GNSS Lab Project

Comparison of PPP and RTK under static and dynamic scenarios

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Content

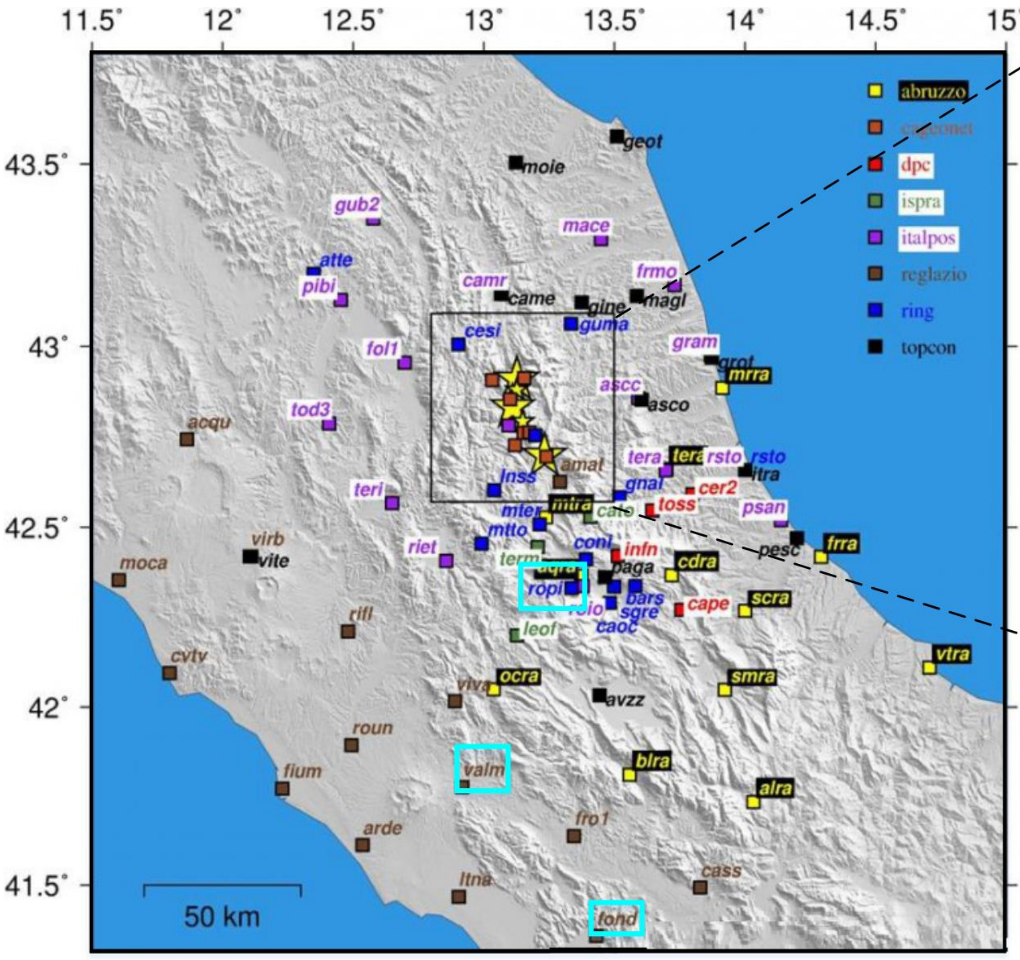
Introduction

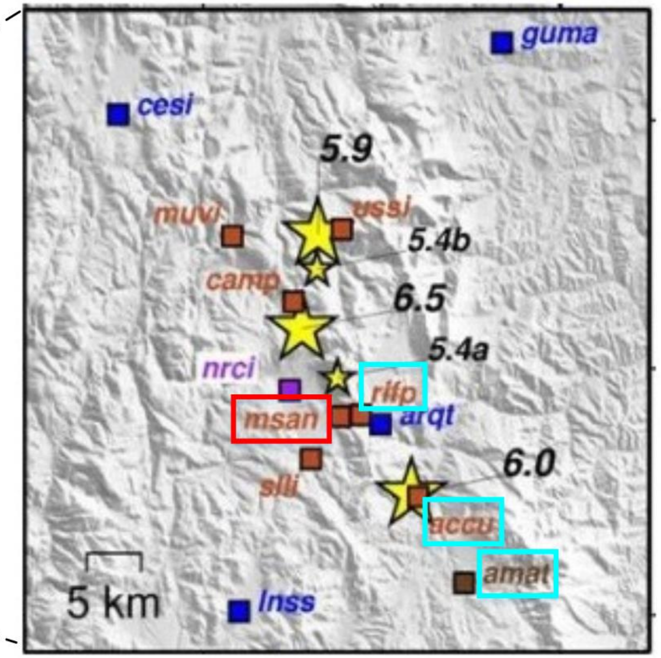
Introduction

- RTK & PPP

- RTKLIB
- PPP-WIZARD
- PRIDE PPP-AR

Dataset





Date	Origin Time (UTC)	Latitude (DD.dddd)	Longitude (DD.dddd)	Depth (km)	Mw
2016-08-24	01:36:32.00	42.6983	13.2335	8.1	6.0
2016-08-24	02:33:28.00	42.7922	13.1507	8.0	5.4a
2016-10-26	17:10:36.34	42.8802	13.1275	8.7	5.4b
2016-10-26	19:18:05.85	42.9087	13.1288	7.5	5.9
2016-10-30	06:40:17.36	42.8322	13.1107	9.2	6.5

RING RETE INTEGRATA NAZIONALE GNSS
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Dataset preparation

Static Dataset

Frequency: 1 Hz (originally 10 Hz)

Duration: 1/11/2016 (DOY306) 09:00-13:00

Rover station: **MSAN**

Base station: from shortest to longest baseline

RIFP (~1km to MSAN, short baseline)

AMAT (~20km to MSAN, medium baseline)

FOND (~170km to MSAN, long baseline)

Dynamic Dataset

5.4b earthquake of October 26, 2016

Frequency: 10 Hz

Duration:

Dynamic: 26/10/2016 (DOY300) 16:00-19:30 (earthquake at 17:10)

Static Reference: 24/10/2016 (DOY298) 16:00-19:30

Rover Station: station closest to the centre of earthquake, **MSAN** (~10km to earthquake centre)

Base Station: station farthest from the centre of earthquake, **FOND** (~175km to earthquake centre)

Procedure

Data Conversion

- Standard RINEX Observation File

Ground Truth

- PRIDE PPP-AR

RTK Solution

- RTKLIB
- Different Baseline Length

PPP Solution

- PPP WIZARD

Methods

What is PPP?

- **PPP (precise point positioning)** refers to users using the carrier phase and pseudocode range observations of a GNSS receiver, using high-precision satellite orbit and clock difference products, and carefully considering the influence of satellite, signal propagation path and receiver-related errors on positioning to achieve high-accuracy positioning

What is PPP?

Advantages:

- No need of base station from user end
- No limitation of distance
- Flexible and cost-effective (hand-held moving devices)

Main Challenge in PPP

- **Fix integer ambiguity will greatly improve the positioning quality**
  - Fractional-cycle biases destroy the integer property
  - Network solution could not be applied due to a single receiver
- **The integer property of PPP ambiguities should be recovered through the pre-calibration of phase biases**

Integer Clock Model (what is used in PPP Wizard)

- Network Solution
- PPP Solution
- CNES Product

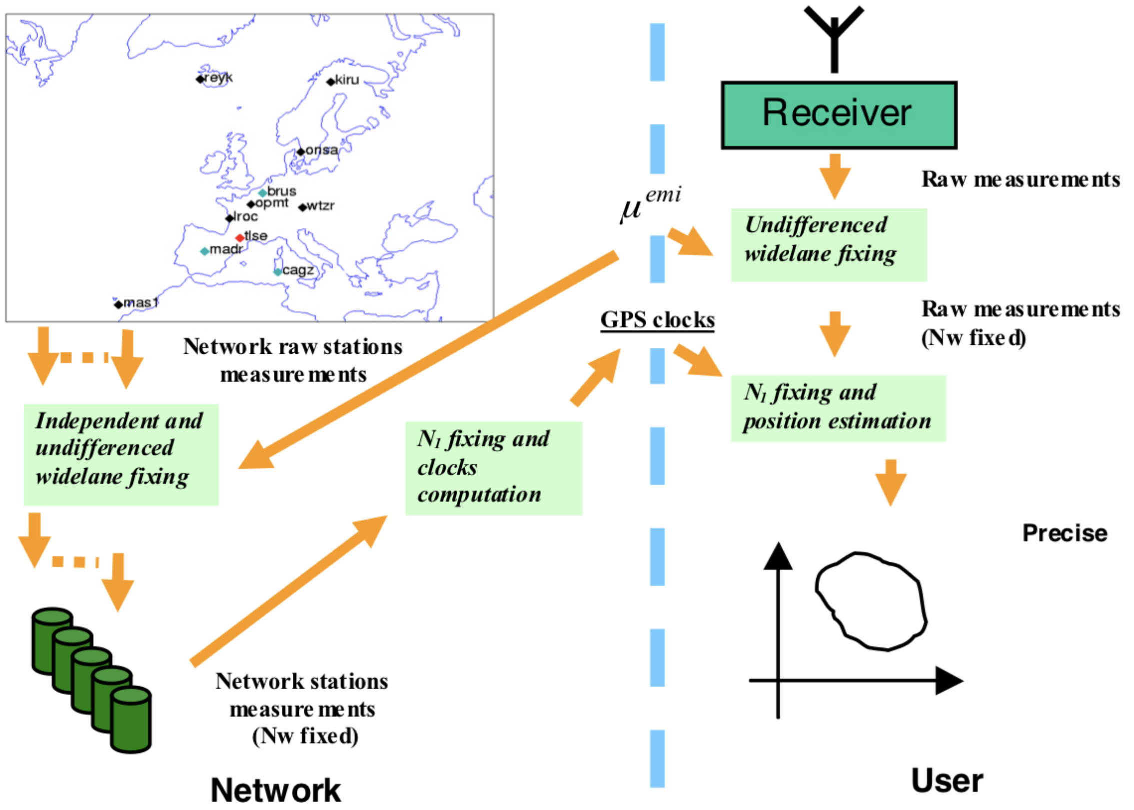


Figure from: [D. Laurichesse., et al., 2008]

Integer Clock Model (what is used in PPP Wizard)

- **Network Solution**

- Zero-difference wide-lane integer ambiguity fixing is performed independently for each receiver of the network using previously determined satellite delays

- The remaining ambiguities are fixed globally over the whole network using zero-differenced narrow-lane integer ambiguity fixing

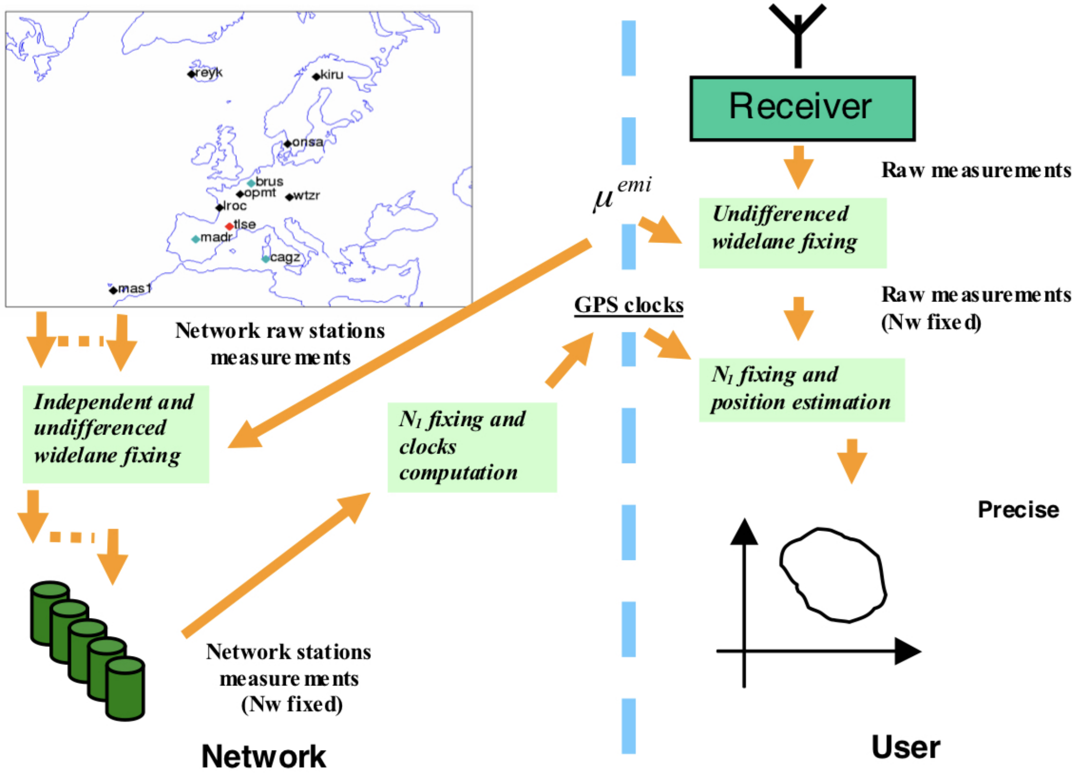


Figure from: [D. Laurichesse., et al., 2008]

Integer Clock Model (what is used in PPP Wizard)

- **PPP Solution**

- The same first processing step is applied to any receiver to fix its zero-difference integer wide-lane ambiguities, using the same satellite delays as the ones used in the network solution

- Integer phase clocks are used to fix the remaining ambiguities on the first frequency, leading to 'absolute' centimetre-level PPP

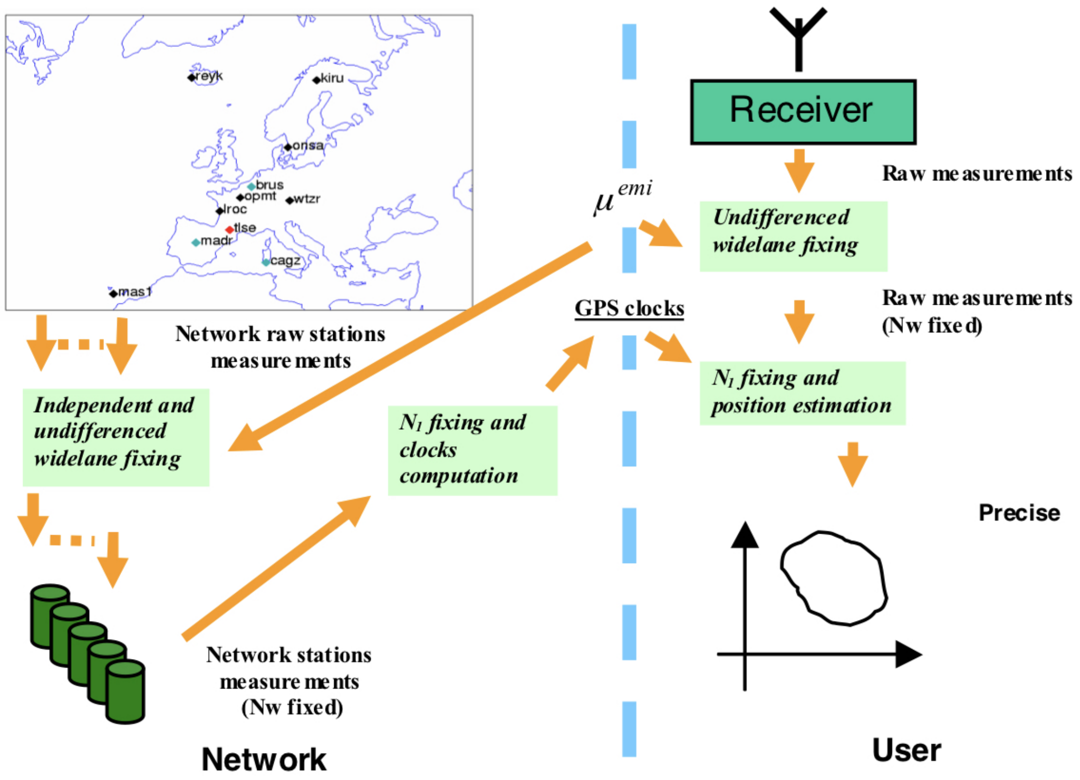


Figure from: [D. Laurichesse., et al., 2008]

Solution to Realize Phase Bias Computation

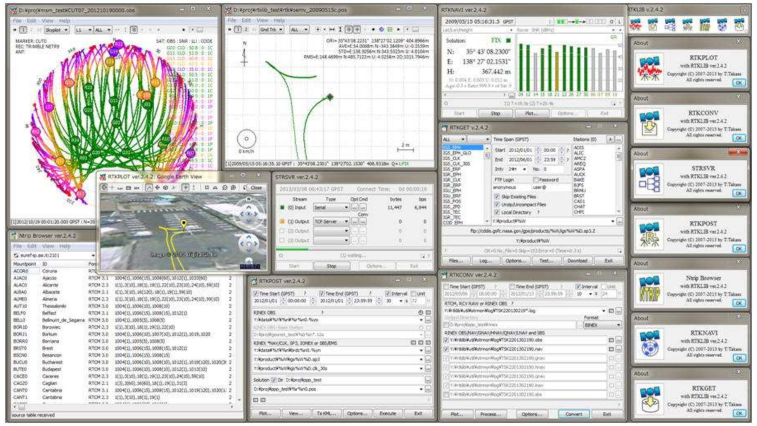
- **FCB (fractional cycle bias) -based Method**
- UPD Model

- **IRC (integer recovery clocks) -based Method**
- Integer Clock Model
- De-coupled Clock Model

Experiment Settings

RTKLib configurations

RTK with different baseline length



<table>
<tr><th rowspan="2"></th><th rowspan="2">BL (km)</th><th colspan="4">Error Elimination</th><th rowspan="2">Strategy</th></tr>
<tr><th>Ephem</th><th>Ionos</th><th>Tropos</th><th>Others</th></tr>
<tr><td>S</td><td>0 – 10</td><td>Broadcast</td><td>-</td><td>-</td><td>-</td><td rowspan="2">Conventional RTK</td></tr>
<tr><td rowspan="2">M</td><td rowspan="2">10 – 100</td><td rowspan="2">Broadcast</td><td>Dual-Freq</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Interpolation</td><td>-</td><td>Network RTK</td></tr>
<tr><td>L</td><td>100 – 1,000</td><td>Real-time Precise (IGU)</td><td>Dual-Freq</td><td>Estimate ZTD + MF</td><td>Earth Tides</td><td>Long-Baseline RTK</td></tr>
</table>

Table 3. Option settings of RTPOST for the offline test to evaluate proposed long baseline RTK strategy

Option	Setting
Positioning Mode	Kinematic
Frequencies	L1+L2
Receiver Dynamics	OFF
Earth Tides Correction	ON
Elevation Mask	7°
Ionosphere Correction	Estimate STEC
Troposphere Correction	Estimate ZTD + Gradient
Satellite Ephemeris	Precise
Ambiguity Validation Threshold	3.0
Min Elevation to Fix Ambiguity.	25°
Min Elevation to Hold Ambiguity	35°
Code/Carrier-Phase Error Ratio	100
Carrier Phase Error	0.003 + 0.003 / sin El m
Process Noise of Vertical Iono. Delay	10^{-3} m / sqrt(s)
Process Noise of ZTD	10^{-4} m / sqrt(s)
Satellite Antenna Model	IGS05.ATX
Receiver Antenna Model	IGS05.ATX

Tabel from [Tomoji.T.,et al.,2010]

PPP Wizard configurations

Realtime-PPP

```
mode_PPP_AR mode
igs14_1992.atx antexFileName
1 1 0 AR/JumpsIndicators
1 useGPS
1 useGlonass
0 useGalileo
0 useBeidou
0 sbasCorrection
0 convergence
0 outputVerbose
1.0 pas
10.0 maxAge
3600 nbMin
2 maxReject
1 raim
6.0 threRab
0.5 sigIniTro
0.000005 sigModTro
0 nbSatFixAmb
0.01 threAmb
0.0 sigIniBiasClk
0.001 sigModBiasClk
10.0 sigIniIono
0.002 sigModIono
```

[D. Laurichesse,et al.,2010]

```
1.0 1.0 0.0 sigMesIono
5.0 threMesIono
0.1 sigMesTropo
1.0 threMesTropo
5 sigIniPos
0.002 sigModPos
300 pretDTMax
10.0 threMesCode
0.05 threMesPhase
1.0 sigMesCodeGps
0.01 sigMesPhaseGps
5.0 sigMesCodeGlo
0.01 sigMesPhaseGlo
1.0 sigMesCodeGal
0.01 sigMesPhaseGal
5.0 5.0 5.0 sigMesCodeBds
0.01 0.01 0.01 sigMesPhaseBds
0.0 smooth
```

Used files/products

- P1C11611.DCB
- P1P21611.DCB
- P2C21611.DCB
- P2C21611_RINEX.DCB

- cnt19212.sp3
- cnt19212.clk
- cnt19212.bia

- msan3060.16o
- msan3060_1hz.16o

- igs14_1992.atx

Pride PPPAR configurations and results

Post-processing PPP

PRIDE Lab — Positioning Racers to Image & Decipher the Earth

[Geng.,et al.,2019]

Download OTL BLQ file from

Ocean tide loading provider

holt.oso.chalmers.se

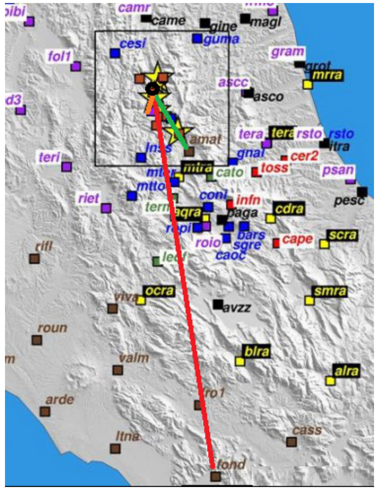
```
## strategies
Remove bias       = YES                    ! change to NO if AR method is LAMBDA
ZTD model         = PWC:60                 ! troposphere estimation. PWC: piece-wise constant, 60: 1 hour
HTG model         = PWC:720                ! troposphere horizontal gradient. PWC/NON

## ambiguity fixing options
Ambiguity fixing    = FIX                  ! Ambiguity fixing: NO/FIX/LAMBDA
Common observing    = 600                  ! common observation time in seconds
Cutoff elevation    = 15                   ! cutoff angles for eligible ambiguities in AR
Widelane decision   = 0.20 0.15 1000.      ! deriation, sigma in WL-cycle
Narrowlane decision = 0.15 0.15 1000.      ! deriation, sigma in NL-cycle
Critical search     = 2 4 1.8 3.0
```

Station	X(m)	Y(m)	Z(m)	std.X(mm)	std.Y(mm)	std.Z(mm)	Notes
MSAN	4567666.272	1067487.265	4308726.184	1.8	0.9	1.0	ROVER
RIFP	4567491.529	1069312.105	4309206.113	5.1	2.6	3.1	BASE(1km)
AMAT	4574948.639	1080829.780	4297745.196	1.4	0.9	0.8	BASE(20km)
FOND	4663468.185	1113756.262	4192232.917	1.0	0.7	0.6	BASE(170km)

Experiment Results and Analysis

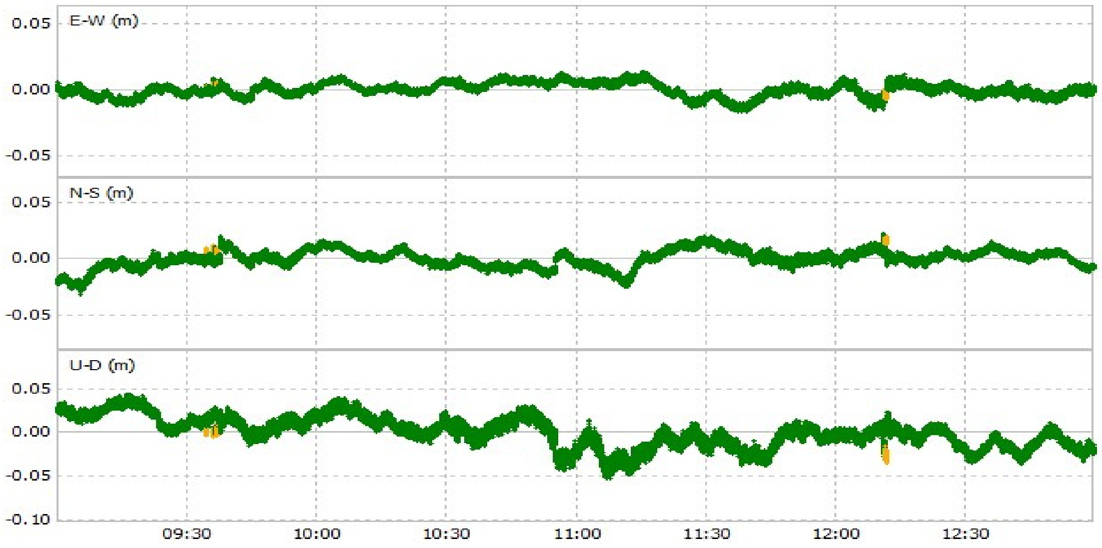
Experiments on Static Dataset

Our results of RTK

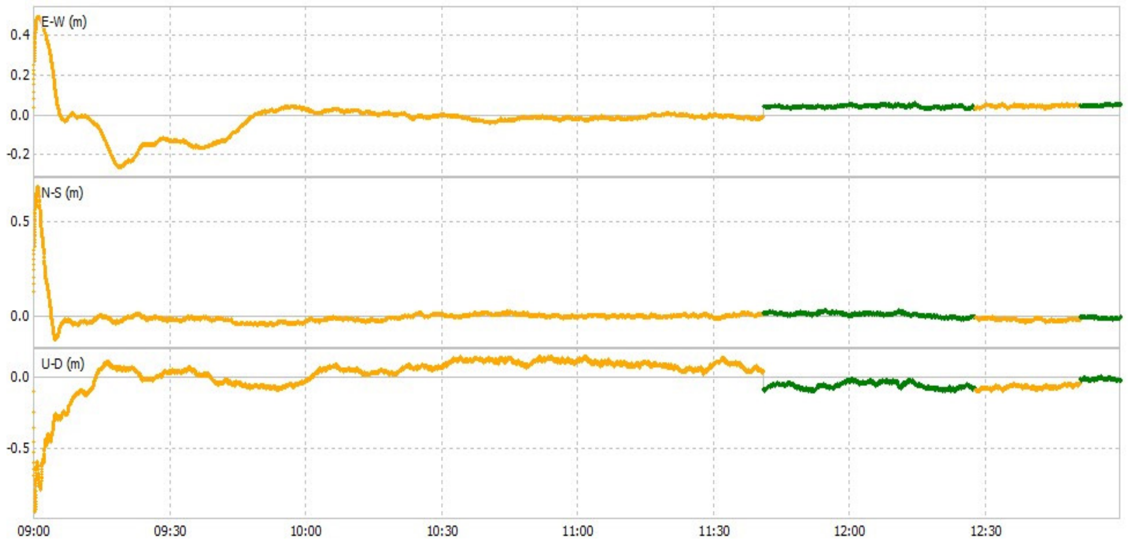


4 hours time sequence

Baseline length (km)	fixing ratio	average standard devaition (cm)		
		E-W	N-S	U-D
1 (short)	98%	0.5	0.2	1.2
20 (medium)	85%	1.0	0.3	2.6
170 (long)	34%	0.9	0.4	4.2



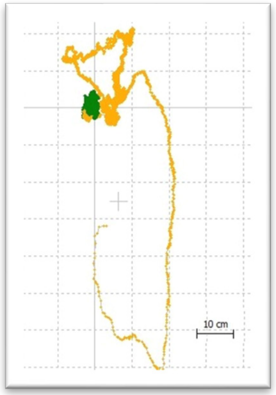
Short baseline

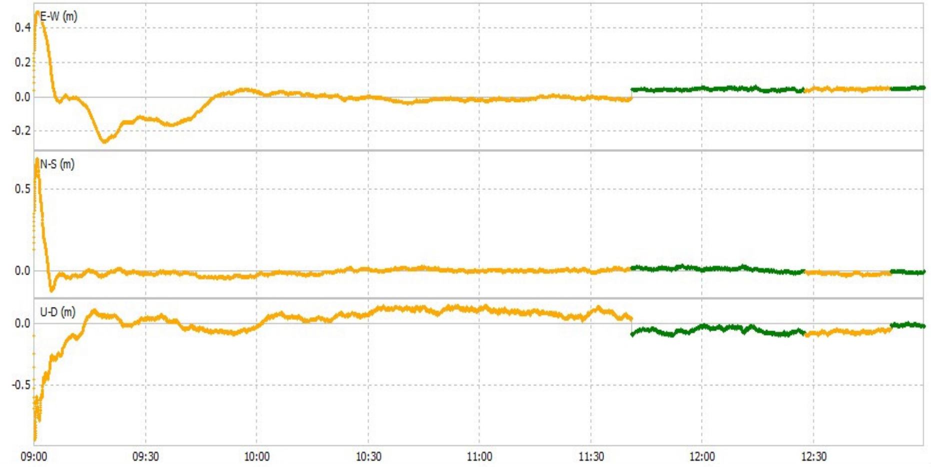


Long baseline

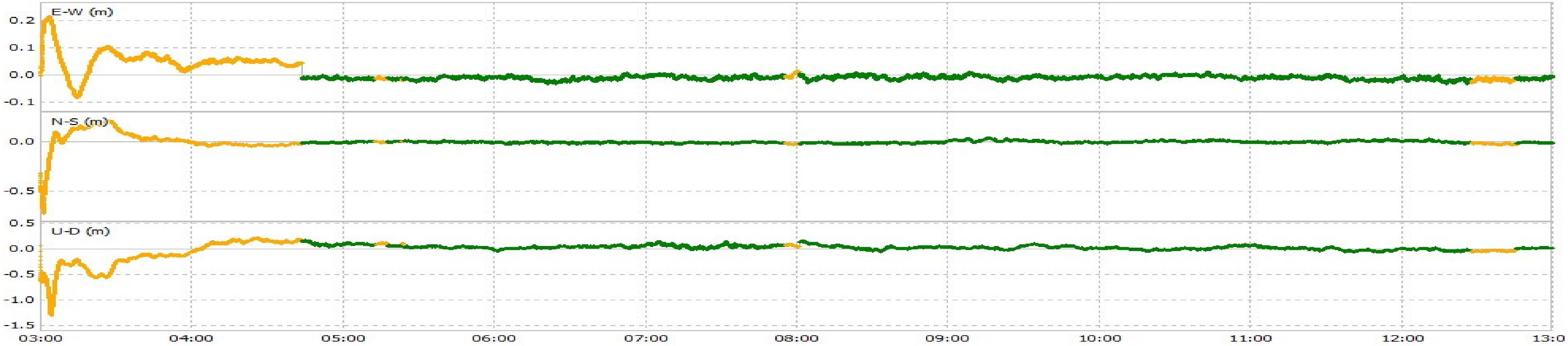
Our results of long baseline RTK

ambiguity fixing ratio





4 hours , Fixing ratio: 34%

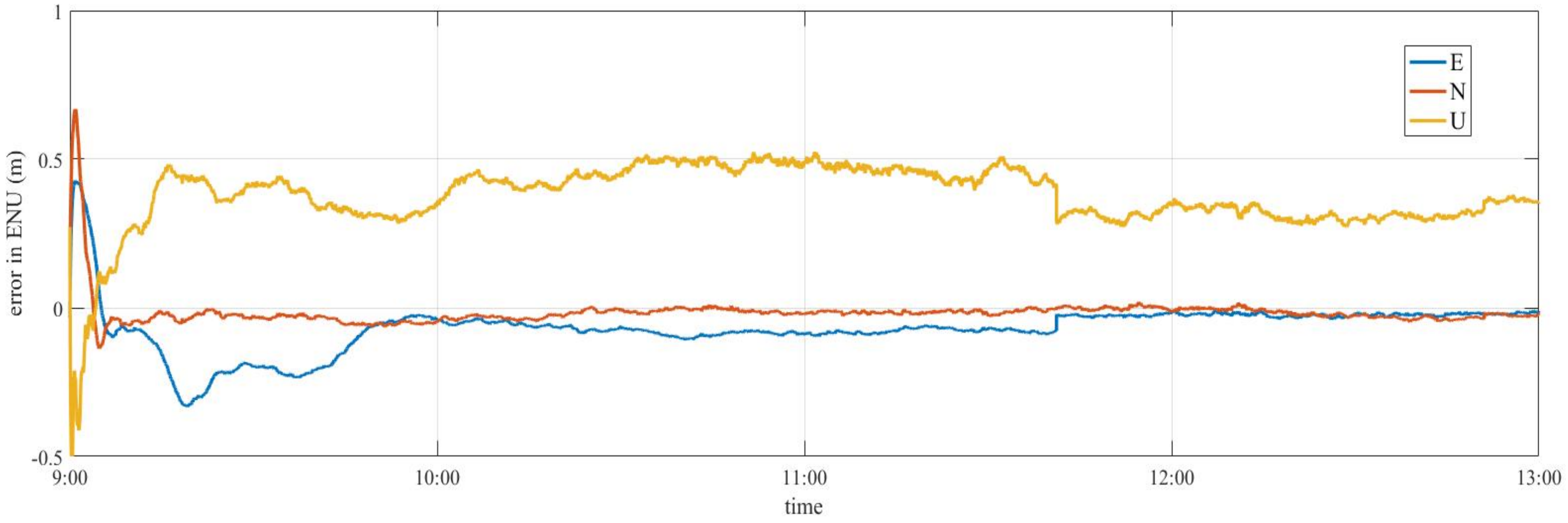


10 hours, Fixing ratio: 82% (Use longer time sequence to get better result)

Experiments on Static Dataset
Our results of long baseline RTK

Rover: MSAN, Base: FOND (170km baseline)

	E(cm)	N(cm)	U(cm)
final bias	1.9	1.2	33.7
final standard deviation	0.6	0.2	1.8

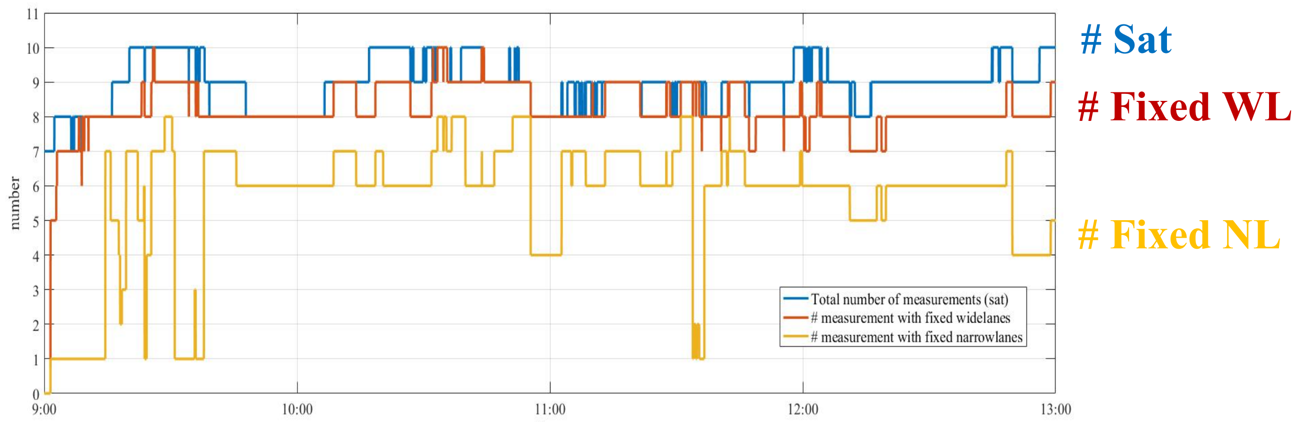


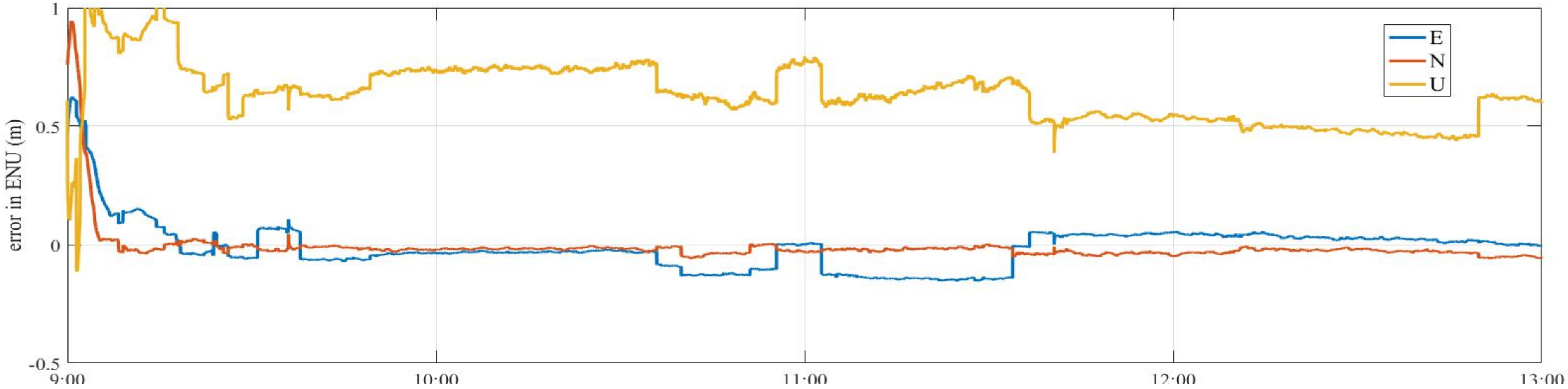
In comparison, we get sub centimeter-level vertical bias on short and medium baseline RTK.

Experiments on Static Dataset

Our results of Realtime PPP solved by PPP Wizard

	E(cm)	N(cm)	U(cm)
final bias	0.4	4.3	55.1
final std.	0.7	0.1	3.3





Issue Analysis
possible source of the bias

- Wrong result of Postprocessing PPP ('ground truth')? Probably NO.

reference coordinate solution	RTK baseline length	bias of RTK on rover station		
		X(cm)	Y(cm)	Z(cm)
Pride PPP AR (one-day solution)	short(1km)	2.3	0.5	1.1
PPP Wizard (converged 10 hour-mean)	short(1km)	15.2	3.6	9.5
Pride PPP AR (one-day solution)	long(110km)	23.9	4.3	11.8
PPP Wizard (converged 10 hour-mean)	long(110km)	49.1	7.0	18.4

Besides, the real-time PPP's result of RTKLib agree with PPP Wizard.   (common bias)

- Solid Earth Tide

Diurnal change ranging to 20 cm vertically

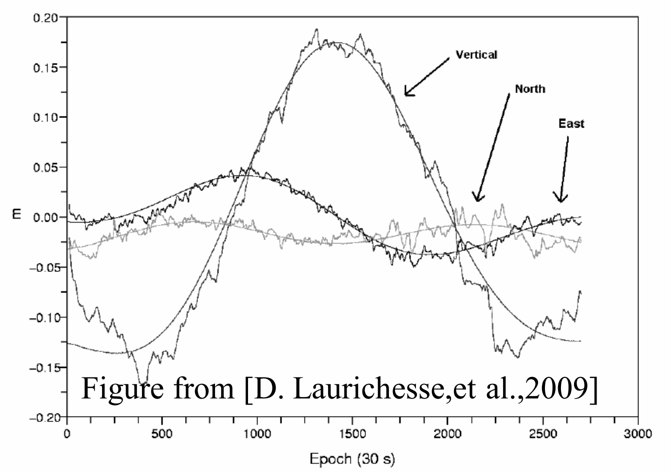
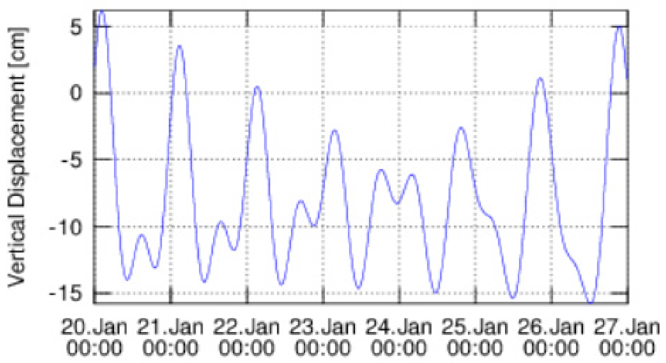


Figure from [D. Laurichesse,et al.,2009]



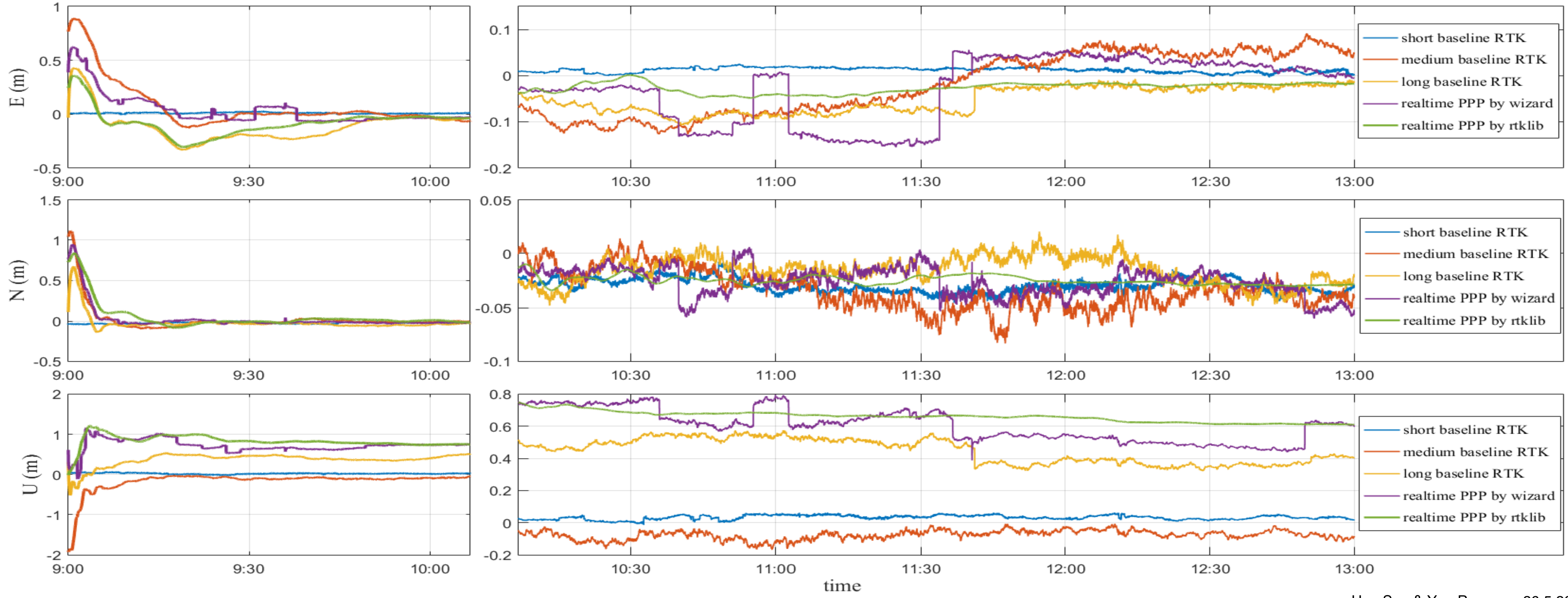
Copyright: Wiki

Experiments on Static Dataset

Comparison of RTK and real-time PPP

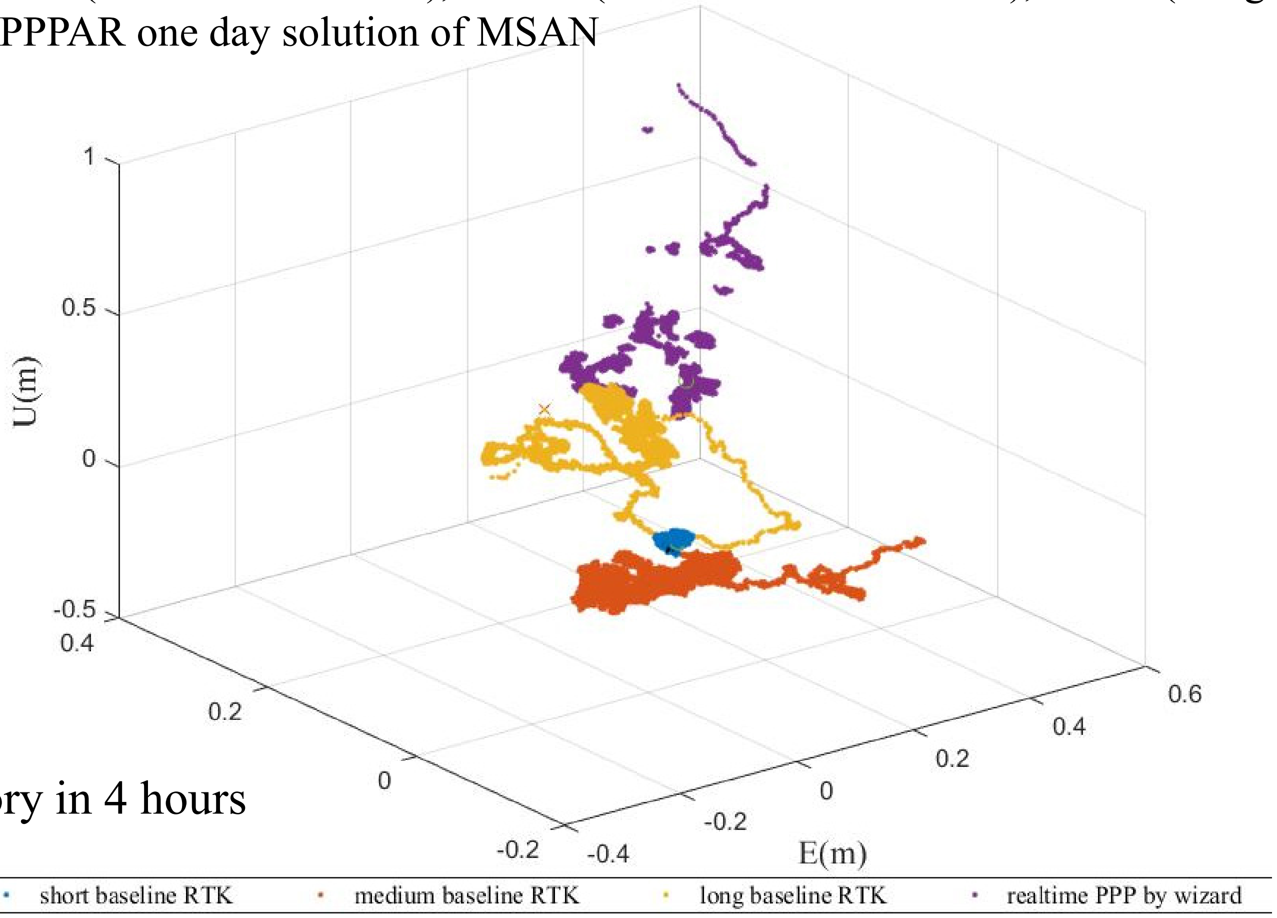
Solution	average standard devaition (cm)		
	E-W	N-S	U-D
RTK 1km(short)	0.5	0.2	1.2
RTK 20km (medium)	1.0	0.3	2.6
RTK 170km(long)	0.9	0.4	4.2
Real-time PPP	1.1	0.3	3.3

Rover: MSAN, Base: RIFP(Short baseline 1km), AMAT(Medium baseline 20km), FOND(Long baseline 170km)
ENU reference: Pride-PPPAR one day solution of MSAN



Experiments on Static Dataset
Comparison of RTK and real-time PPP

Rover: MSAN, Base: RIFP(Short baseline 1km), AMAT(Medium baseline 20km), FOND(Long baseline 170km)
ENU reference: Pride-PPPAR one day solution of MSAN



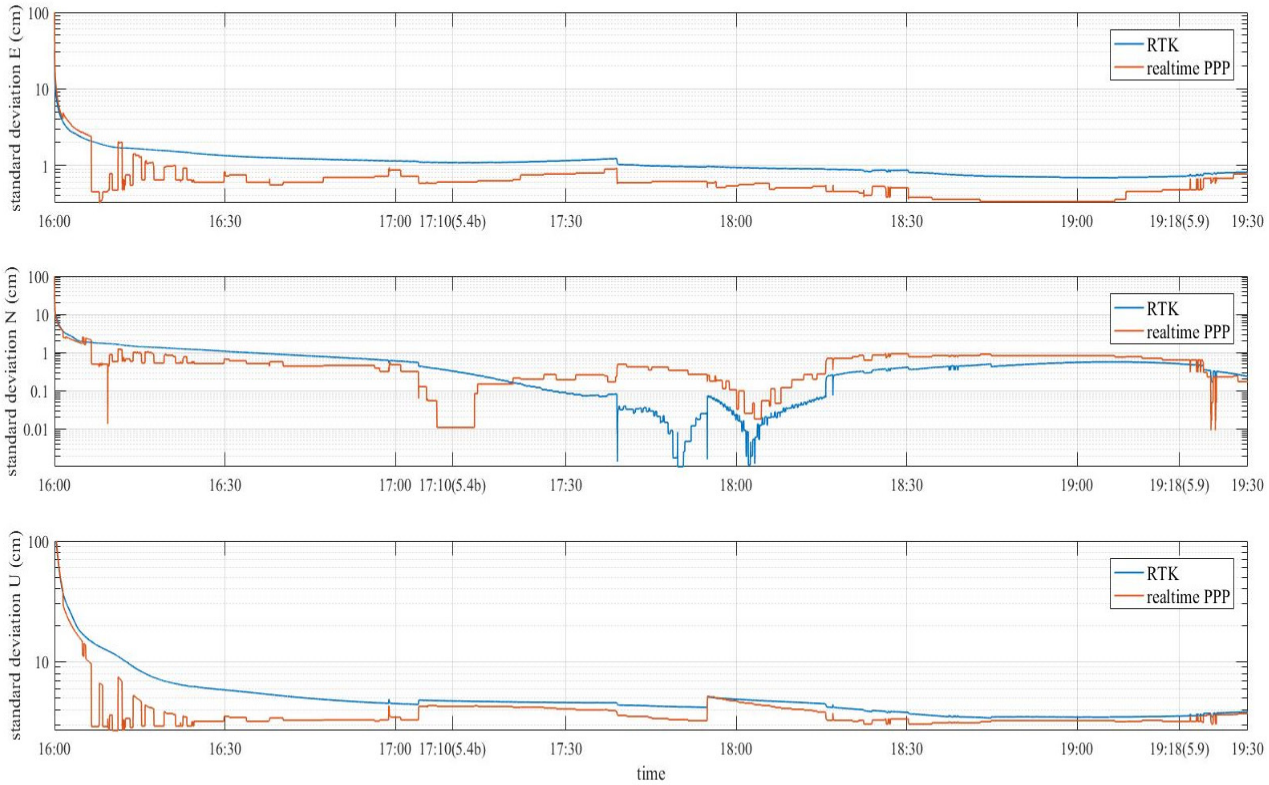
Trajectory in 4 hours

Experiment on Dynamic Dataset
Central Italy Earthquakes on October 26, 2016

Date	Origin Time (UTC)	Latitude (DD.dddd)	Longitude (DD.dddd)	Depth (km)	Mw
2016-10-26	17:10:36.34	42.8802	13.1275	8.7	5.4b
2016-10-26	19:18:05.85	42.9087	13.1288	7.5	5.9

Rover station: MSAN (10km to Earthquake 5.4b's center)
Base station: FOND (175km to Earthquake 5.4b's center)

Comparison of standard deviation (measurement noise)



	Solution	E(cm)	N(cm)	U(cm)
static std.	PPP	**0.4**	**0.1**	**3.8**
dynamic std.		0.6	**0.1**	4.2
static std.	RTK	1.1	0.5	4.3
dynamic std.		1.1	0.4	4.7

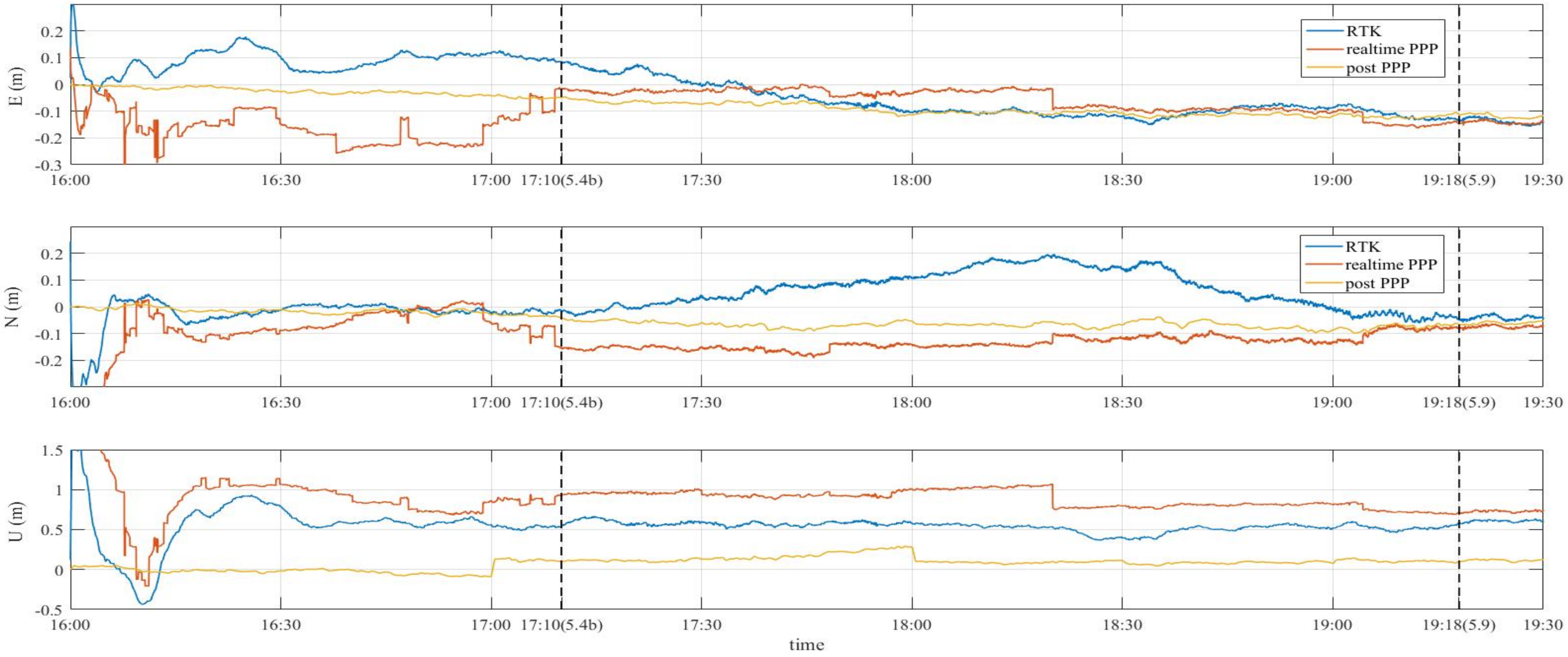
Static sequence:
2016-10-24 17:10:30-17:11:30
Dynamic sequence (Mw5.4b):
2016-10-26 17:10:30-17:11:30

Experiment on Dynamic Dataset

Central Italy Earthquakes on October 26, 2016

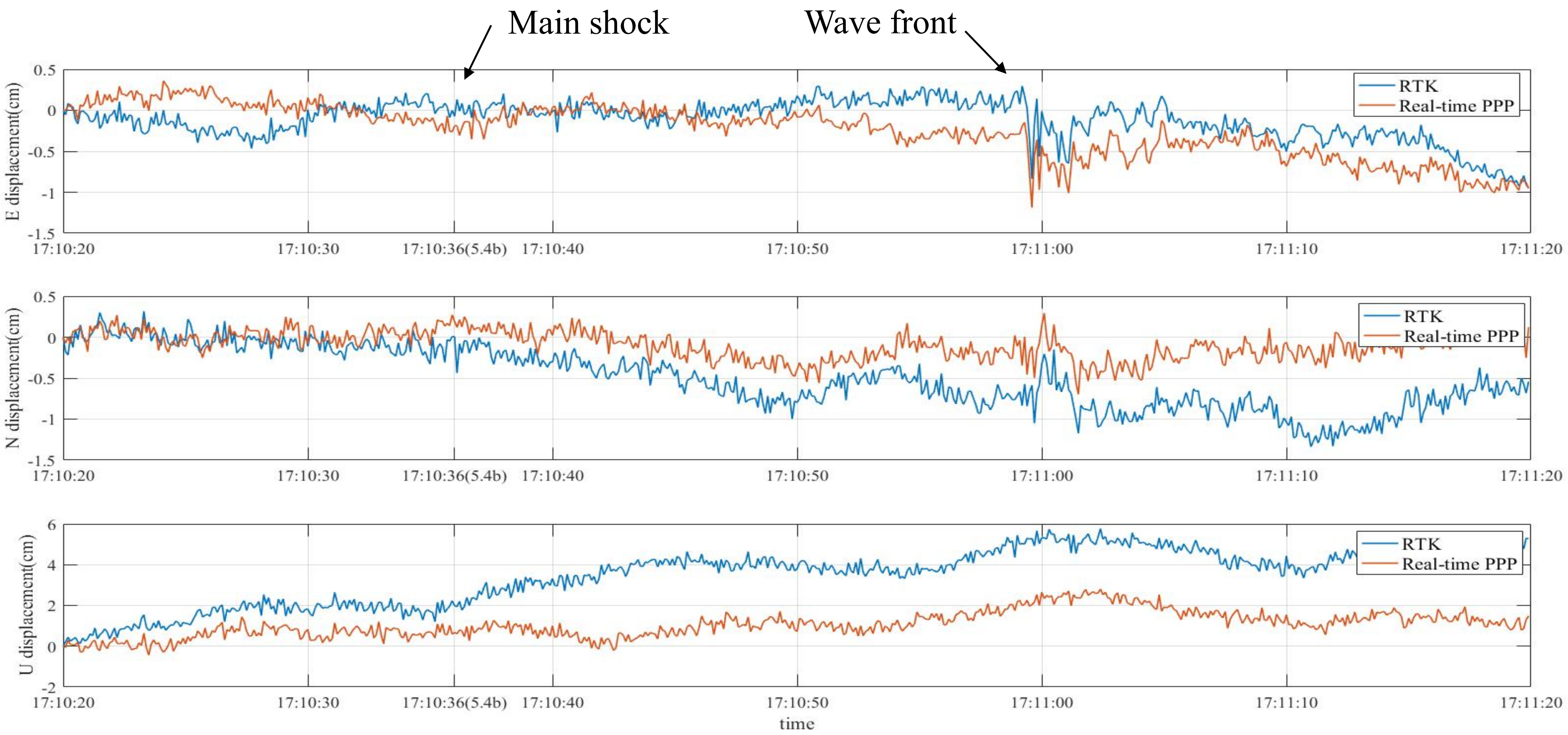
Date	Origin Time (UTC)	Latitude (DD.dddd)	Longitude (DD.dddd)	Depth (km)	Mw
2016-10-26	17:10:36.34	42.8802	13.1275	8.7	5.4b
2016-10-26	19:18:05.85	42.9087	13.1288	7.5	5.9

Rover station: MSAN (10km to earthquake 5.4b's center), Base station: FOND (175km to earthquake 5.4b's center)



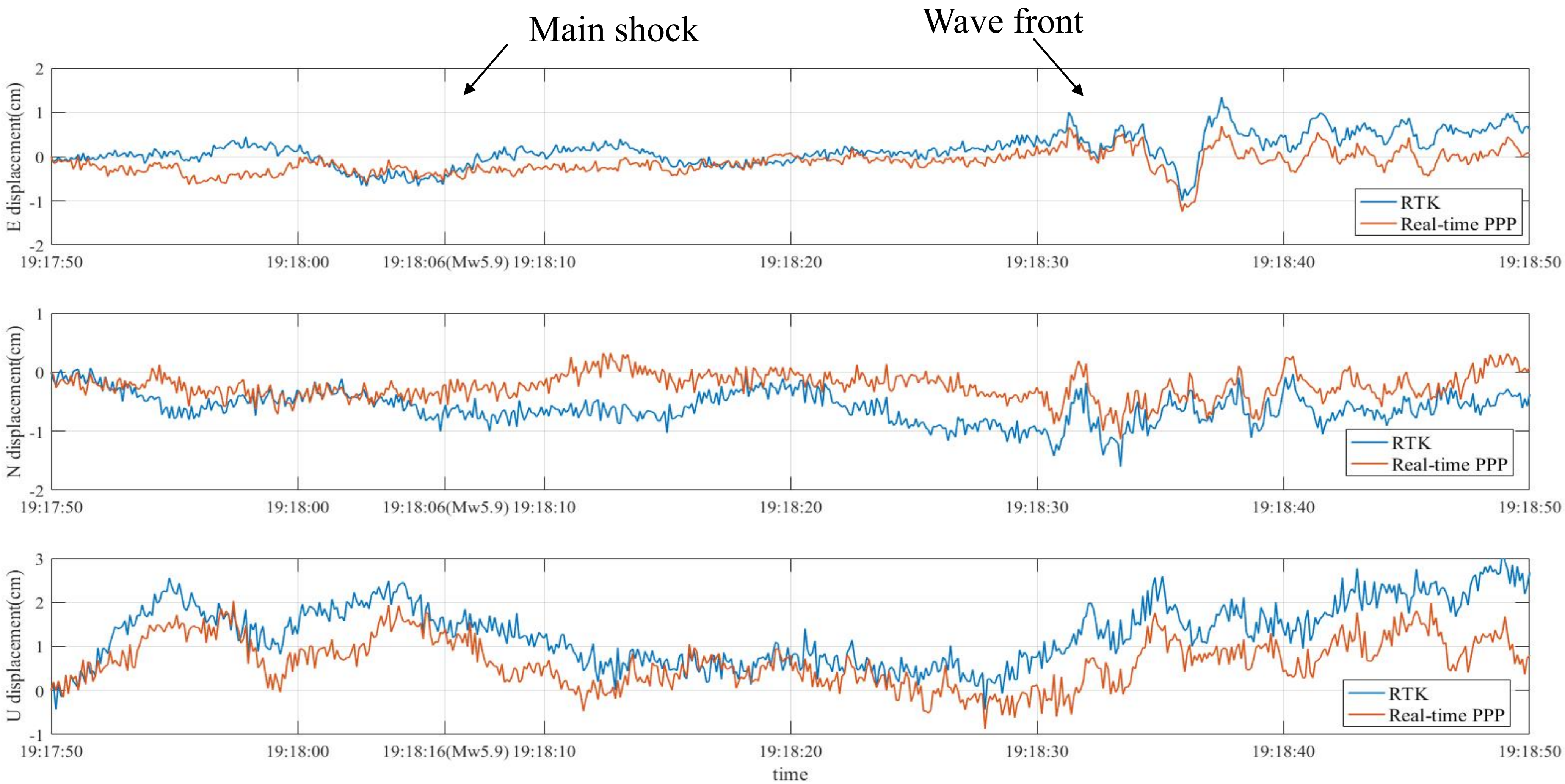
Experiment on Dynamic Dataset

“Mw 5.4b” Earthquake on October 26, 2016



Experiment on Dynamic Dataset

"Mw 5.9" Earthquake on October 26, 2016



Conclusions

- Comparison of RTK and real-time PPP on static scenarios
  - Noise: short/medium baseline RTK < real-time PPP < long baseline RTK (vertical > horizontal)
  - Bias [horizontal]: short/medium/long baseline RTK and real-time PPP are all on sub-cm level
  - Bias [vertical]: short baseline RTK < medium baseline RTK << long baseline RTK < real-time PPP
- Comparison of noise on dynamic and static scenarios: in the same order of magnitude for both RTK and PPP
  - RTK and PPP agree with each other on dynamic scenario (indicate the same pattern of seismic wave)

Puzzles and future work

- Decimeter level vertical bias of long baseline RTK and real-time PPP
- Time delay of seismic wave on 2016 Central Italy Earthquake Dataset
- Shorten the convergence time

Q & A