An evaluation of open-source multi-GNSS precise point positioning (PPP) software packages

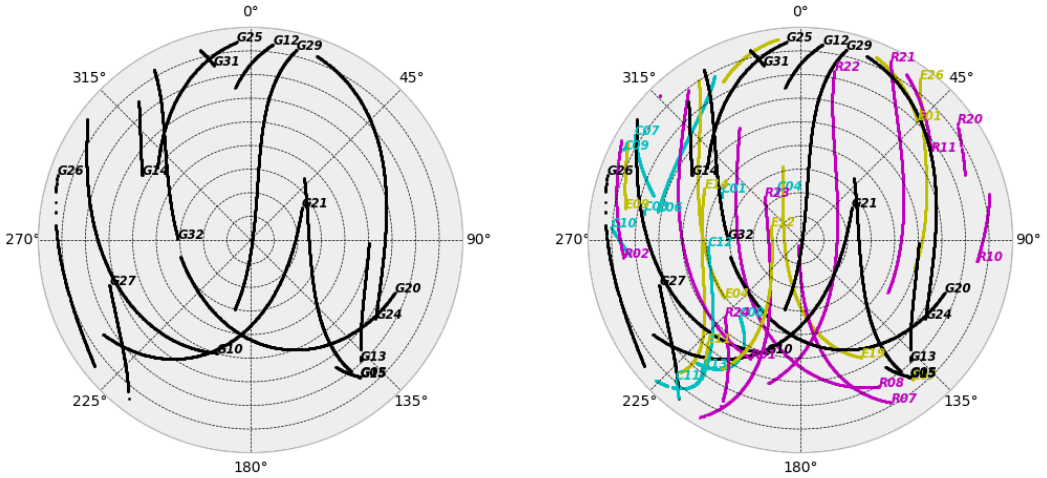
Bryan Stressler, Jacob Heck, Jordan Krcmaric, Steve Hilla
NOAA, National Geodetic Survey

2018 AGU Fall Meeting
December 14th, 2018, Session G51A

Precise Point Positioning (PPP)

- A well-studied positioning approach capable of cm-level accuracy without the need for reference stations
  - Relative positioning → eliminate error sources (e.g., clocks, troposphere)
  - PPP→ apply models
- PPP would not be possible without IGS products!
  - Precise orbits, clocks, biases, etc.
- New GNSS constellations provide opportunities (and challenges) to improve PPP performanc

4 hour sky plots for GPS-only (left) and multi-GNSS (right).

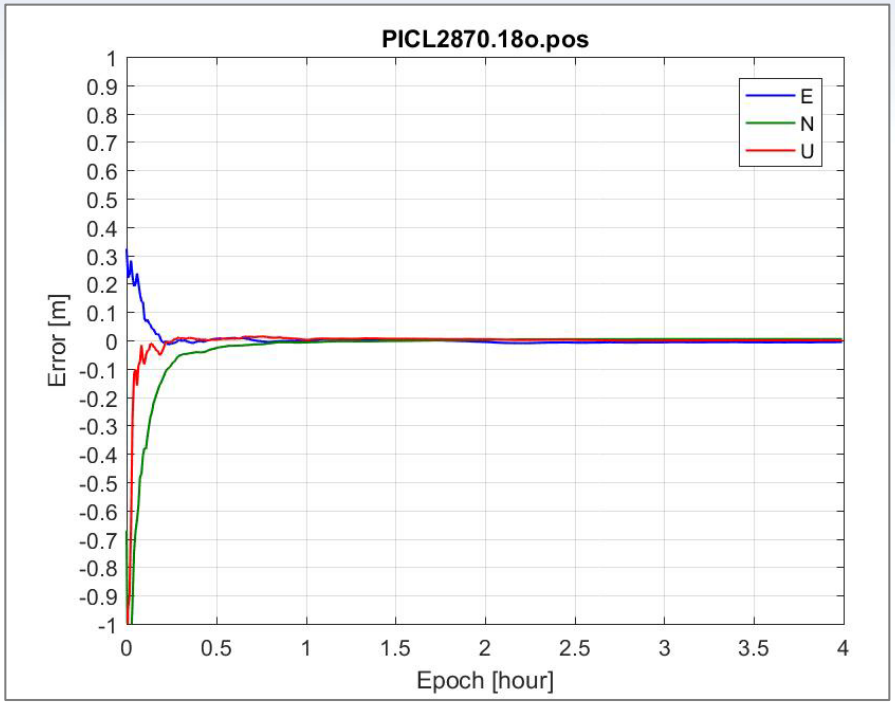


Motivation

- Recently, several open-source multi-GNSS PPP software packages have been made available (https://www.ngs.noaa.gov/gps-toolbox/)
  - GAMP (Zhou et al., 2018)
  - PPPH (Bahadur & Nohutcu 2018)
- Various online PPP engines available
- This study aims to:
  - Evaluate/compare the performance of these two new open-source PPP packages
  - Compare the performance of GPS/GPS+GLO to full multi-GNSS solutions

GAMP (Zhou et al., 2018)

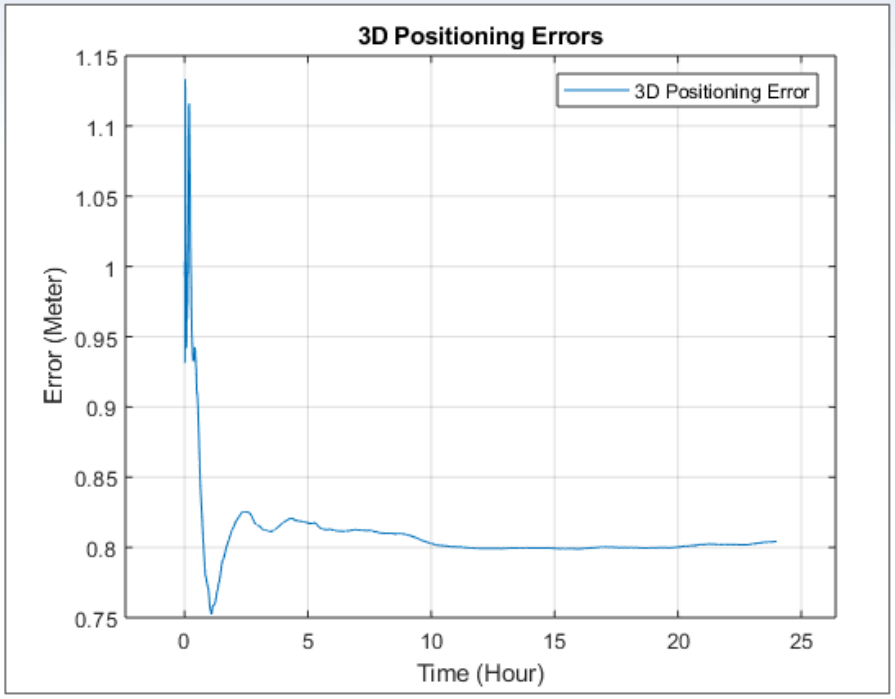
- C programming language, built upon RTKLIB
- GPS/GLO/GAL/BDS/QZSS
- Undifferenced, uncombined
- Sequential Least Squares
- Utility scripts for file downloads and analysis



Example convergence plot from GAMP Matlab plotting tool.

PPPH (Bahadur & Nohutcu, 2018)

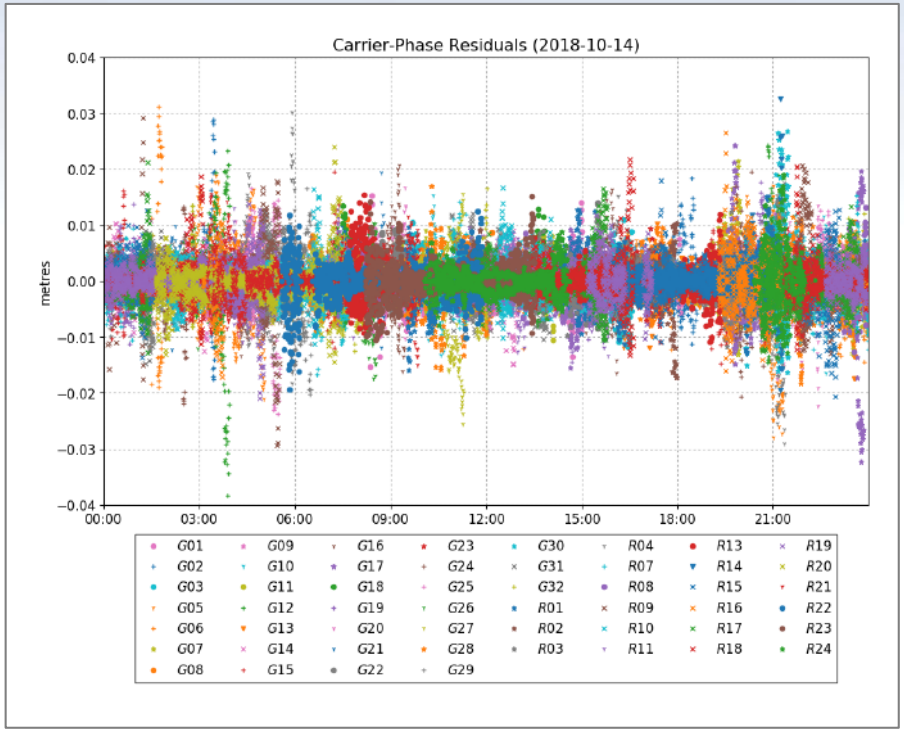
- Matlab- with GUI
- GPS/GLO/GAL/BDS
- Undifferenced, Ion-Free combination
- Extended Kalman Filter
- Plotting and analysis tools



Example convergence plot from PPPH.

NRCAN Online PPP

- Online platform
- IGS Final orbits/clocks
- GPS+GLO Solutions
- 2018-08: Updated from GPSPACE to SPARK Software
  - Reported height bias correction (4-5mm)

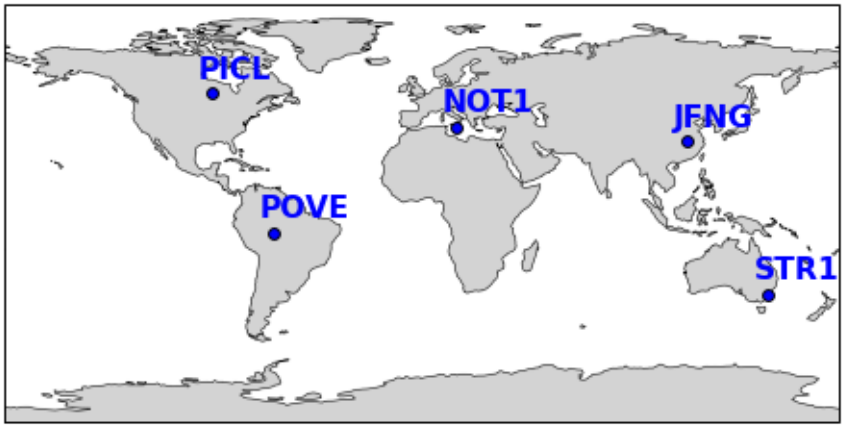


Example carrier phase residual plot from NRCAN PPP.

https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php

Test 1: 24 Hour Solutions

- Daily 24 hour solutions for GPS week 2023 (2018 Oct. 14 - 20)
- **GAMP** and **PPPH**→ GPS, GPS+GLO, multi-GNSS solutions
- **NRCAN CSRS-PPP**→ GPS+GLO

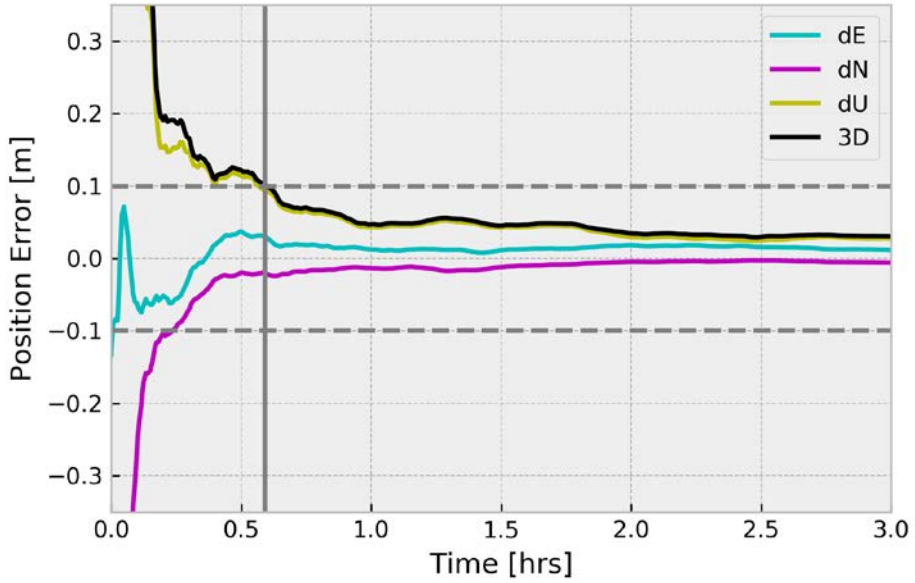


Station	Country	Constellations	Receiver	Antenna
JFNG	CHN	GRECJ	TRIMBLE NETR9	TRM59800.00 + NONE
NOT1	ITA	GREC	LEICA GR30	LEIAR20 + NONE
PICL	CAN	GRE	SEPT POLARX5	TPSCR.G3 + NONE
POVE	BRA	GRECJ	TRIMBLE NETR9	TRM115000.00 + NONE
STR1	AUS	GRECJ	SEPT POLARX5	ASH701945C_M + NONE

Multi-GNSS IGS stations used in this study.

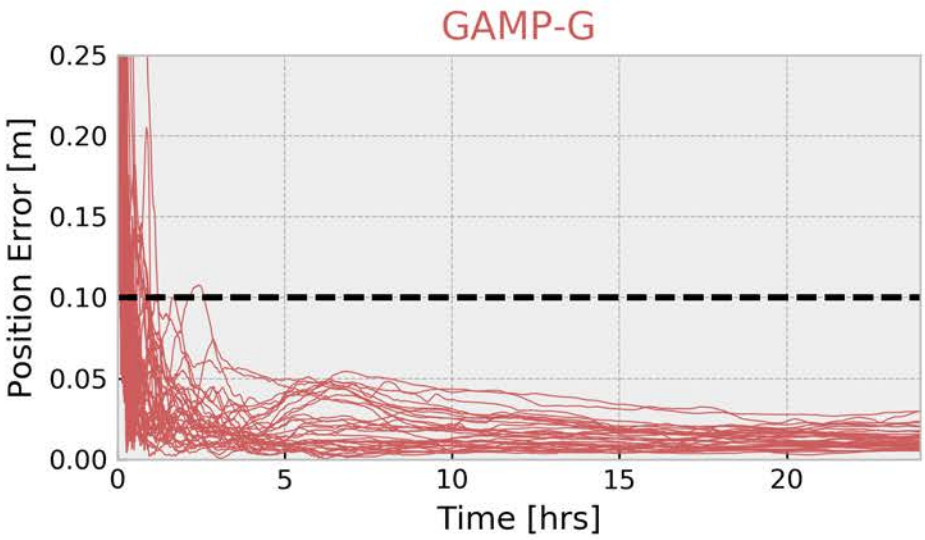
Processing/Analysis

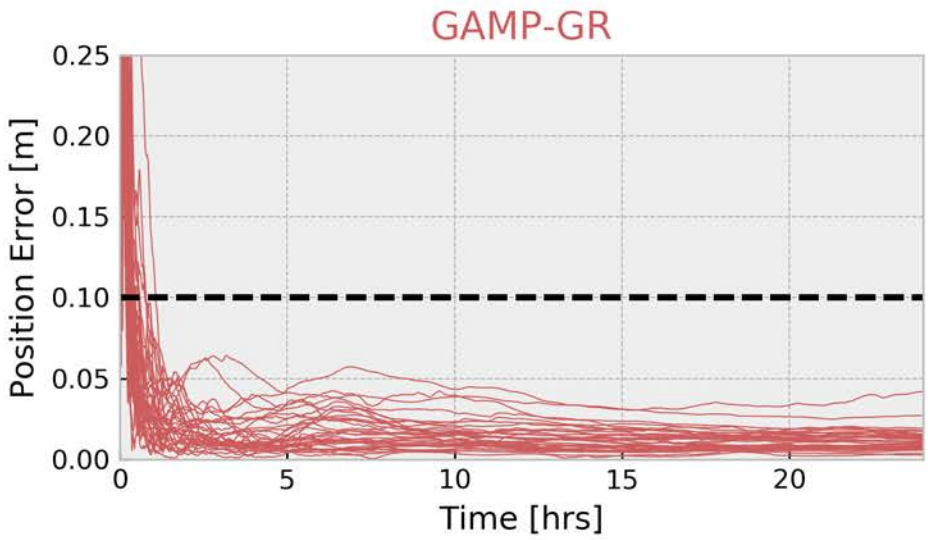
- GAMP/PPPH processed using the same MGEX products
  - GFZ orbit/clock files
- NRCAN PPP uses IGS Final orbits/clocks
- In general, default processing parameters were used for each software
- Convergence time = sub-decimeter 3D error for > 10 min
  - Reference coordinates from weekly IGS SINEX file

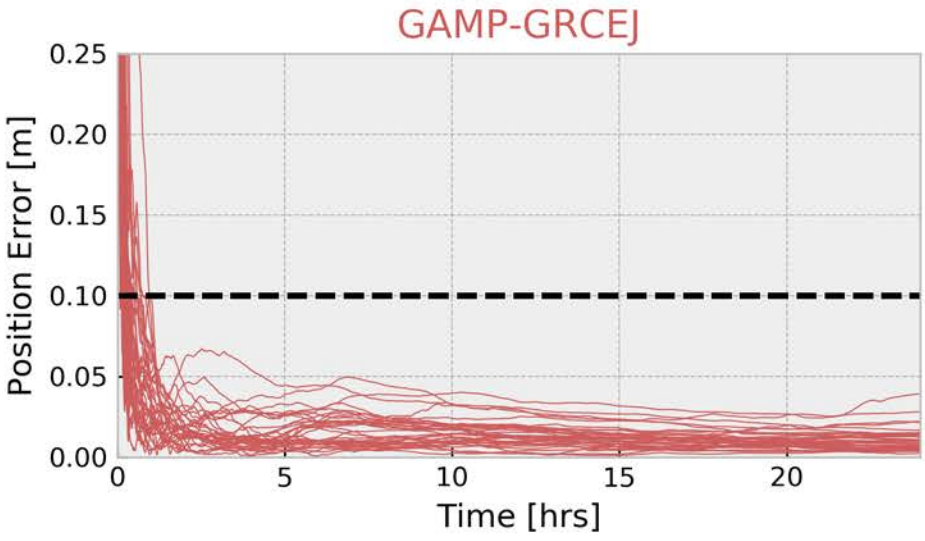


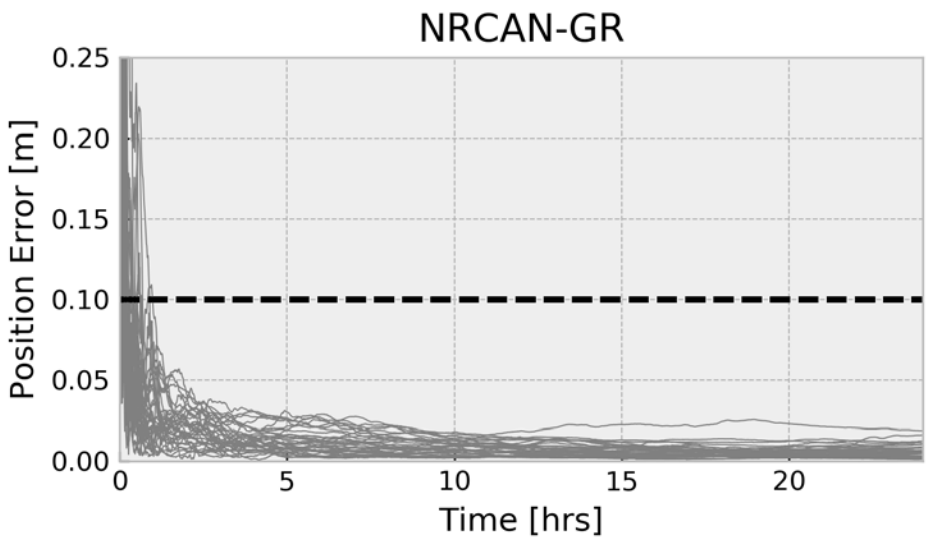
Example convergence plot showing east, north, up, and 3D errors. Vertical gray line indicates convergence time.

GAMP-24hrs

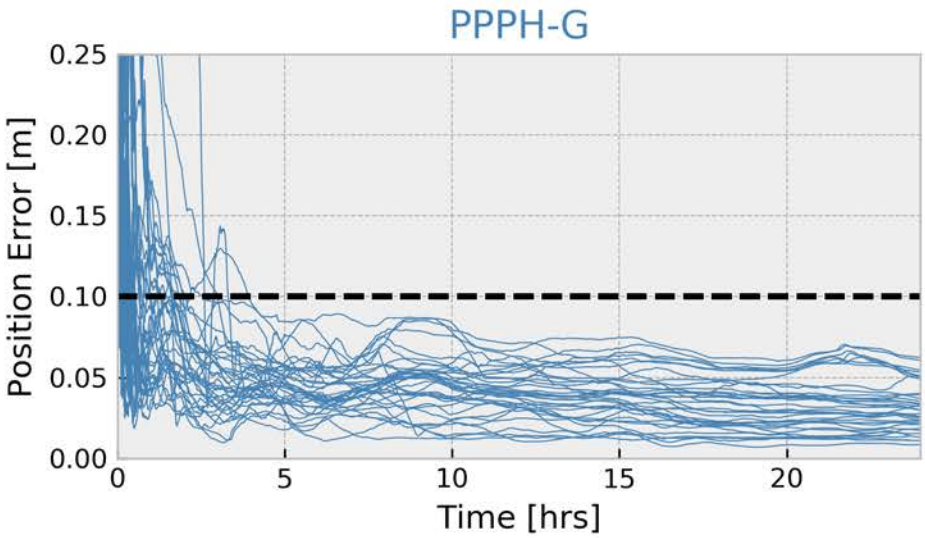

GAMP-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]

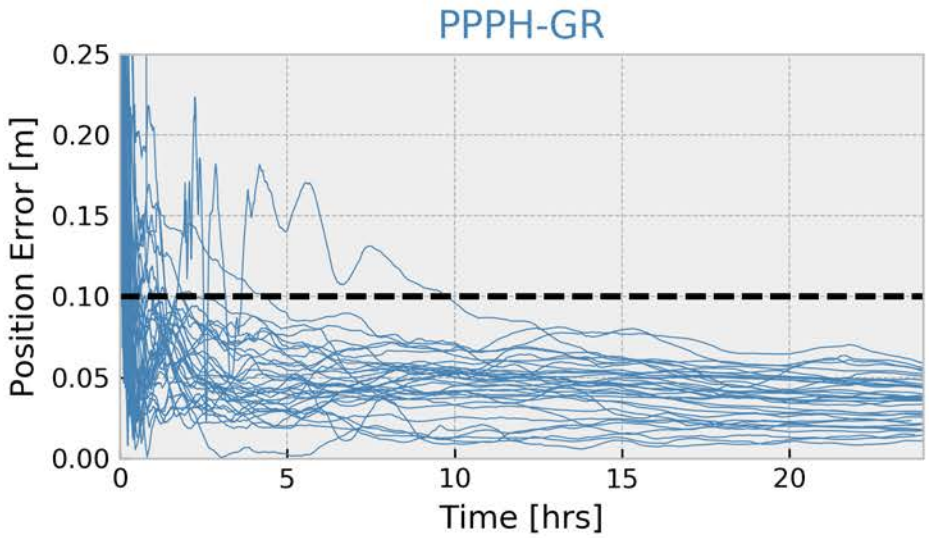

GAMP-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]

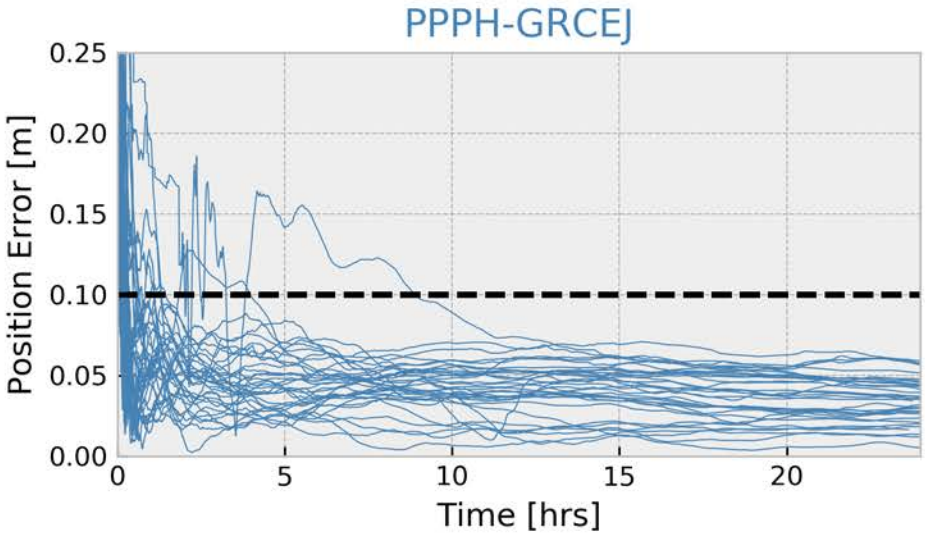

GAMP-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]

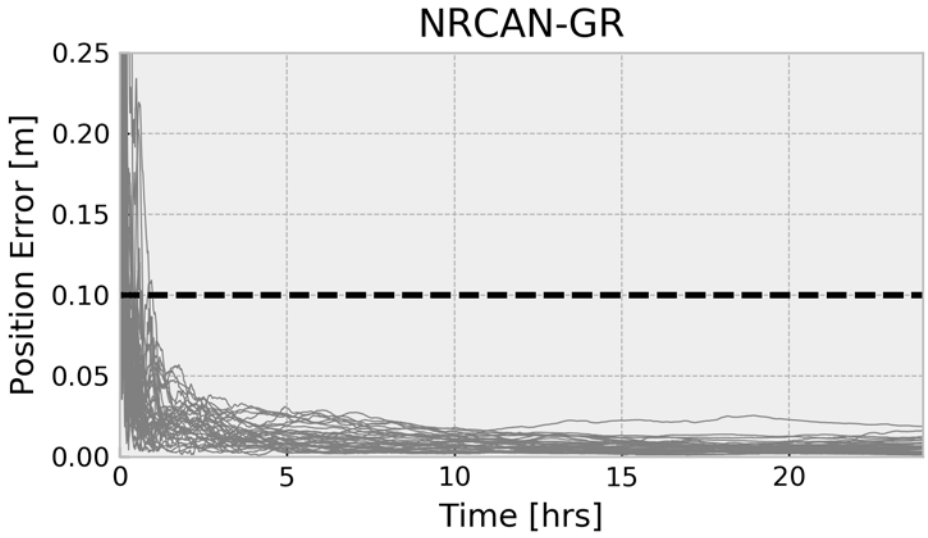

NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]

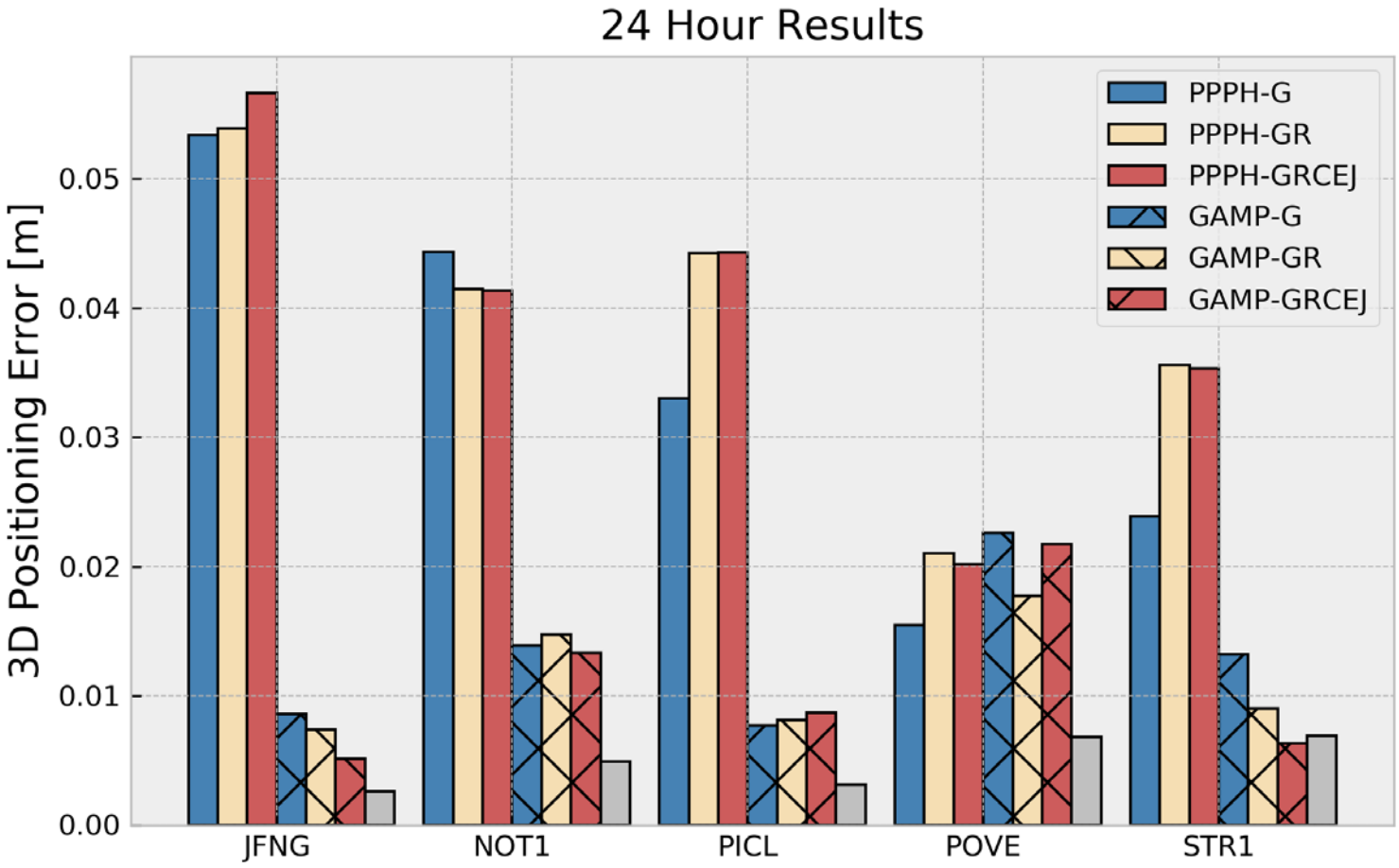
PPPH-24hrs


PPPH-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]


PPPH-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]

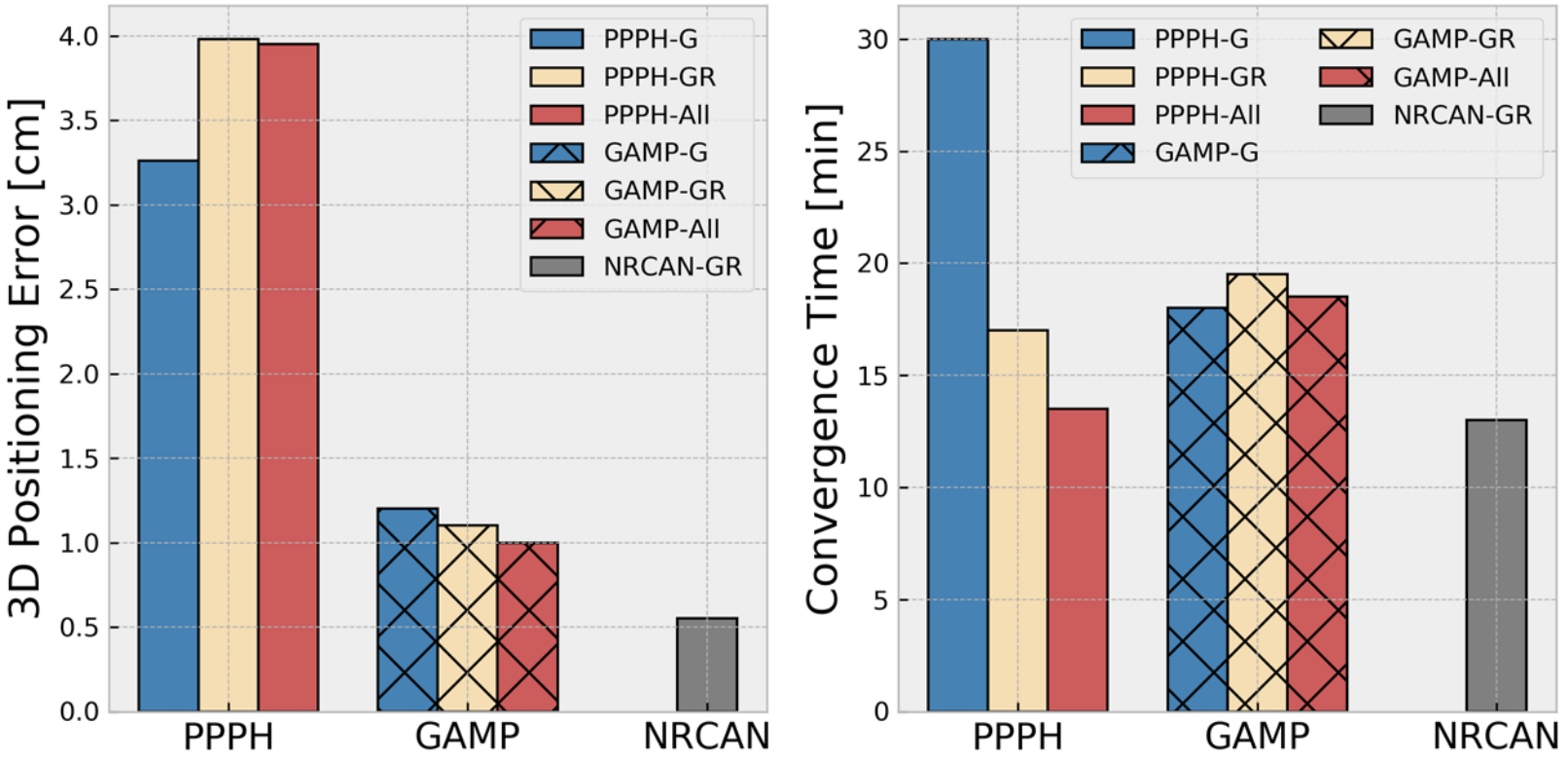

PPPH-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]


NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time [hrs]



- PPPH ~2-5 cm errors
- GAMP ~1-2 cm errors
- NRCAN ~ 0.5 cm errors

- Variability on station by station basis
- N = 35, small sample size!



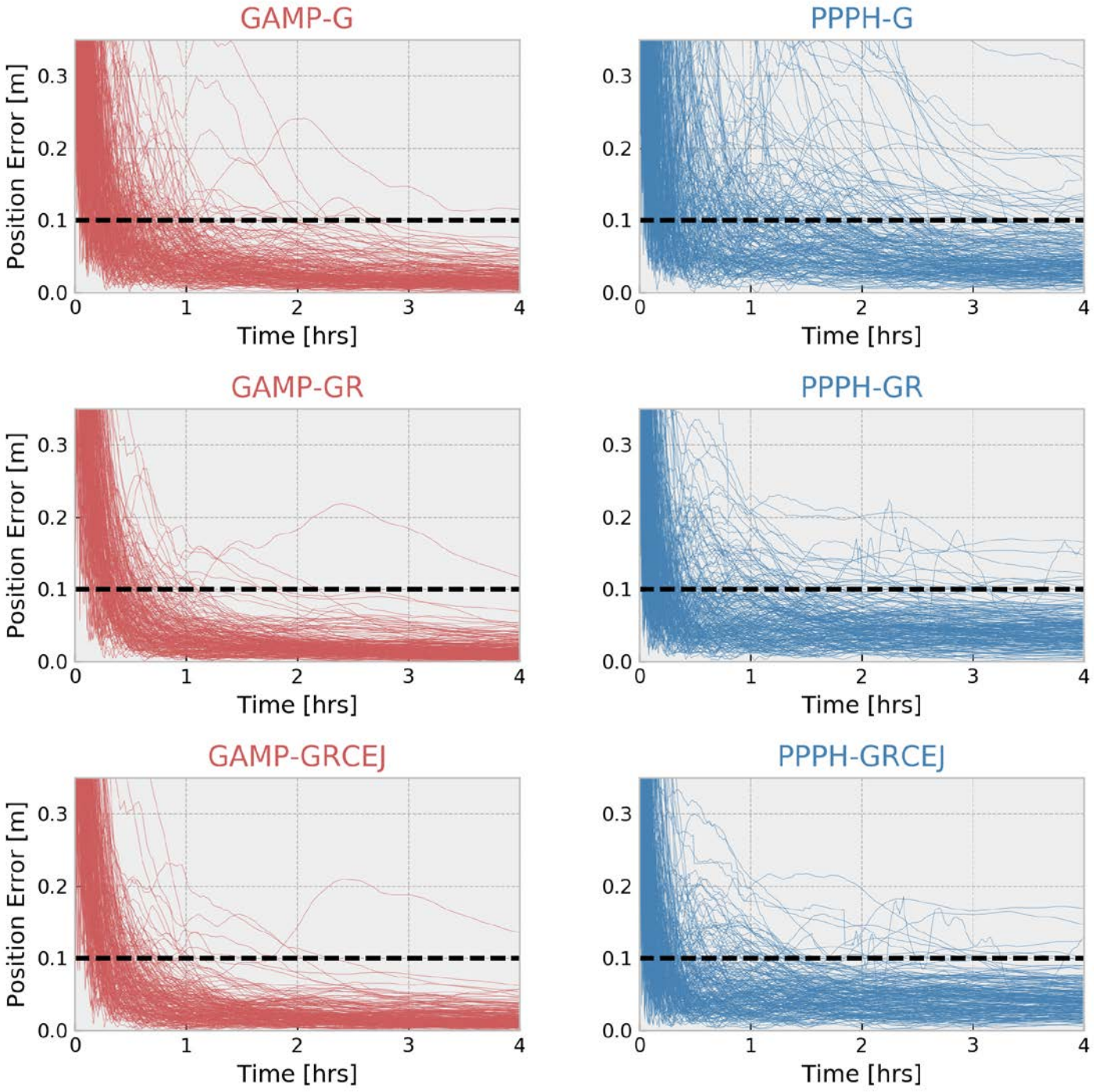
Median 3D errors and convergence times for each software/combination.

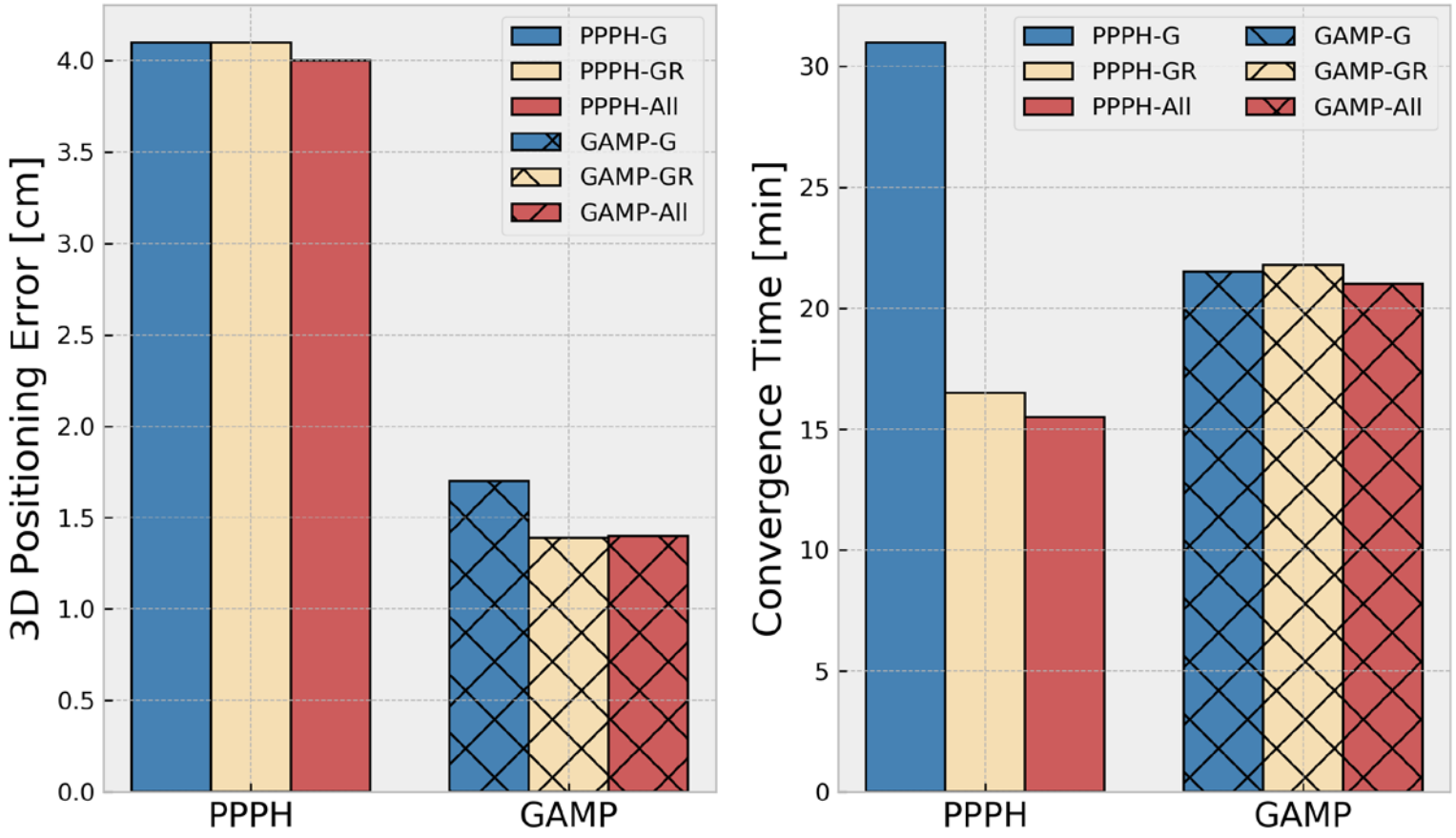
- With added constellations:
  - GAMP shows improvement in 3D errors
  - PPPH shows improvement in convergence time

Test 2: 4 Hour Sessions

- Same weekly observations broken into 4 hour subsets
  - Larger sample to evaluate PPP performance
  - 42 sessions/station
  - Each processed with GPS only, GPS+GLO, and full multi-GNSS

- How do GAMP and PPPH perform for shorter sessions?
- What is the impact of multi-GNSS?


GAMP-G
PPPH-G
GAMP-GR
PPPH-GR
GAMP-GRCEJ
PPPH-GRCEJ
Position Error [m]
Time [hrs]
0.0
0.1
0.2
0.3
0
1
2
3
4



- In general, 4 hour results are consistent with 24 hour solutions
  - Only slight degradation in positioning accuracy

Summary

- GAMP and PPPH capable of achieving cm-level accuracy for static positioning
  - GAMP ~ 1-2 cm average 3D errors
  - PPPH ~ 3-5 cm average 3D errors
- Impact of multi-GNSS processing is likely more noticeable under poor surveying conditions (i.e., high multipath, polar regions)
  - More stations + more data should be processed to confirm

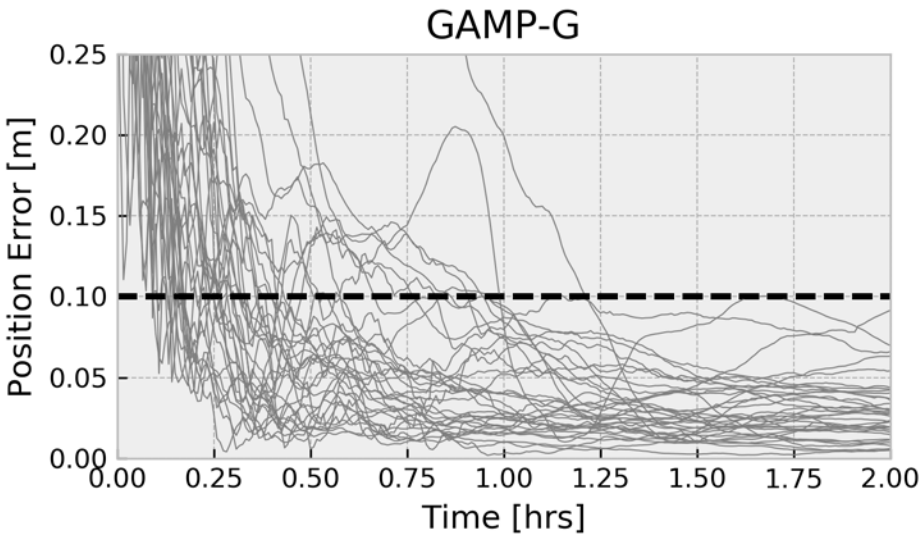
References

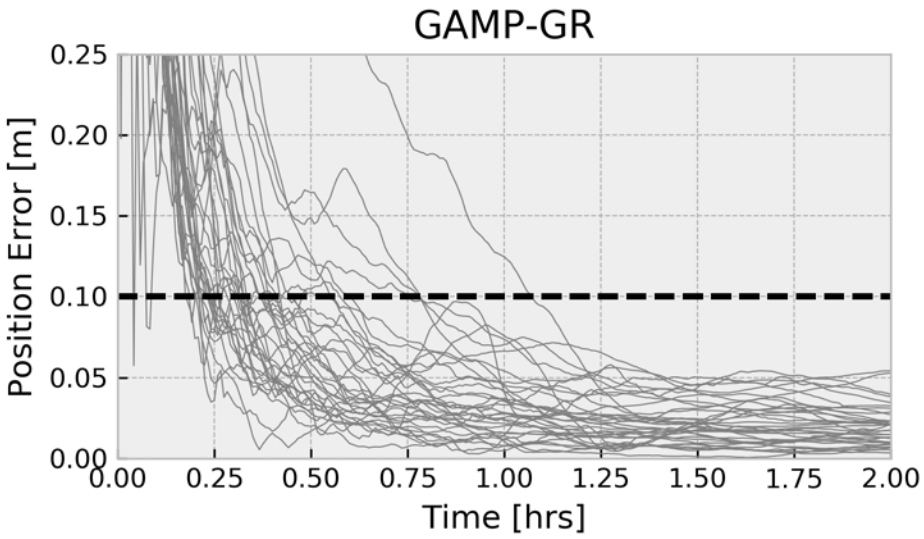
- Bahadur, B. & Nohutcu, M. (2018), PPPH: a MATLAB-based software for multi-GNSS precise point positioning analysis, *GPS Solutions*, 22: 113. https://doi.org/10.1007/s10291-018-0777-z

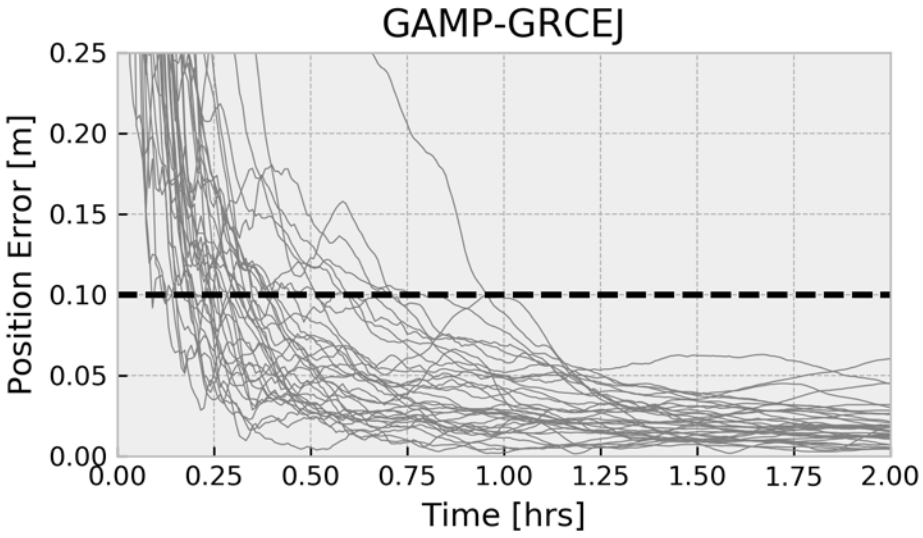
- Zhou, F., Dong, D., Li, W., Jiang, X., Wickert, J., & Schuh, H. (2018), GAMP: An open-source software of multi-GNSS precise point positioning using undifferenced and uncombined observations. *GPS Solutions*, 22. https://doi.org/10.1007/s10291-018-0699-9.

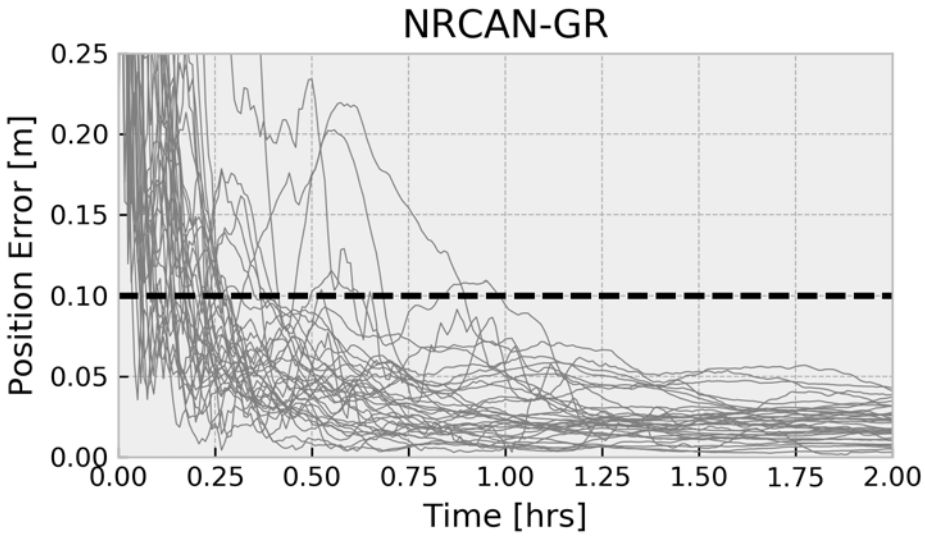
Extra Slides

GAMP-2hrs

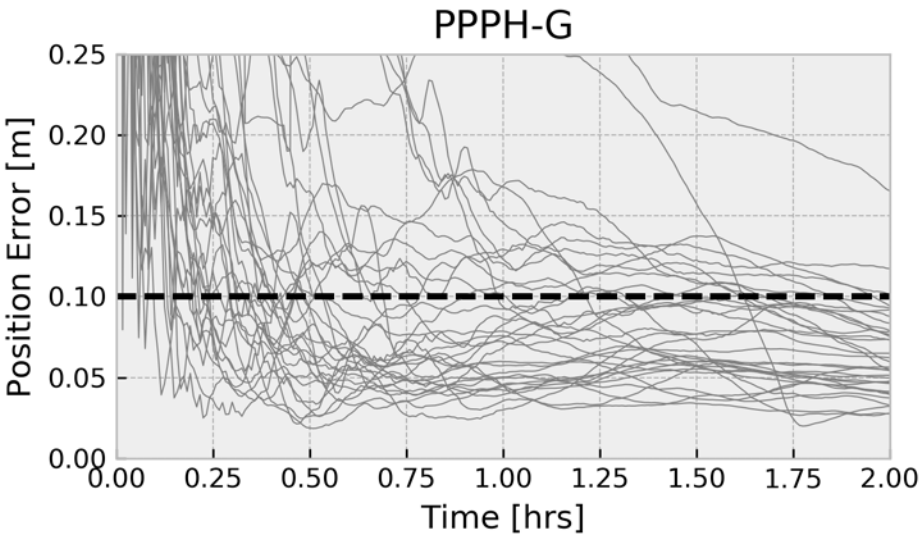

GAMP-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

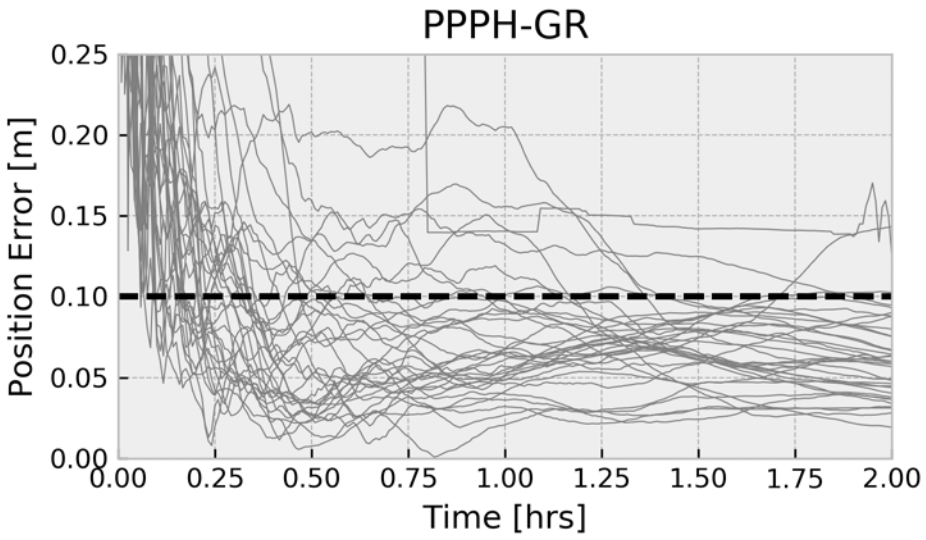

GAMP-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

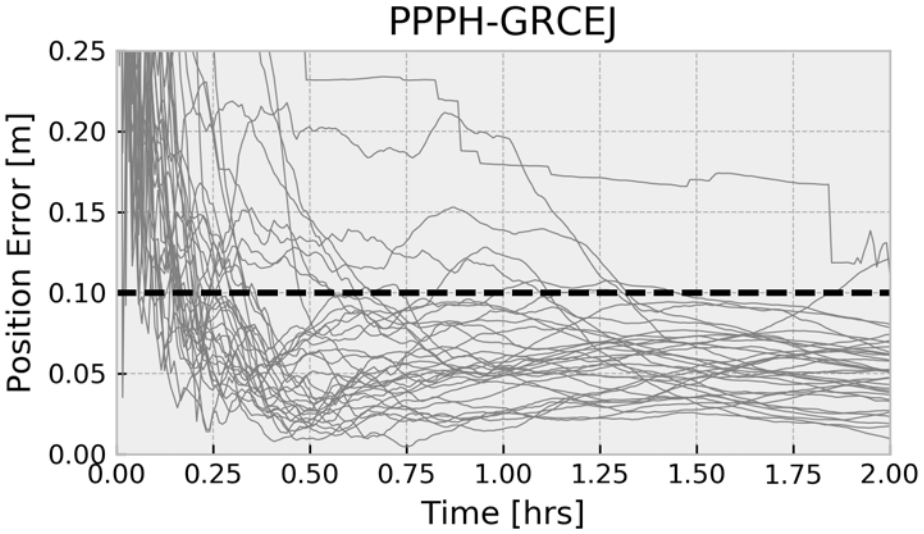

GAMP-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

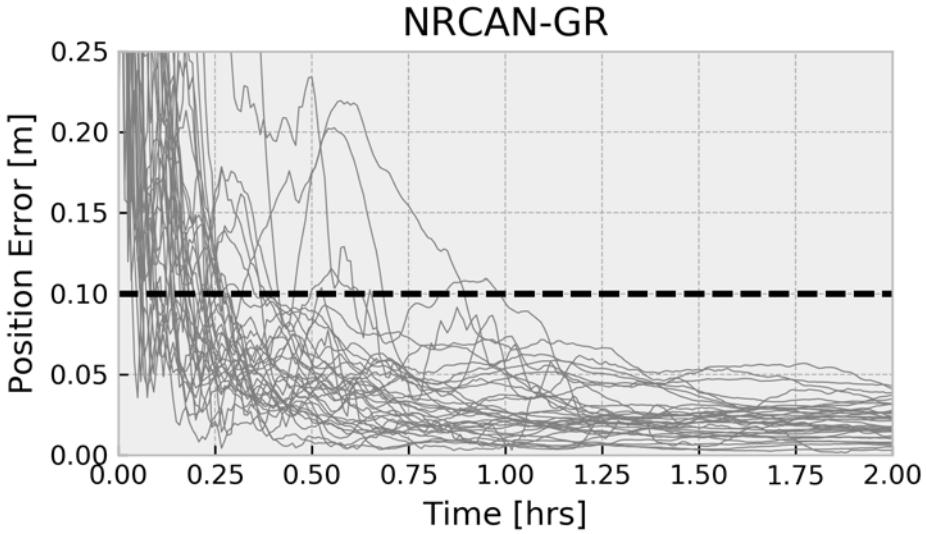

NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

PPPH-2hrs

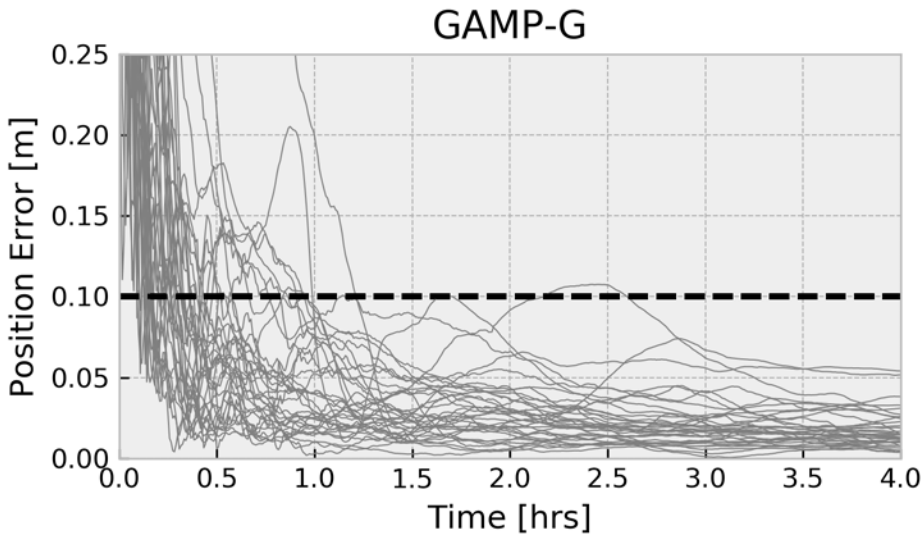

PPPH-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

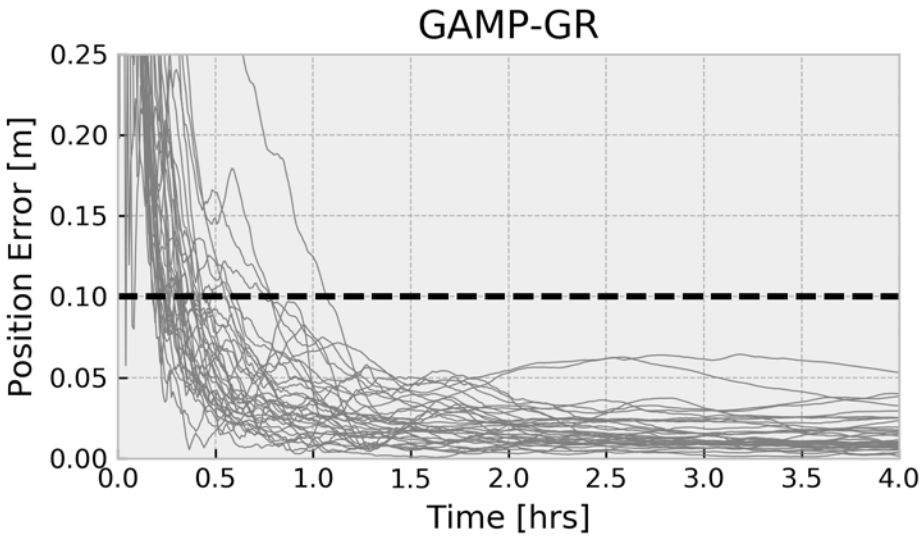

PPPH-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

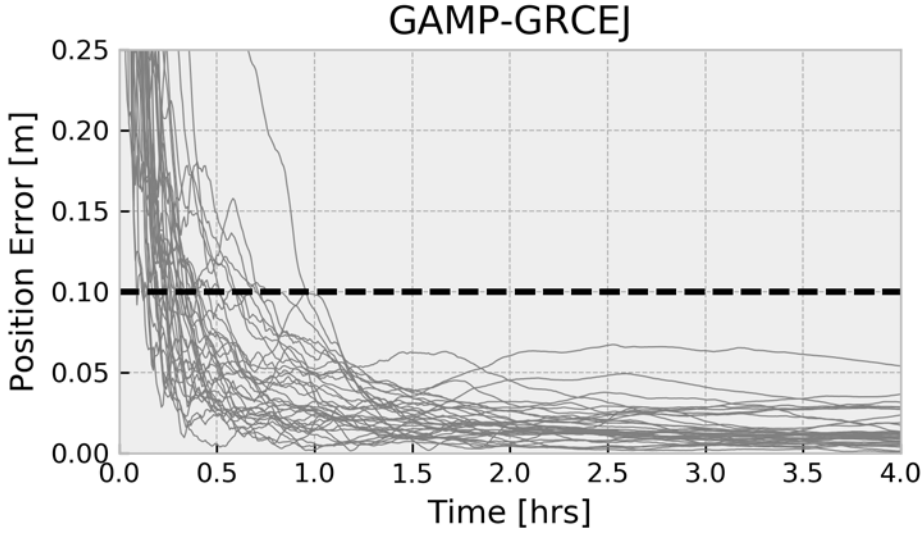

PPPH-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

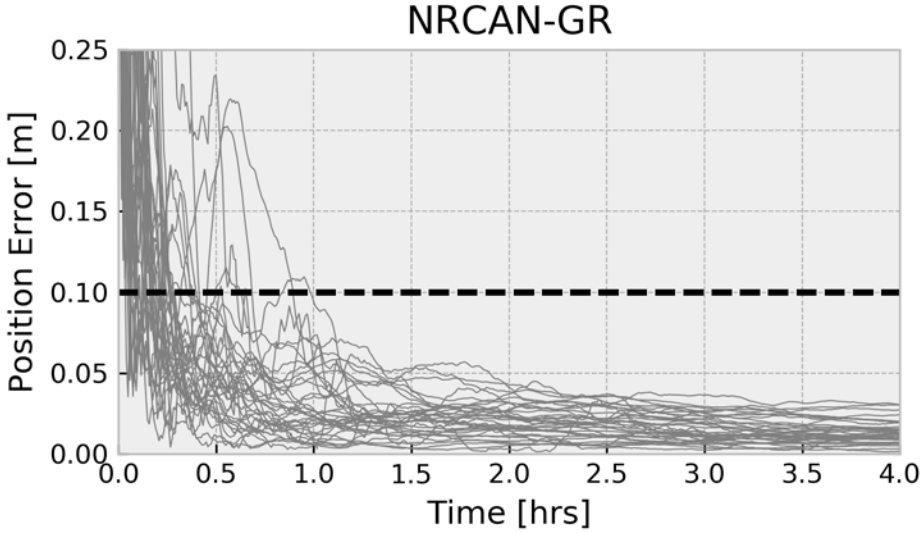

NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Time [hrs]

GAMP-4hrs

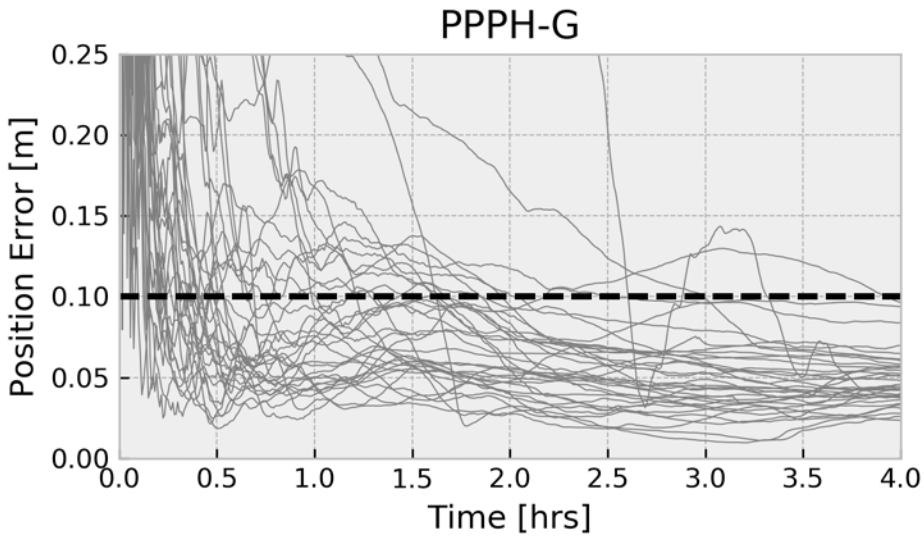

GAMP-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

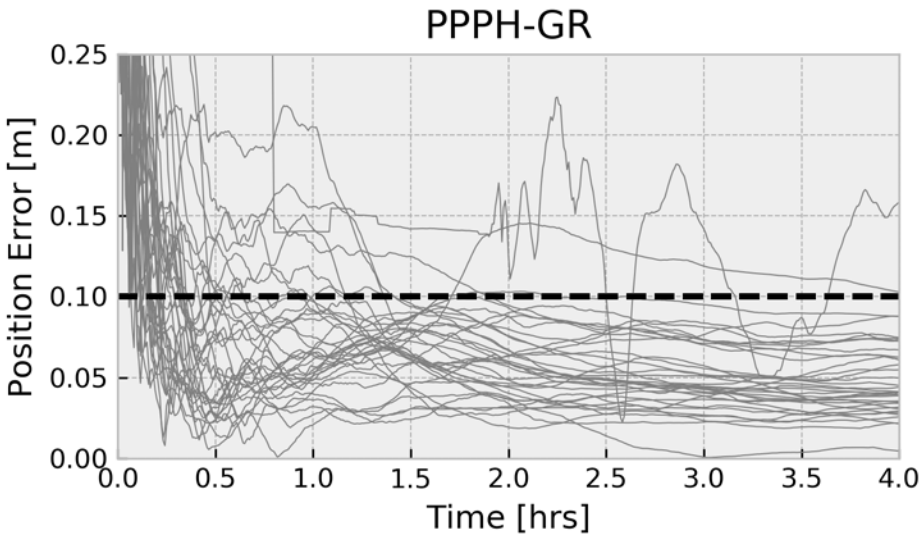

GAMP-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

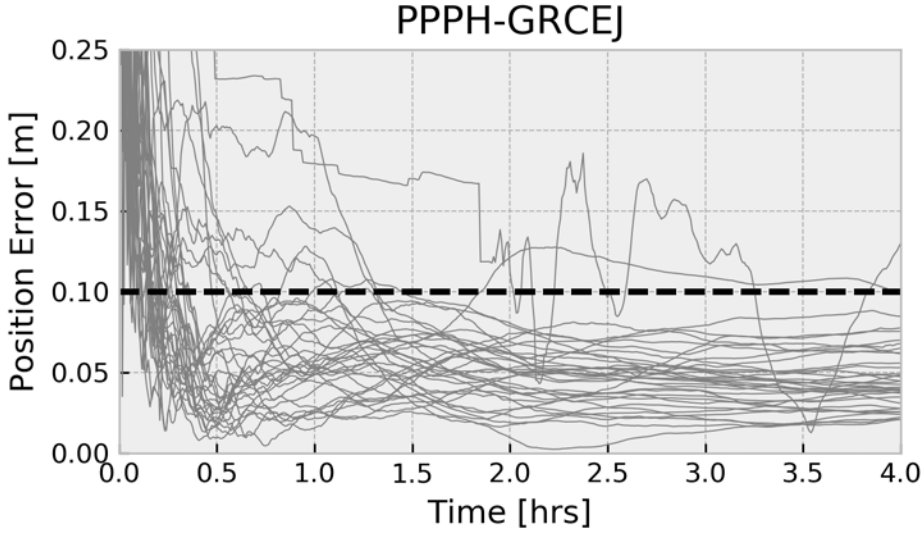

GAMP-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

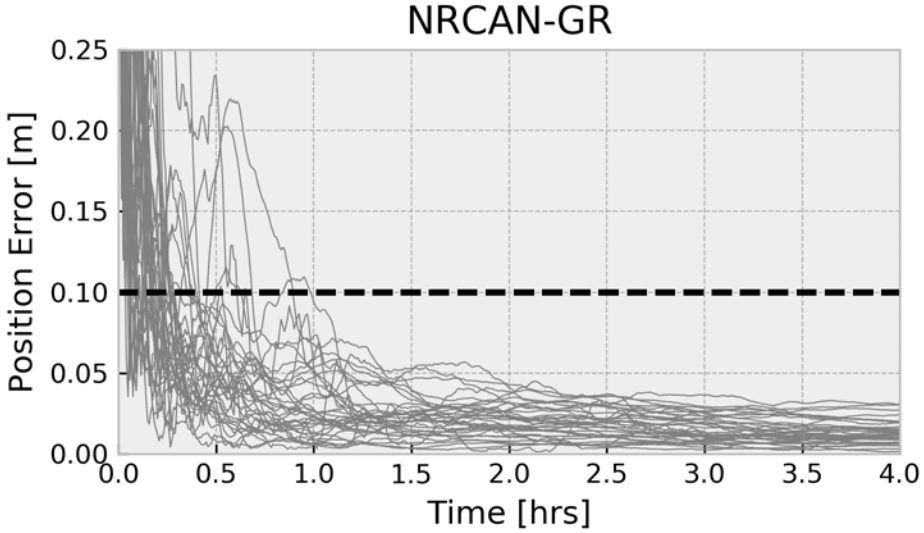

NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

PPPH-4hrs


PPPH-G
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]


PPPH-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]


PPPH-GRCEJ
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

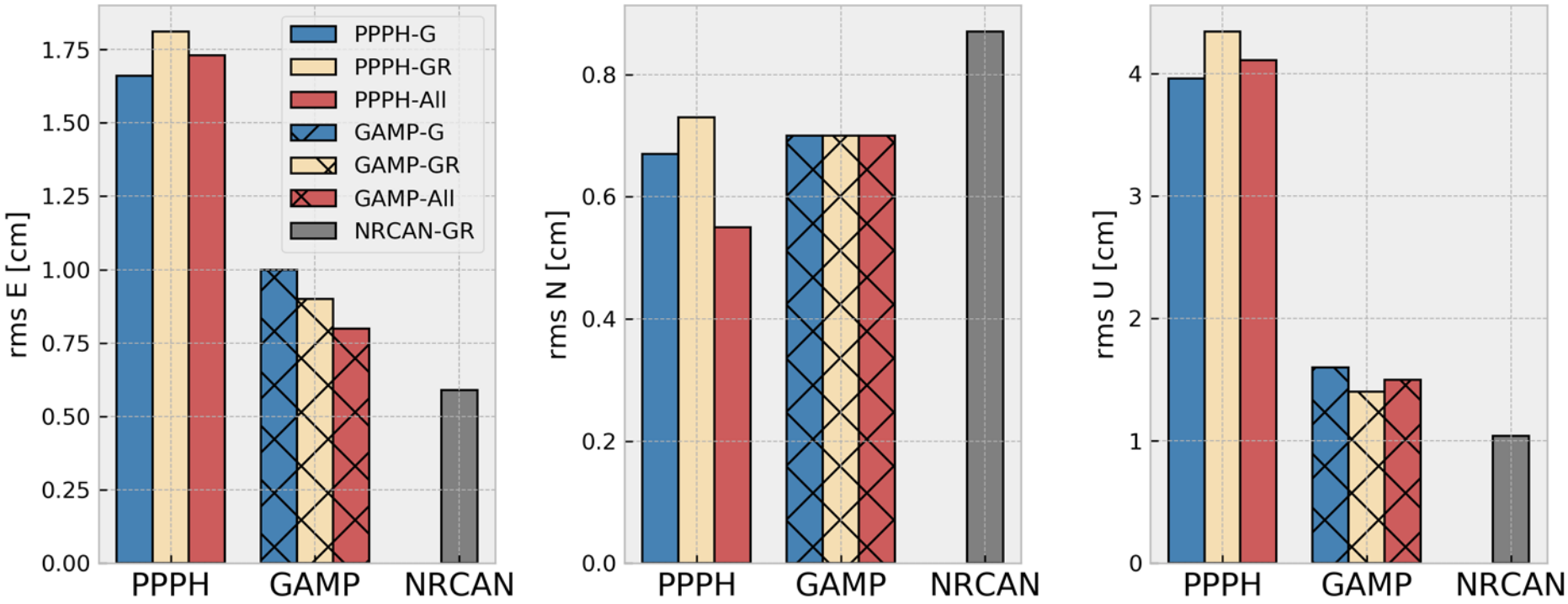

NRCAN-GR
Position Error [m]
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time [hrs]

Test 1: 24 Hour Sessions

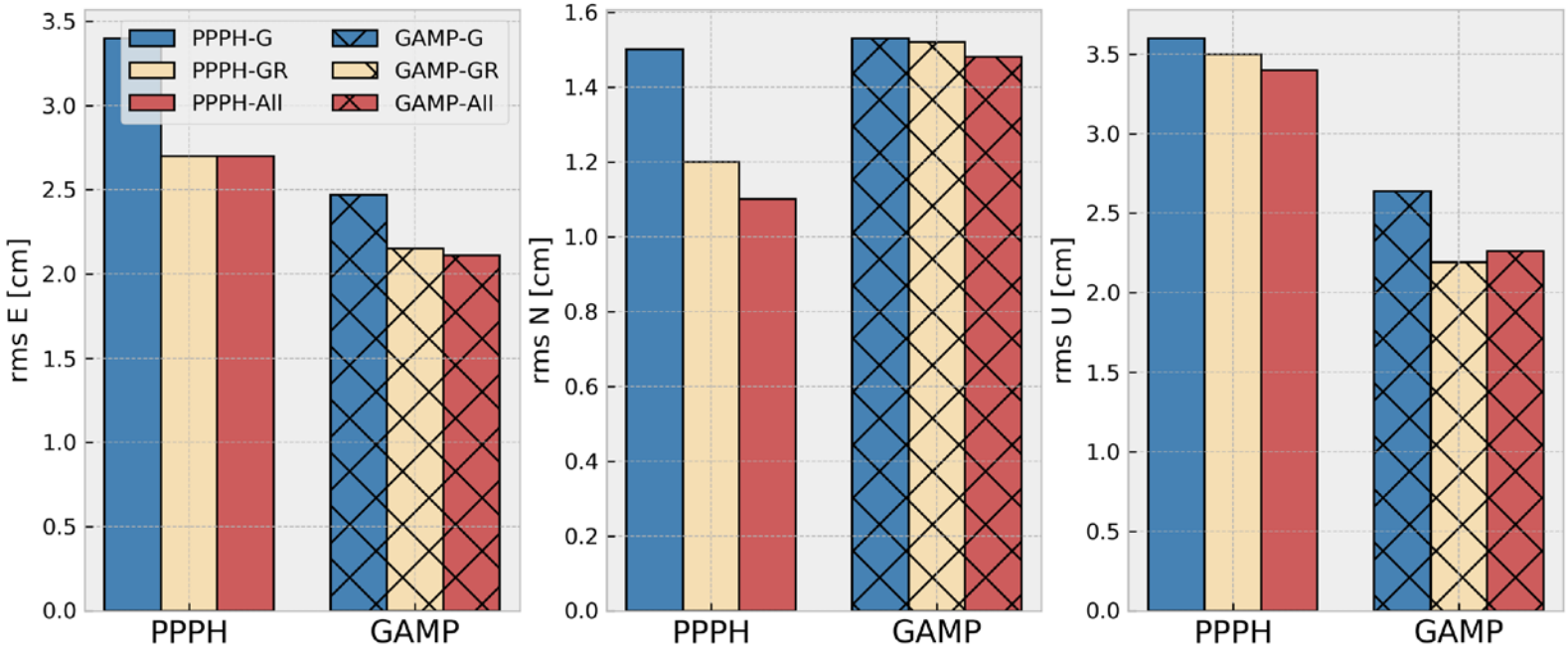
Software	GAMP			PPPH			NRCAN
Combination	GPS	GPS/GLO	ALL	GPS	GPS/GLO	ALL	GPS/GLO
Convergence Time [min]	18.0	19.5	18.5	30.0	17.0	13.5	13.0
3D Error [cm]	1.2	1.1	1.0	3.26	3.98	3.95	0.55
rmsE [cm]	1.0	0.9	0.8	1.66	1.81	1.73	0.59
rmsN [cm]	0.7	0.7	0.7	0.67	0.73	0.55	0.87
rmsU [cm]	1.6	1.4	1.5	3.96	4.34	4.11	1.04

Test 2: 4 Hour Sessions

	Software	GAMP			PPPH		
	Combination	GPS	GPS/GLO	ALL	GPS	GPS/GLO	ALL
Median Values	Convergence Time [min]	21.5	21.8	21.0	31.0	16.5	15.5
	3D Error [cm]	1.70	1.39	1.40	4.1	4.1	4.0
	rmsE [cm]	2.47	2.15	2.11	3.4	2.7	2.7
	rmsN [cm]	1.53	1.52	1.48	1.5	1.2	1.1
	rmsU [cm]	2.64	2.19	2.26	3.6	3.5	3.4
% Improvement on GPS-Only	Convergence Time	-	-1.2	2.3	-	46.8	50.0
	3D Error	-	18.5	17.9	-	-0.3	2.8
	rmsE	-	13.0	14.8	-	19.2	21.1
	rmsN	-	1.0	3.6	-	22.0	22.8
	rmsU	-	17.1	14.4	-	1.5	5.1
% Improvement on GPS+GLO	Convergence Time	-	-	3.45	-	-	6.06
	3D Error	-	-	-0.72	-	-	3.09
	rmsE	-	-	2.09	-	-	2.28
	rmsN	-	-	2.63	-	-	1.03
	rmsU	-	-	-3.20	-	-	3.63

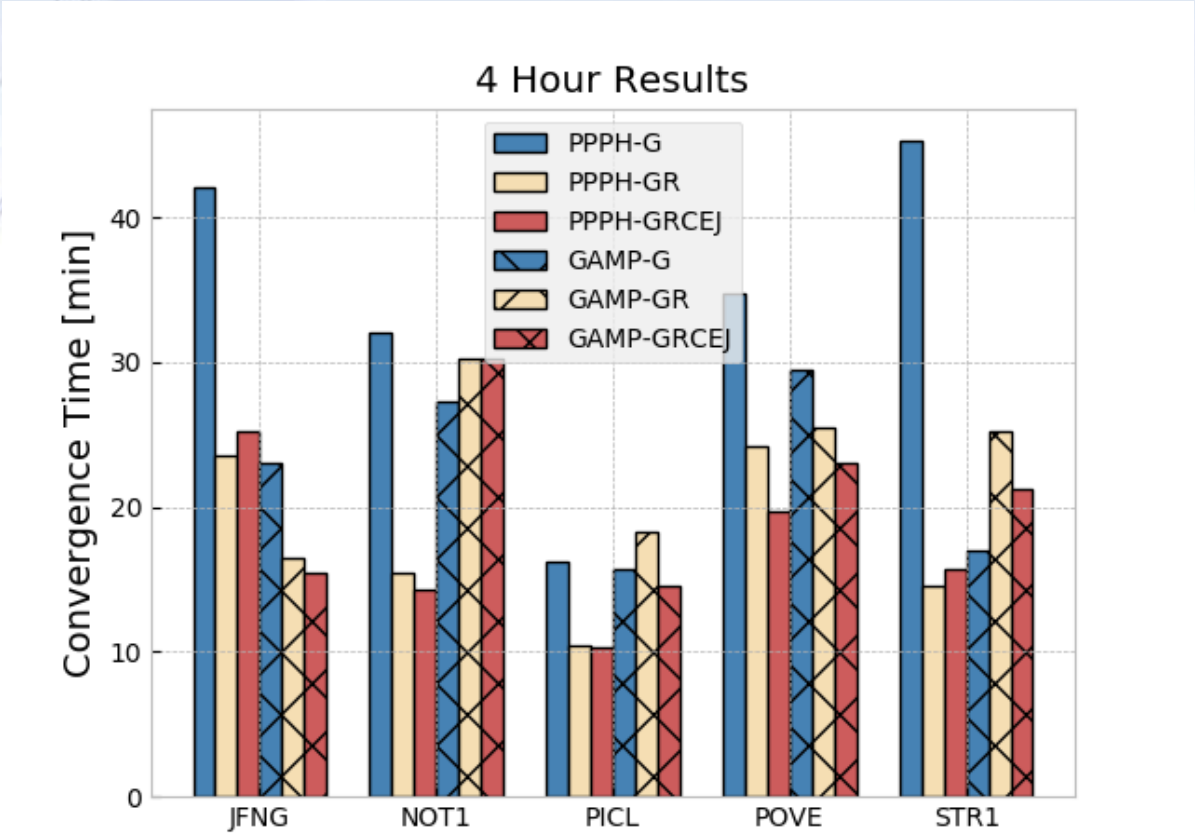


- 24 hours – RMS
- PPPH- Notably large RMS in the Up component


PPPH-G
PPPH-GR
PPPH-All
GAMP-G
GAMP-GR
GAMP-All
rms E [cm]
rms N [cm]
rms U [cm]
PPPH
GAMP
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0.2
0.4
0.6
0.8
1.2
1.4
1.6

- 4 hour- RMS

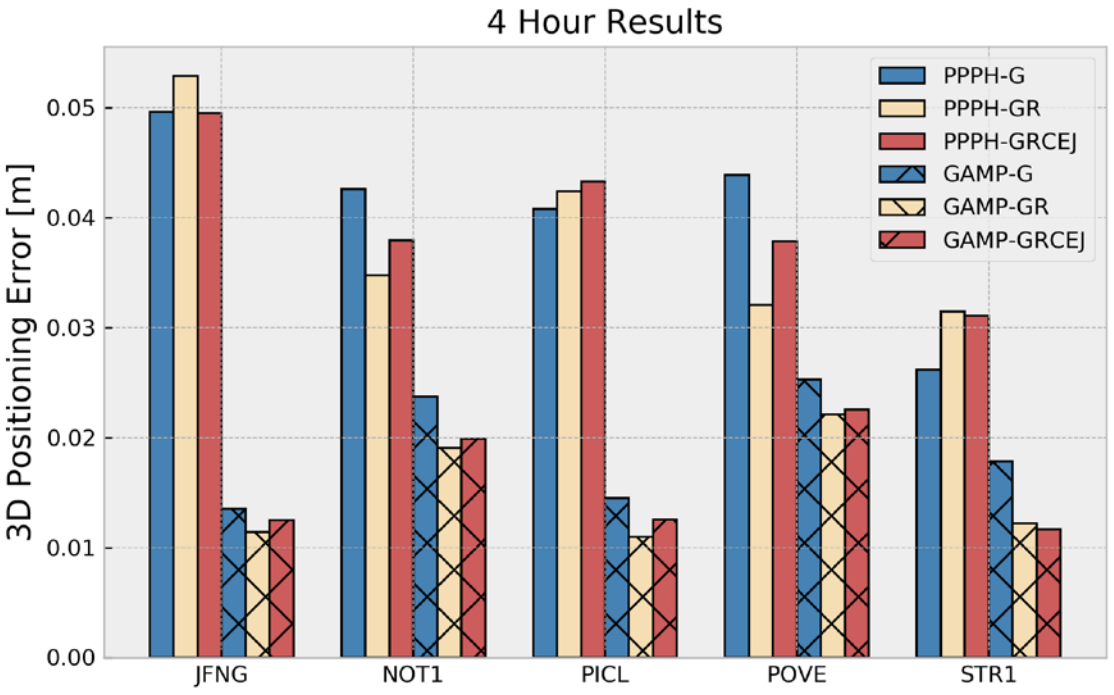
Test 2: 4 Hour Sessions



Test 2: 4 Hour Sessions

- GAMP ~ 1-2 cm 3D errors
- PPPH ~ 3-5 cm 3D errors

- Performance of each program varies on a station by station basis



GAMP vs. PPPH

- Similarities
  - Handling of satellite and receiver antenna PCOs/PCVs
  - Float ambiguities
- Differences
  - Handling of GLO IFBs
  - Uncombined vs. Ion Free
  - Weighting?
  - Handling of DCBS?
  - Pole tides
  - Tropo