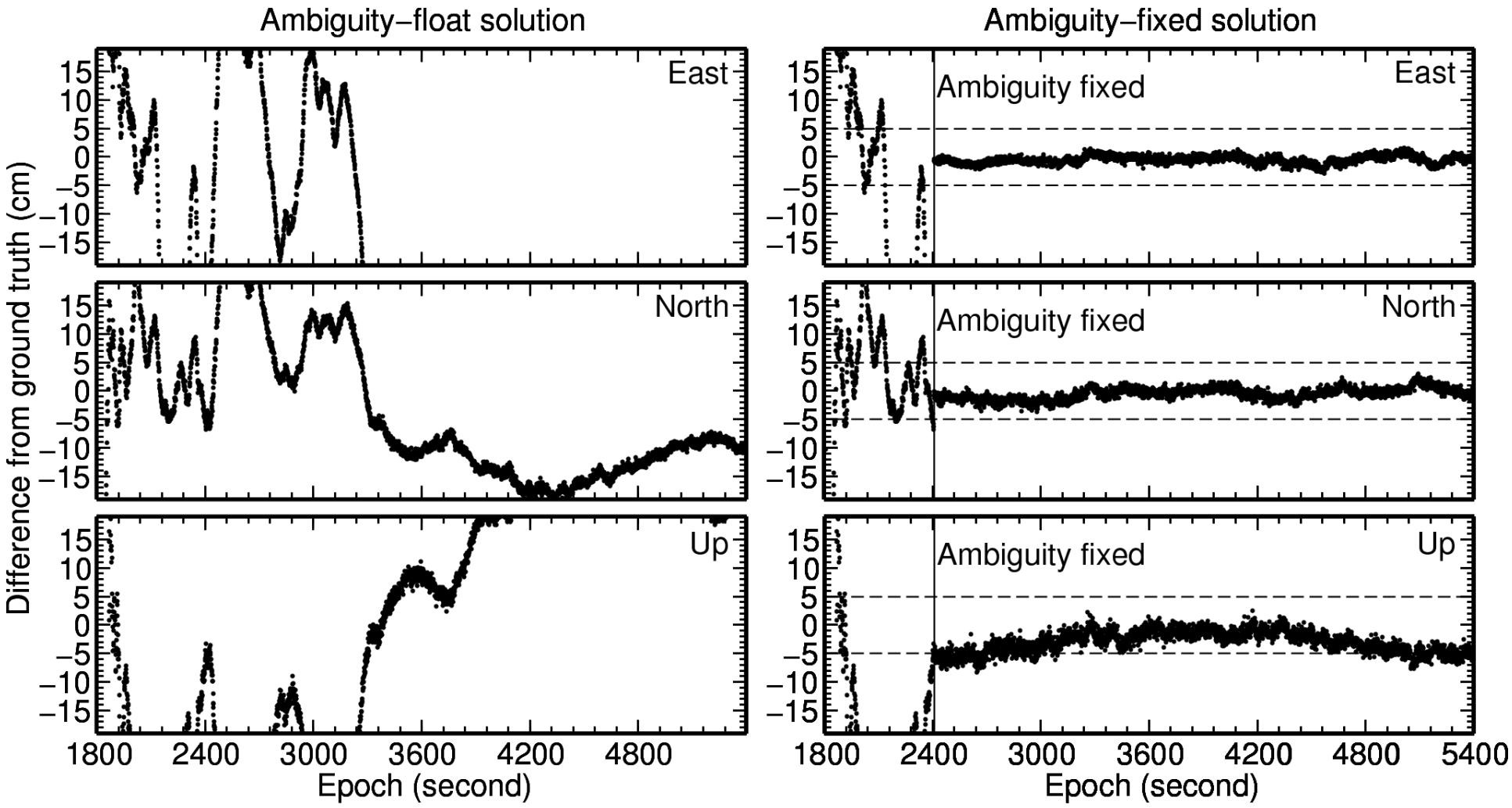
Static test: hourly observations with PPP ambiguity fixing

Station	Float Solutions (cm)				Fixed Solutions (cm)				3D Improvement
	East	North	Up	3D	East	North	Up	3D	
BRUS	3.3	1.4	2.8	4.5	0.4	0.4	1.3	1.5	67.8%
CAGL	4.8	1.9	4.0	6.5	1.0	0.8	2.0	2.4	63.8%
DUBR	5.6	1.9	3.3	6.8	0.4	0.6	1.3	1.4	78.7%
GOPE	4.5	1.8	2.9	5.7	0.3	0.4	1.5	1.6	72.1%
GRAS	2.4	1.1	2.4	3.6	0.4	0.4	1.3	1.4	60.6%
HERS	4.1	1.3	2.4	5.0	0.3	0.4	1.2	1.3	74.1%
LAMA	3.8	1.5	2.6	4.8	0.7	0.6	1.4	1.7	65.1%
MAR6	3.3	1.6	2.3	4.3	0.7	0.7	1.5	1.8	58.7%
MAS1	5.4	1.4	4.6	7.2	0.5	0.6	2.5	2.6	64.0%
MDVJ	3.1	1.2	2.2	4.0	0.4	0.7	1.6	1.8	55.7%
NSSP	3.8	1.3	3.1	5.1	0.5	0.5	1.8	1.9	62.3%
POLV	4.0	1.9	3.0	5.3	0.4	0.5	1.7	1.8	66.2%
POTS	3.6	1.4	2.8	4.8	0.3	0.4	1.3	1.4	70.0%
REYK	4.0	2.0	3.2	5.5	0.5	0.6	2.2	2.3	58.2%
TRO1	1.5	1.1	1.8	2.6	0.3	0.3	1.2	1.3	51.6%
VILL	4.1	1.5	3.4	5.6	0.4	0.5	1.5	1.6	70.5%
ZIMM	3.1	1.2	2.4	4.1	0.4	0.4	1.2	1.3	68.2%
Total	**3.9**	**1.5**	**3.0**	**5.1**	**0.5**	**0.5**	**1.6**	**1.7**	**66.1%**

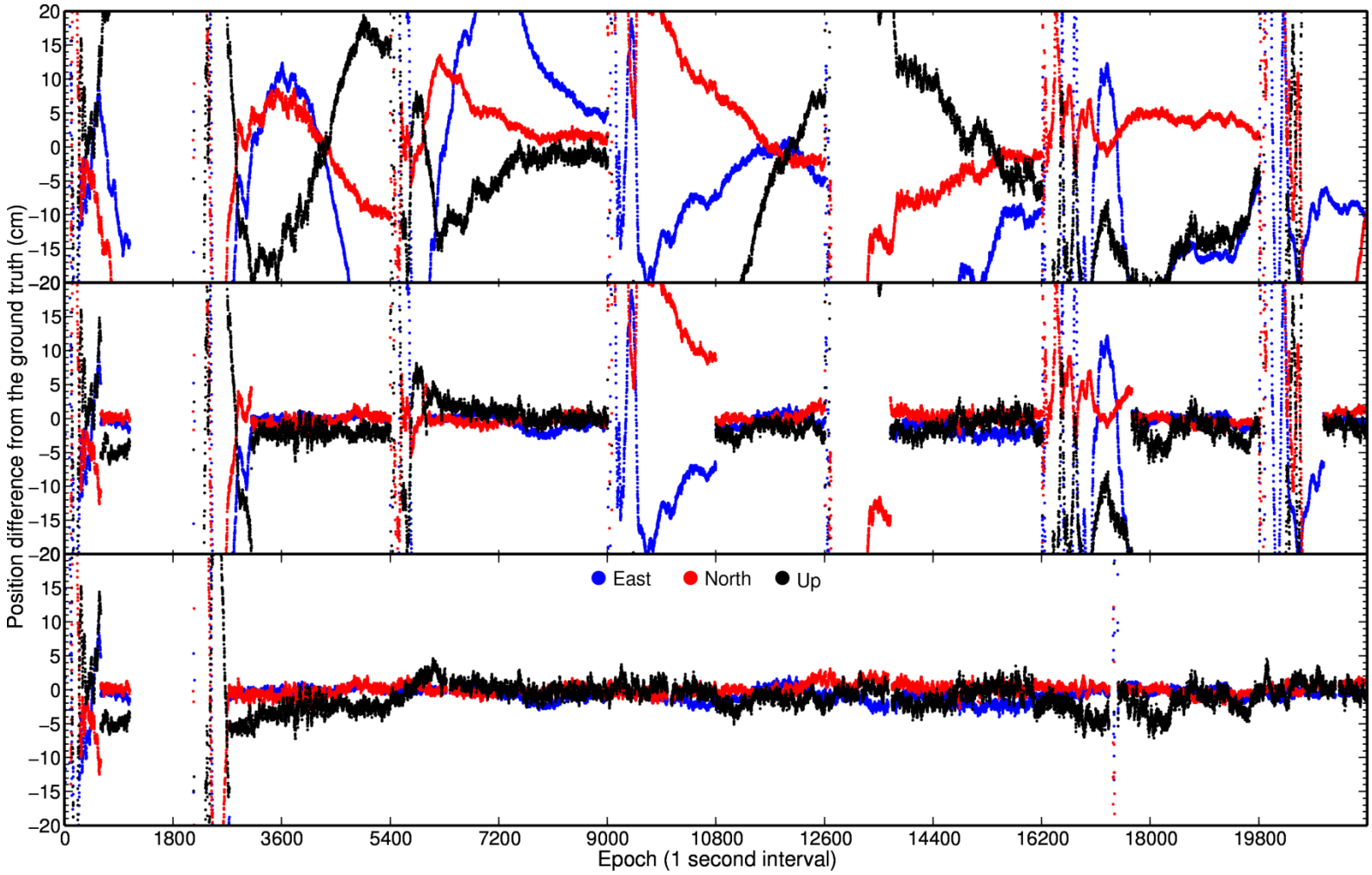
Improvement: East~87.2% North~66.7% Up~46.7%

Can ambiguity fixing speed up convergences in PPP?

- 10 – 20 min are needed before a reliable ambiguity fixing in PPP



Rapid recovery after GPS outages in PPP ambiguity fixing



Conventional PPP

Ambiguity-fixed

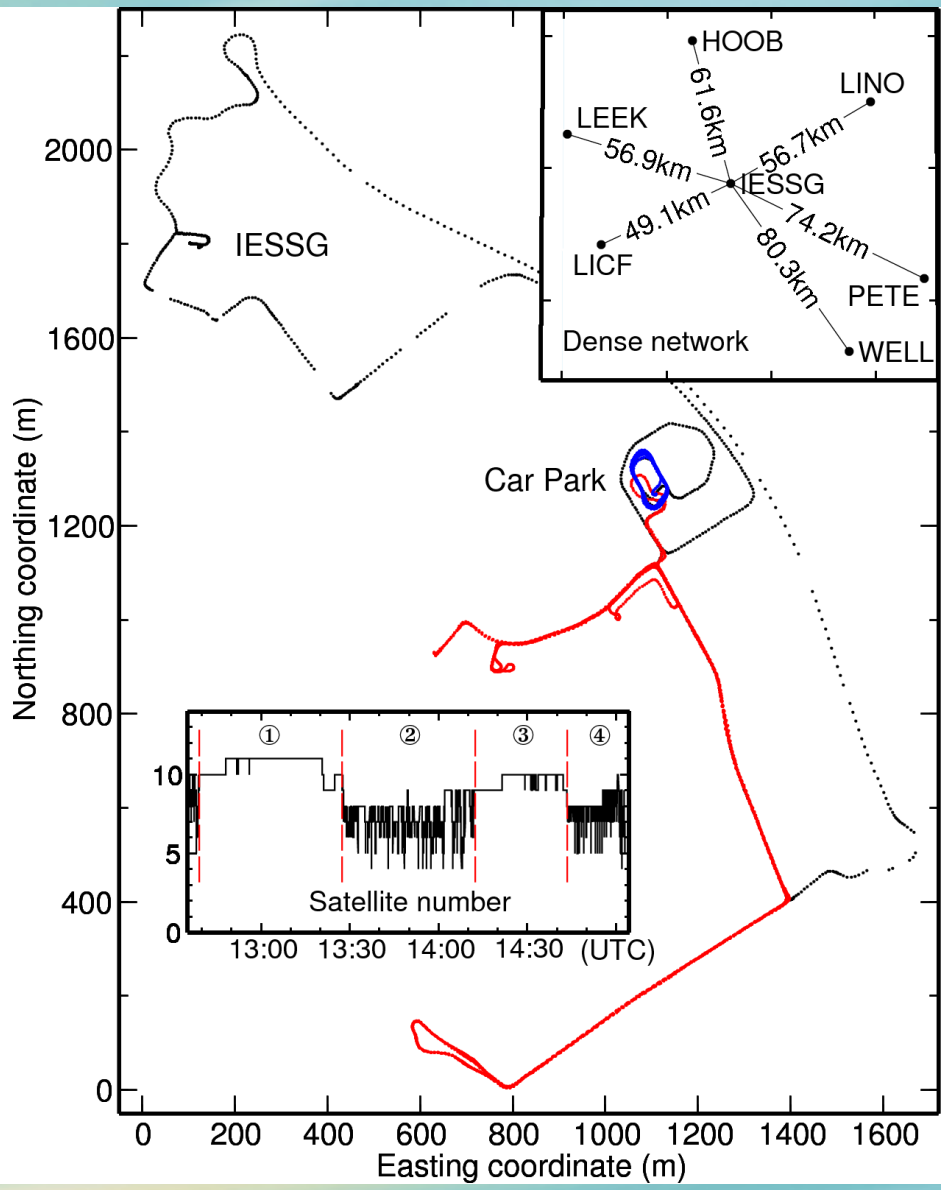
Ambiguity-fixed & rapid recovery

Ambiguity resolution improves positioning accuracy

Rapid recovery improves precise point positioning efficiency

A van experiment to test PPP ambiguity fixing and rapid recovery

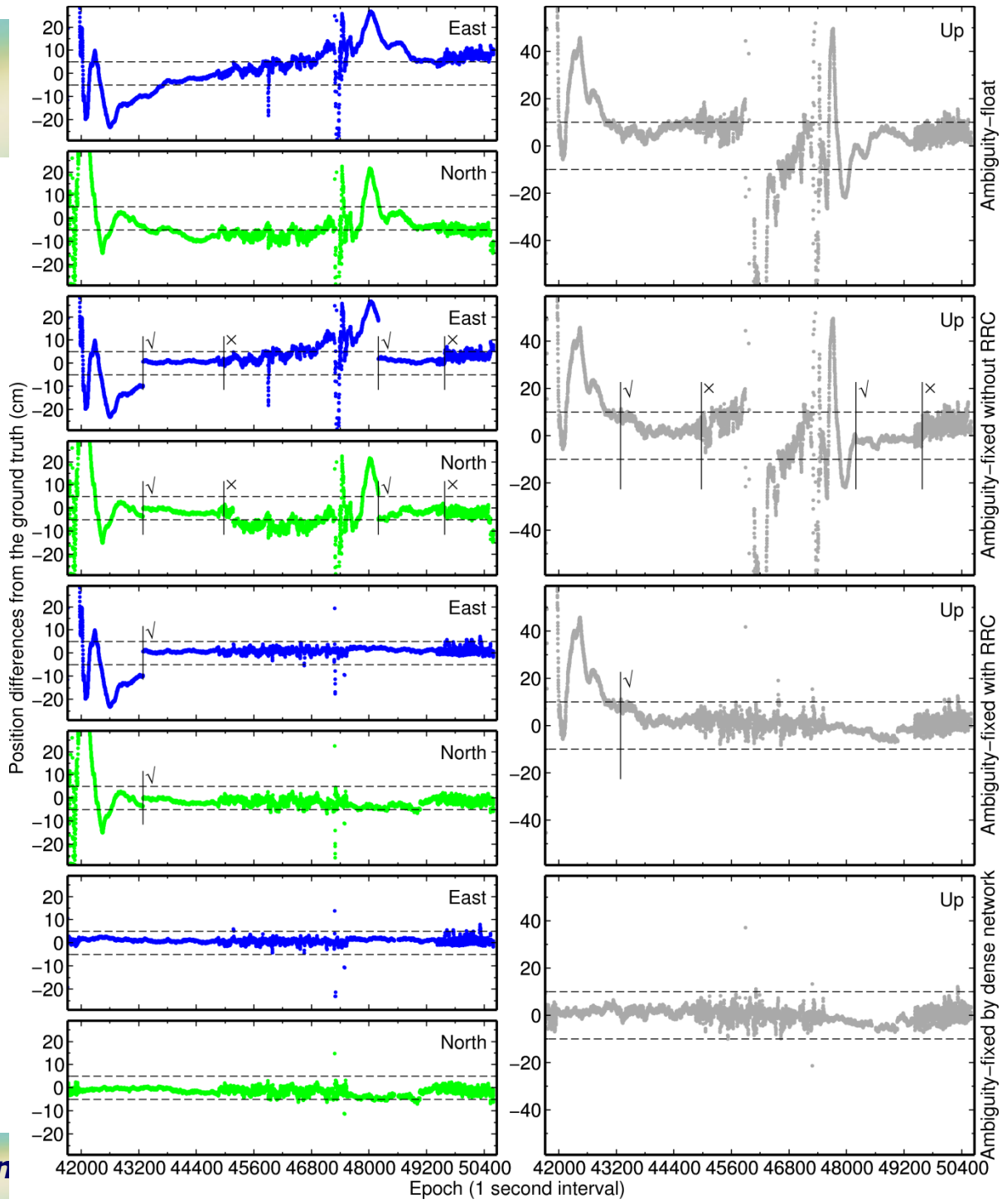
- Experiment
  - A van collecting 1-Hz data
  - Stage 1: Van stopped on the car park (open area)
  - Stage 2: Van repeatedly moved along a busy road (red line). Buildings, large trucks, etc. obstructed signals
  - Stage 3: Van stopped again on the car park
  - Stage 4: Van moved on the car park (blue line)
  - A reference station at IESSG



Performance

- Ambiguity-float solutions
- Ambiguity-fixed solutions without rapid recovery
- Ambiguity-fixed solutions with rapid recovery

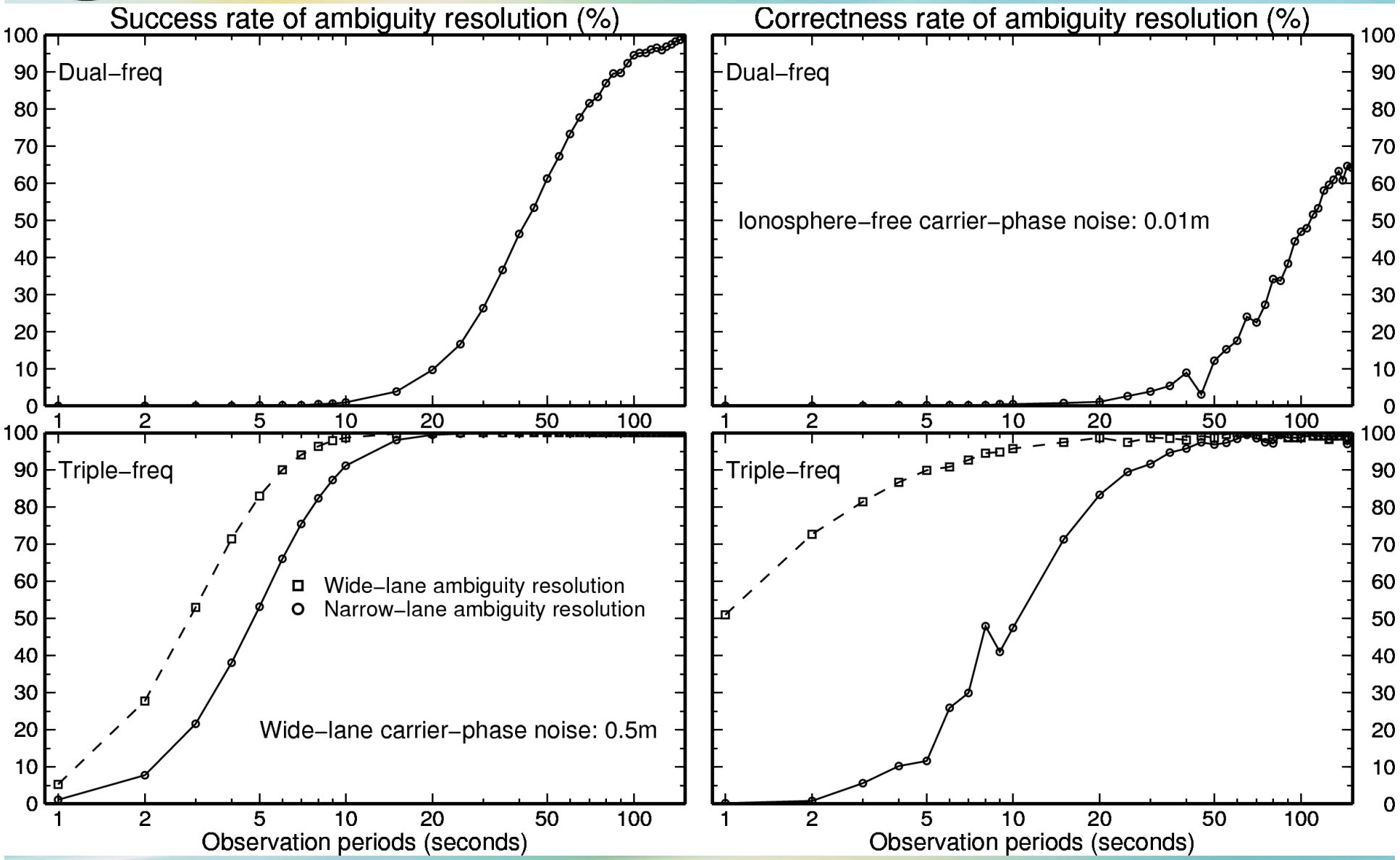
- Ambiguity-fixed solutions augmented by a dense reference network



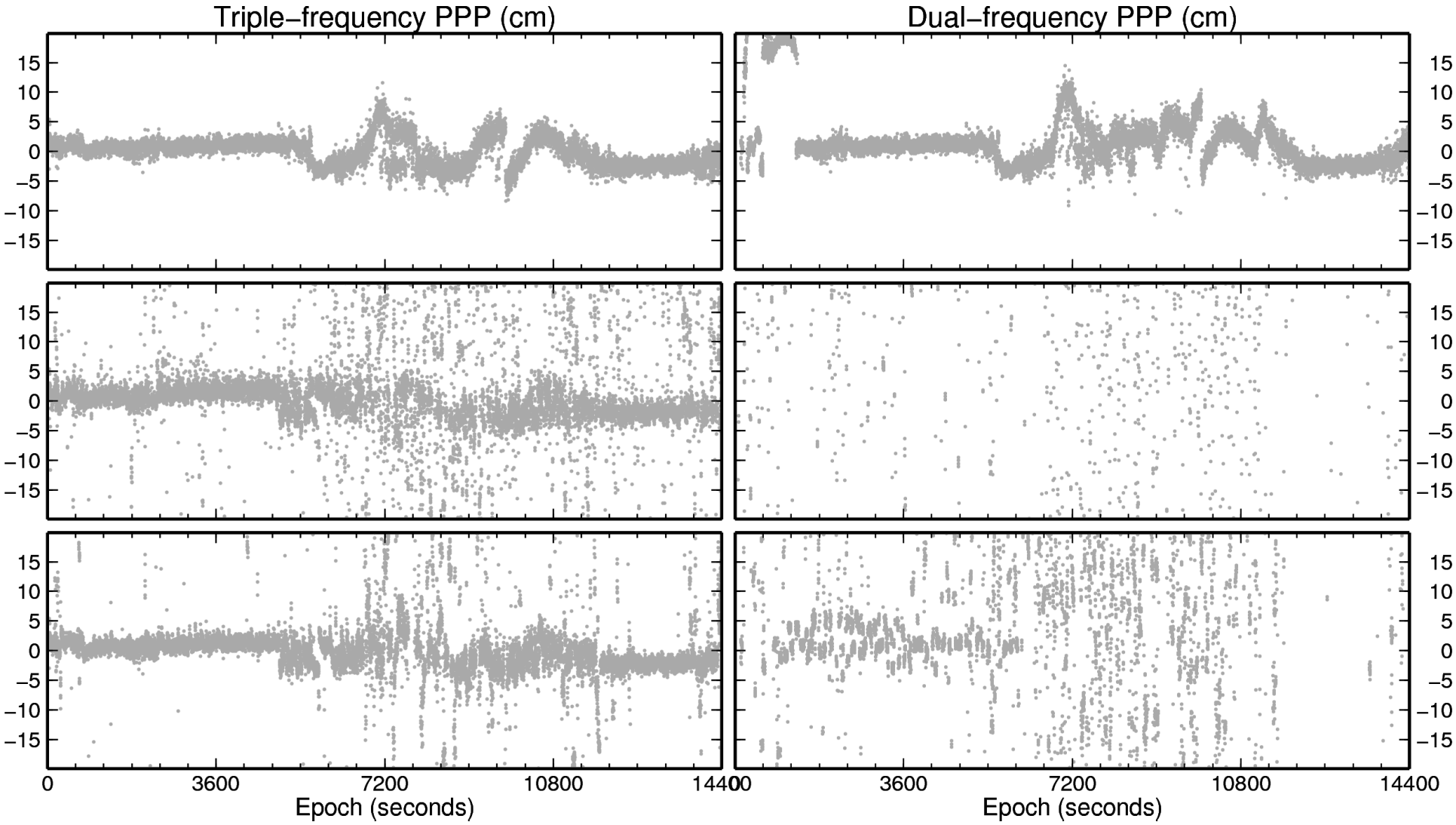
Simulation for triple-frequency data

- GSS8000 hardware simulator by Spirent
- Septentrio receiver
- Troposphere delay: RTCA06
- Ionosphere delay: Klobuchar
- Receiver antenna level pattern is applied
  - Elevation-dependent attenuation
- Use default satellite orbit and satellite clocks
- Land mobile multipath effect
  - Rural environment
  - <15°, reflected signals only
  - <40°, allow reflected signals

Success rate & correctness rate of PPP ambiguity fixing



Multipath effects on triple-frequency PPP ambiguity fixing

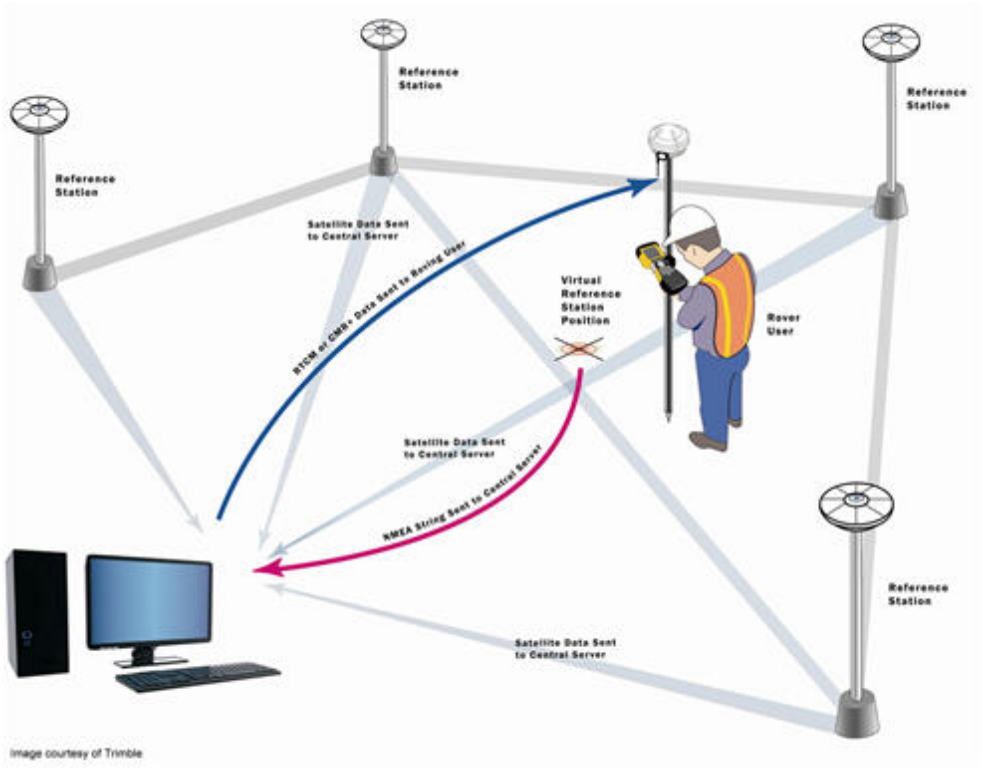


PPP-RTK service for CRTN

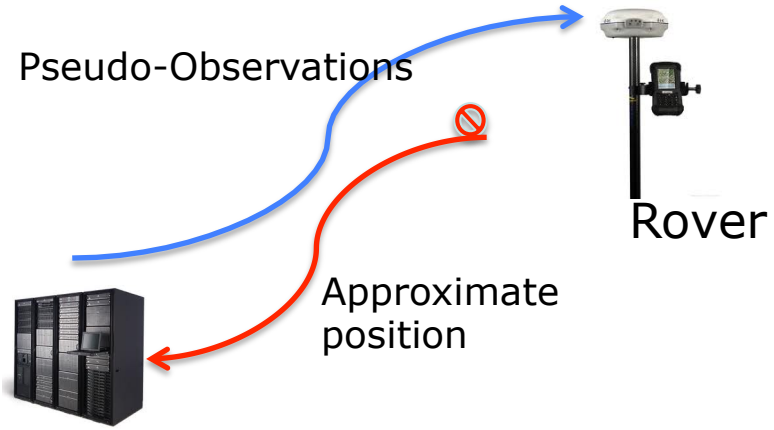
- We are implementing an ambiguity-fixed PPP-RTK service for CRTN that should improve on current network methods and be based on the California Spatial Reference System (CSRS) provided by CSRC . Real-time atmospheric and ionospheric corrections based on true-of-date ITRF2008 coordinates, with ultra-rapid orbits and satellite clock estimated are used to construct pseudo PPP observations for a user's location, transmitted in RTCM3 format.
- Compared with Network RTK service, PPP-RTK will allow precise positioning anywhere in California with respect to a continental-scale or global-scale reference network.

Virtual Reference Station (VRS) based on PPP

VRS based on relative positioning



VRS based on PPP



Server
- Precise orbits/clocks
- Precise atmosphere models

Precise Point Positioning Service for real-time clients developed by SOPAC

Predicted orbits from IGS

ITRF positions & metadata (SOPAC)

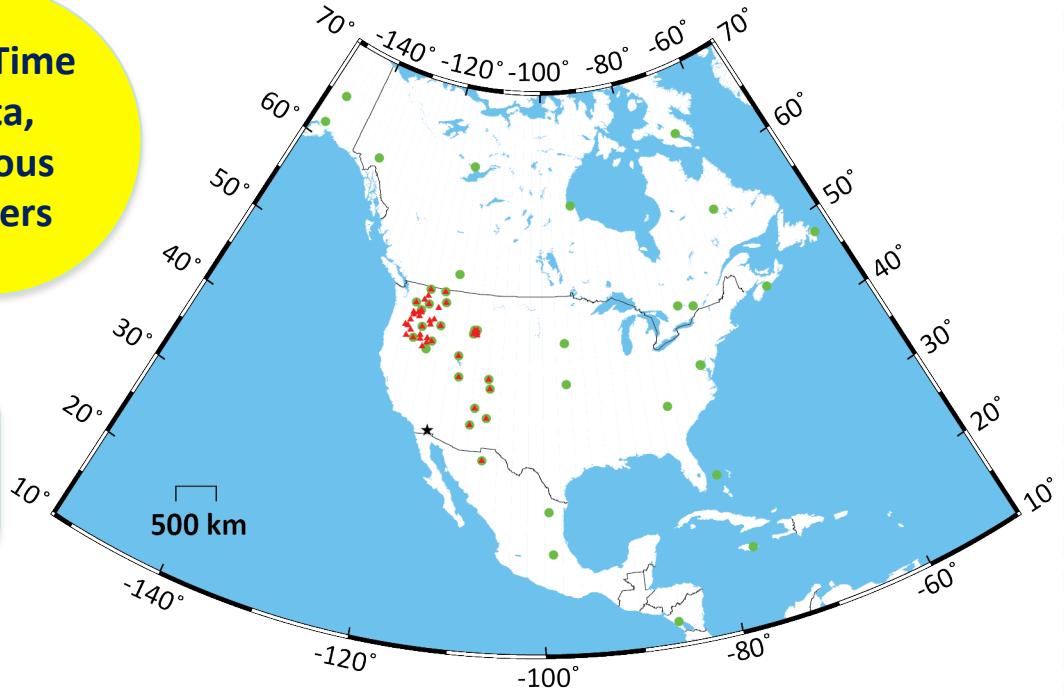
Real-Time Data, Various Servers

Generate Satellite Clocks

Generate Fractional-Cycle Biases

CRTN Server

Operational



Generate California-Based Troposphere and Ionosphere Model

RTCM3

PPP client

RTK User

Structural Monitoring

Other Users

75 stations used as reference stations which are located >200 km away from western US coast