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Evaluating The Characteristics Of Multi-GNSS Signals Received By An Low-Cost Receiver Connected To Various Low-Cost Antennas

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1. Introduction

The Global Navigation Satellite System (GNSS) has revolutionized geodesy and surveying, allowing for precise positioning and remote sensing. Low-cost GNSS receivers can reduce surveying costs despite having limitations compared to geodetic-grade receivers. In this study, we used 14 in-house low-cost receivers with various antennas, including geodetic-grade ones, and built a testing array with reference coordinates from classical geodesy techniques, co-located with the IGS WROC station. This setup enabled calculation of phase center offsets (PCO) for each antenna. We applied the PCOs in multi-GNSS Precise Point Positioning (PPP), PPP with Ambiguity Resolution (PPP-AR), and double-difference (DD) positioning. Additionally, we assessed GNSS observations' noise for the u-blox ZED-F9P module.

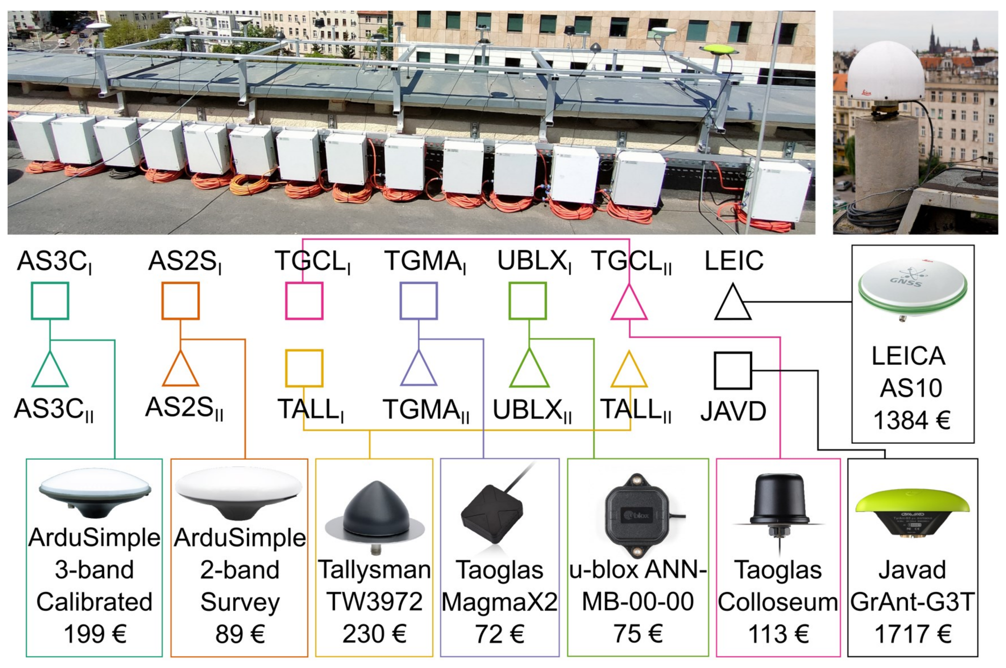

Fig. 1 Testing array with 14 low-cost GNSS receivers connected to 12 low-cost and two geodetic-grade GNSS antennas

2. Methodology

We excluded BeiDou satellites due to low visibility in Wrocław, Poland, increasing other systems' satellite counts. We calculated PCOs using short-baseline relative positioning and implemented them in three different positioning solutions. Additionally, we used a GPS Networking ALDCBS1X8 splitter and processed the data with a custom Matlab script (Tab. 1)

Tab. 1 Measurement assumptions made during the experiments

	DD	PPP	PPP-AR	Observation noise
Period of experiment	05-18.07.2022			26-28.05.2023
Observed GNSS	GPS (G) + GLONASS (R) + Galileo (E)			
Interval	30 sec			
Software	Bernese 5.2	GNSS-WARP	G-Nut/ Geb Pro	Matlab
Used GNSS	G + R + E		G + E	G + R+ E

3. Results

Signal-to-noise

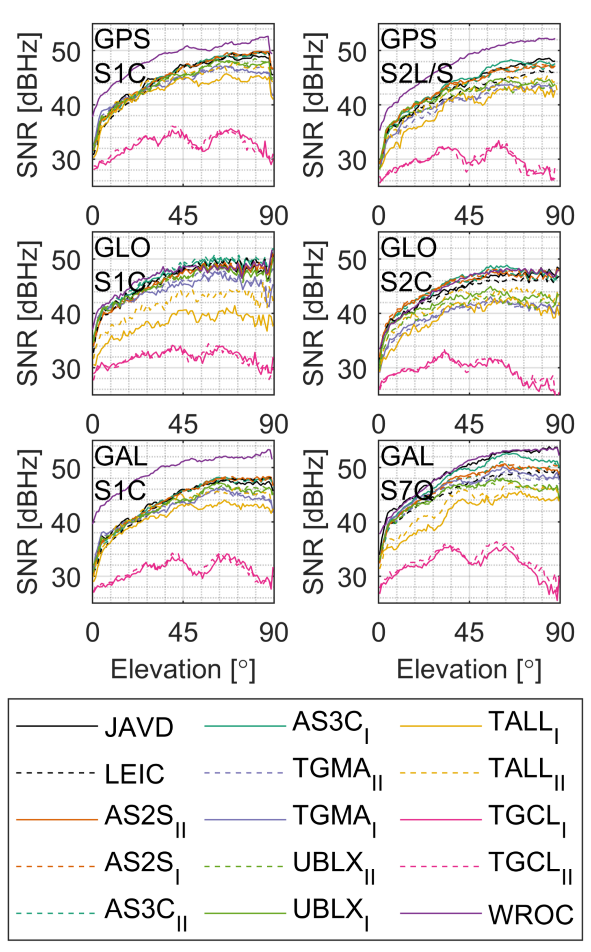

Fig. 2 SNR characteristics with respect to elevation angle for low-cost antennas and station WROC for each satellite system and frequency.

Observation noise

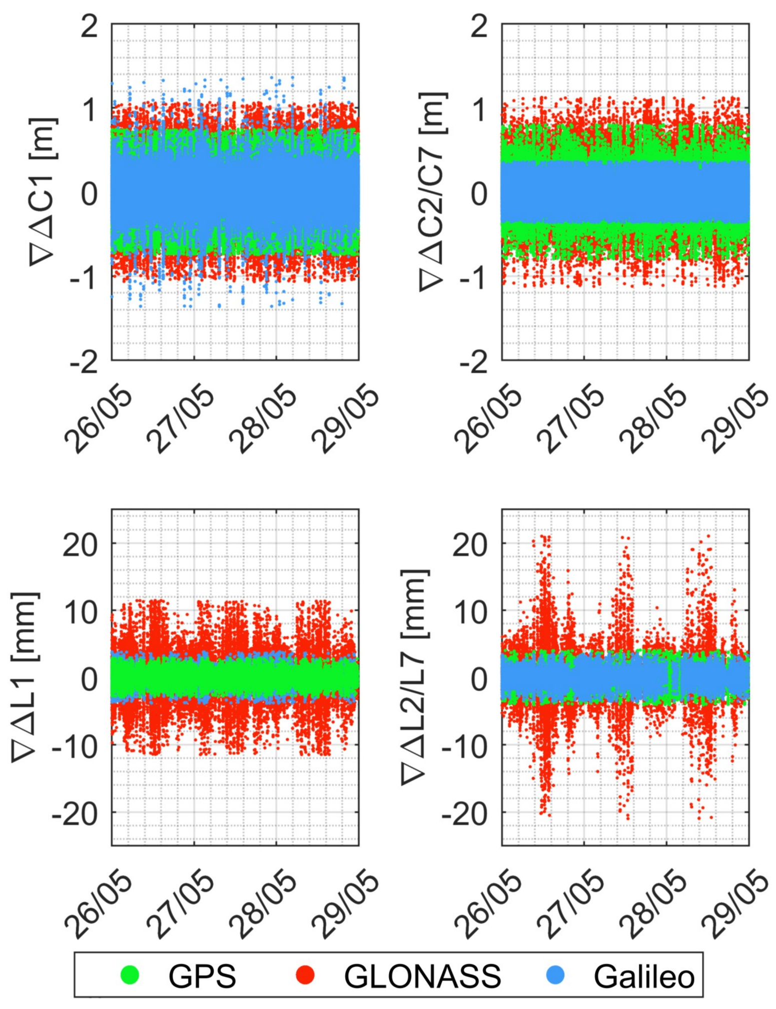

Fig. 4 Double-differenced code (top) and carrier-phase (bottom) observations for the first (left) and the second (right) frequency, GNSS receivers BX03-BX08.

Multipath

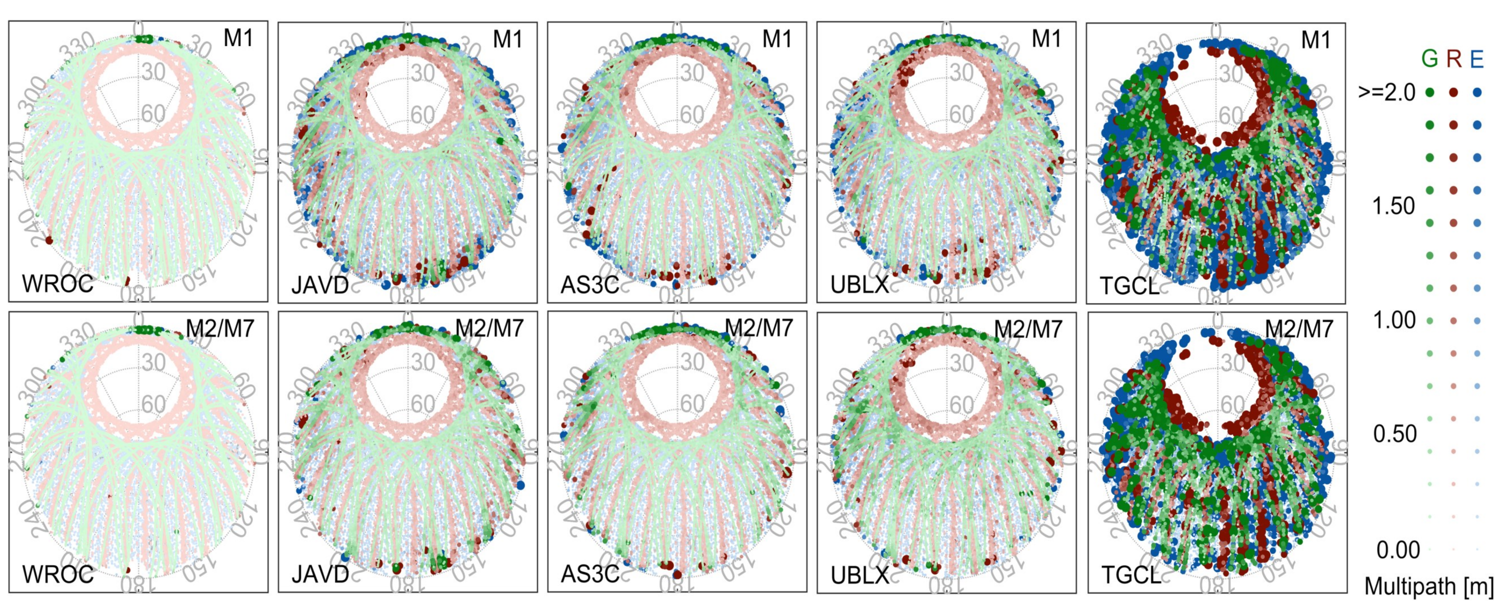

Fig. 3 Multipath effect for WROC station and selected low-cost antennas for the first (above) and the second (below) frequency.

Tab. 2 Estimated vertical PCOs [mm]

[mm]	G1	G2	R1	R2	E1	E5b
JAVD	16.6	29.6	14.4	27.5	14.5	26.1
LEIC	50.1	57.9	51.5	55.5	49.8	54.9
$AS3C_{I}$	48.3	38.2	48.5	41.3	47.6	32.0
$AS3C_{II}$	51.0	51.1	51.8	52.3	50.3	47.6
$AS2S_{I}$	40.5	40.9	41.7	38.8	39.7	39.0
$AS2S_{II}$	48.4	51.0	47.3	52.0	47.0	47.3
$UBLX_{I}$	-0.2	17.3	-0.3	20.7	-1.8	15.8
$UBLX_{II}$	-8.3	14.9	-9.6	13.2	-9.9	4.6
$TGMA_{I}$	3.0	10.0	-7.6	13.7	-0.1	5.5
$TGMA_{II}$	-3.2	10.4	-7.6	15.0	-3.2	6.0
$TGCL_{I}$	23.2	-	-	-	-3.7	-60.2
$TGCL_{II}$	-2.7	-39.5	-	-45.8	8.3	-44.2
$TALL_{I}$	-2.2	-46.8	-2.1	-30.3	-2.9	-52.6
$TALL_{II}$	8.2	-33.8	16.3	-25.7	10.0	-27.3

DD positioning

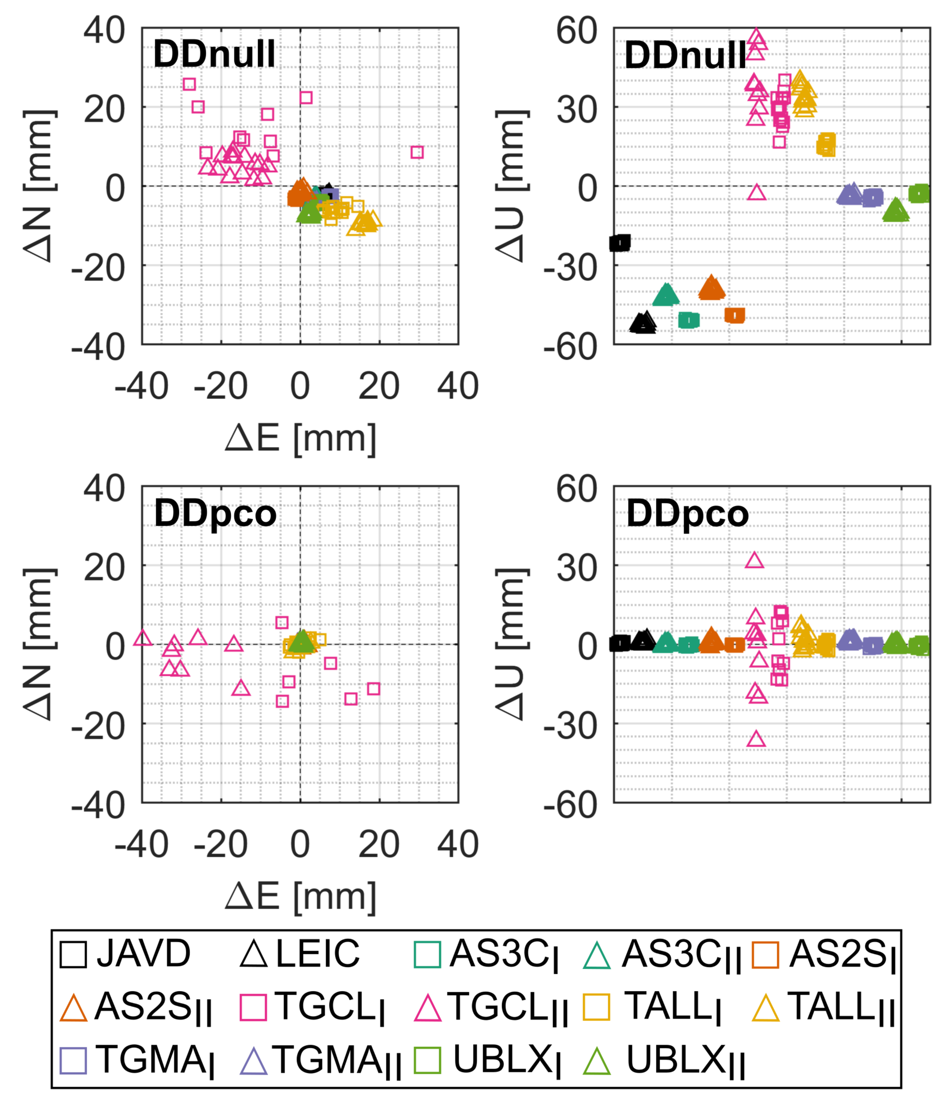

Fig. 5 Horizontal (left) and vertical (right) differences of daily positions from the DD solutions with null PCOs (top) and with the determined PCOs (bottom)

PPP positioning

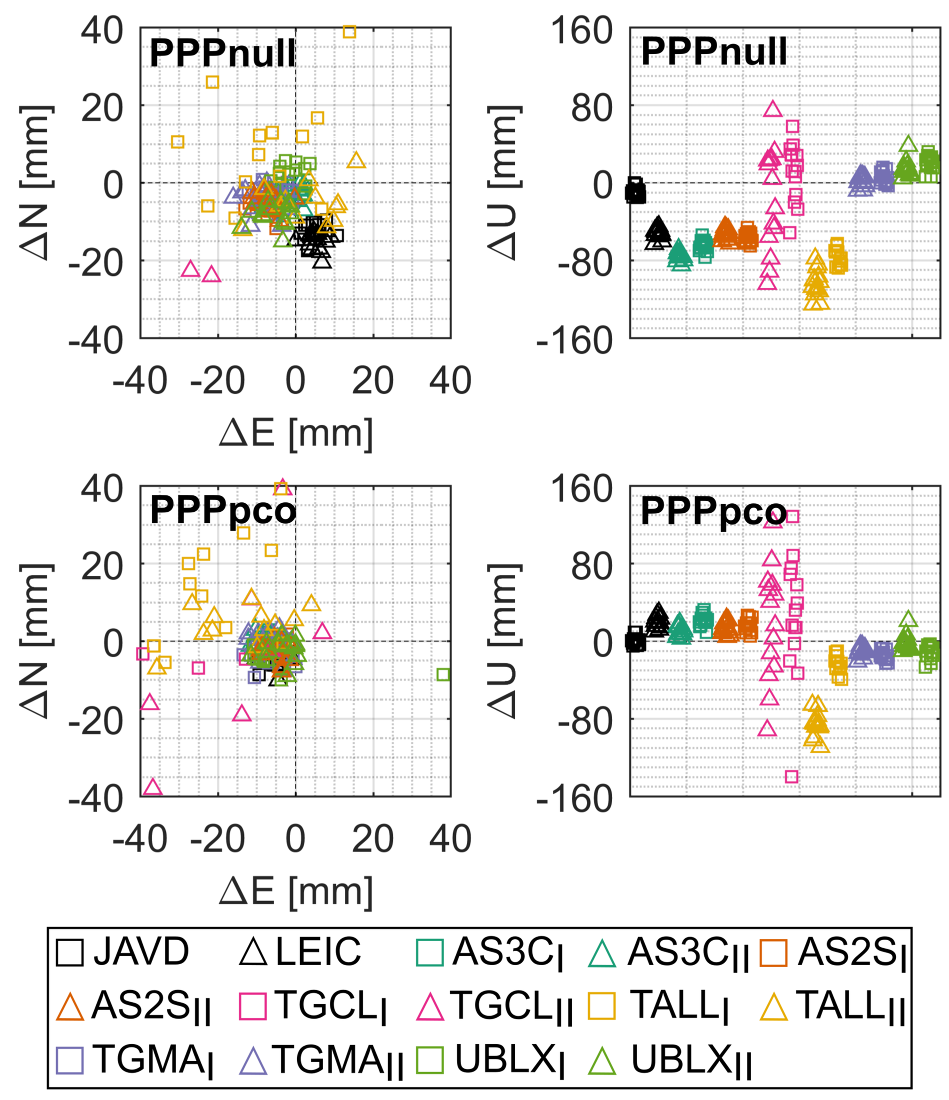

Fig. 6 Horizontal (left) and vertical (right) differences of daily positions from the PPP solutions with null PCOs (top) and with the determined PCOs (bottom)

PPP-AR positioning and convergence time

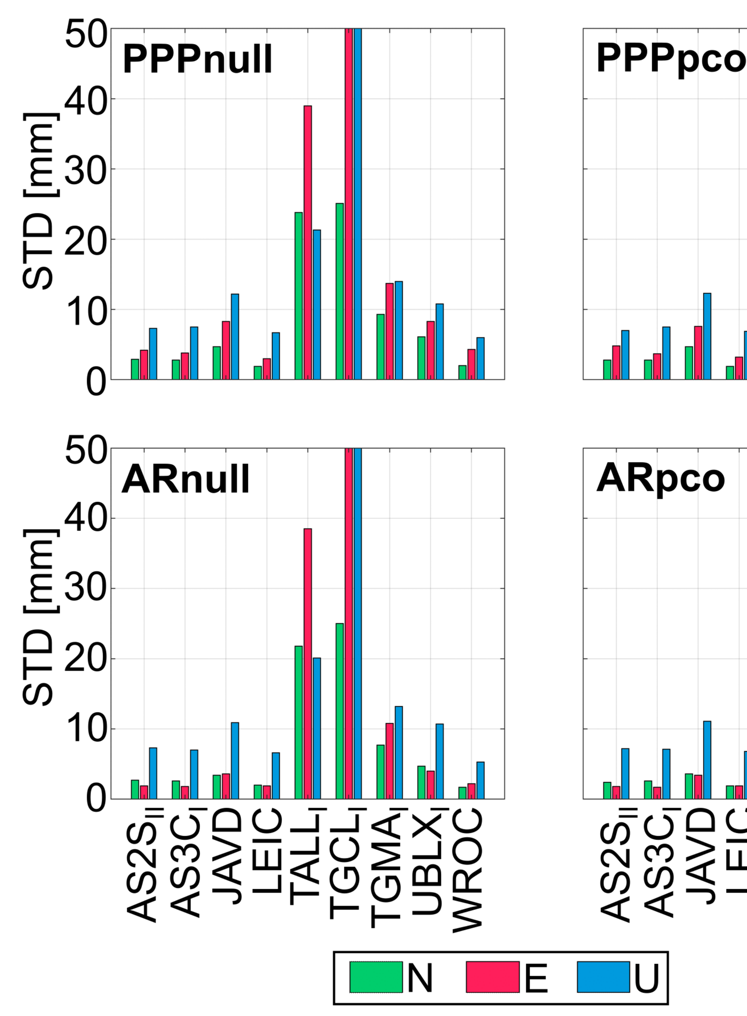

Fig. 7 Repeatability of the North, East and Up coordinates components of float PPP (top) and PPP-AR (bottom) solutions with null (left) and determined (right) PCOs

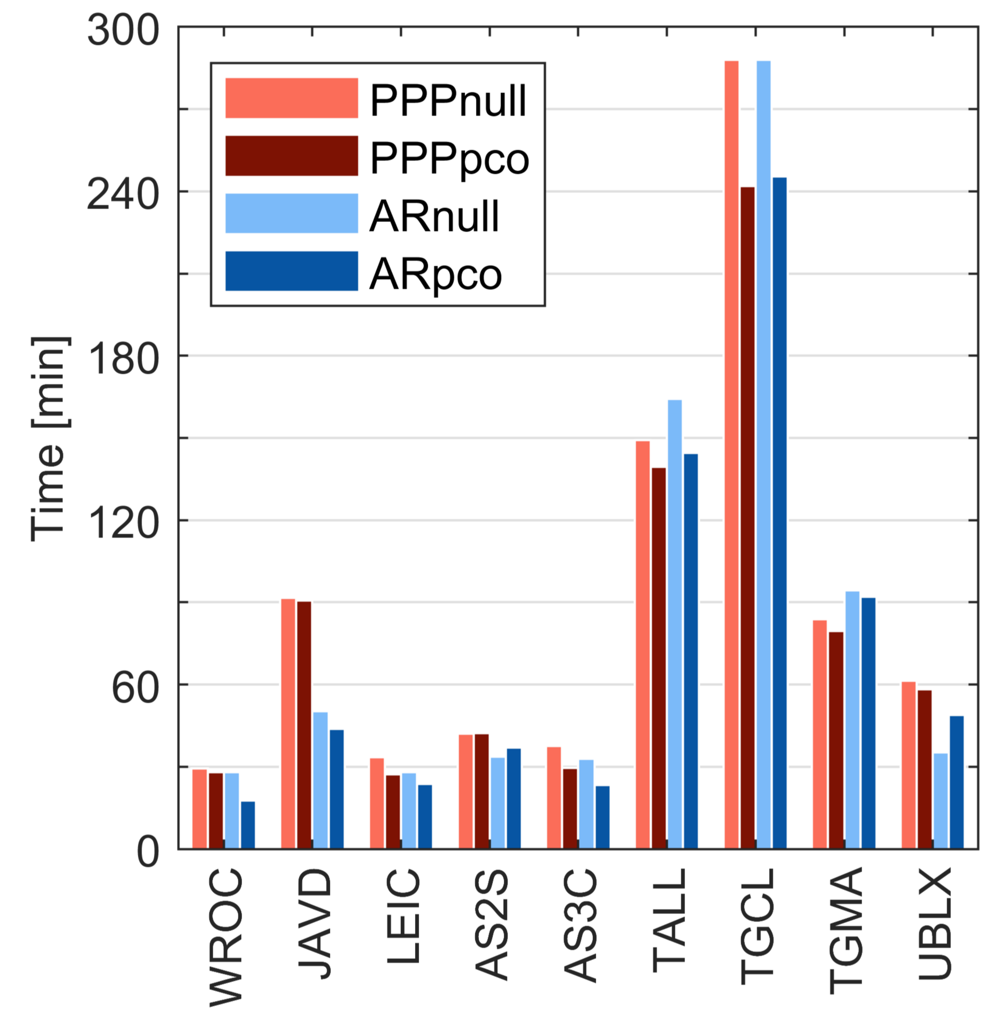

Fig. 8 Average time required to achieve 5 cm horizontal/vertical accuracy (95%) of float PPP and PPP-AR solutions with null and determined PCOs

4. Conclusions

The study finds that low-cost GNSS antennas receive signals 3-9 dB-Hz weaker than geodetic-grade antennas. L1, E1, and E5b signals are well-tracked, but L2 signals are significantly lower, with only 72% and 86% acquired for GPS and GLONASS. Pseudorange noise ranges from 0.12 m for Galileo E5b to over 0.30 m for GLONASS, and carrier-phase noise averages around 1 mm for GPS and Galileo but exceeds 3 mm for GLONASS. Low-cost antennas are more vulnerable to multipath effects, with errors up to 20 times greater. PCO discrepancies can reach 25 mm vertically. Individual calibration improves positioning accuracy, enhancing daily static DD solutions to better than 2 mm horizontally and 3 mm vertically. PPP solutions achieve sub-centimeter horizontal accuracy, though vertical offsets vary from -15 to +30 mm. PPP-AR improves precision and convergence time. The study concludes that properly calibrated low-cost GNSS receivers and antennas can achieve high precision in positioning and complement high-end geodetic receivers in geoscience applications, despite some limitations.

5. Acknowledgments

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6. Reference

The full text is available in the journal GPS Solutions under the DOI number: 10.1007/s10291-024-01628-4