Wrocław University of Environmental and Life Sciences

Real-Time PPP Performance Using Low-Cost GNSS Receivers and Galileo HAS Corrections

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Introduction to GNSS

Definition of GNSS
GNSS refers to satellite systems providing global positioning, navigation, and timing (**PNT**) services.

Key GNSS
GPS (USA), **GLONASS** (Russia), **Galileo** (EU) and **BeiDou** (China)

Applications
Critical in aviation, maritime, surveying, positioning, agriculture, and personal navigation technologies.

Low-cost GNSS Receivers

Key Features
Support for multi-GNSS signals, dual-frequency tracking, and compact designs for cost-efficiency.

Advantages
Affordable, energy-efficient, and suitable for mass-market applications such as drones, IoT, and precision agriculture.

Limitations
Higher susceptibility to multipath effects, limited phase center calibration, and reduced robustness in challenging environments.

Galileo High Accuracy Service (HAS)

What is Galileo HAS?
A free GNSS augmentation service by the EU, enhancing real-time Precise Point Positioning (PPP).

Service Levels
SL1 offers global coverage, while SL2 (under development) provides enhanced ionosphere corrections.

Dissemination Methods
Corrections delivered via E6-B Signal in Space and internet streams in CSSR format.

Target Accuracy
20 cm horizontal and 40 cm vertical accuracy achieved within 300 seconds for SL1.

Correction Availability
High availability rates: ~97% for Galileo, ~95% for GPS with reliable correction data.

Performance Metrics
Static positioning achieves centimeter-level precision, sub-decimeter accuracy in kinematic mode.

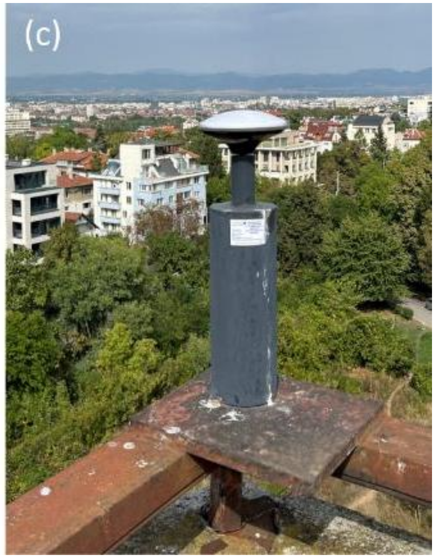
Experimental setup
(static and pseudo-kinematic scenarios)

Low-Cost GNSS Receivers
Prototypes (a) with **u-blox ZED-F9P** chipsets and **Raspberry Pi** microcomputer deployed in Poland and Bulgaria for multi-GNSS tracking.

Observation Stations
PL01 in Wrocław, Poland (b), and **BG01** in Sofia, Bulgaria (c), for static and dynamic GNSS data collection.

Data Acquisition
Real-time GNSS observations from GPS and Galileo processed with proprietary Python software and archived in RINEX format.

Measurements period
29 March to 24 April 2024



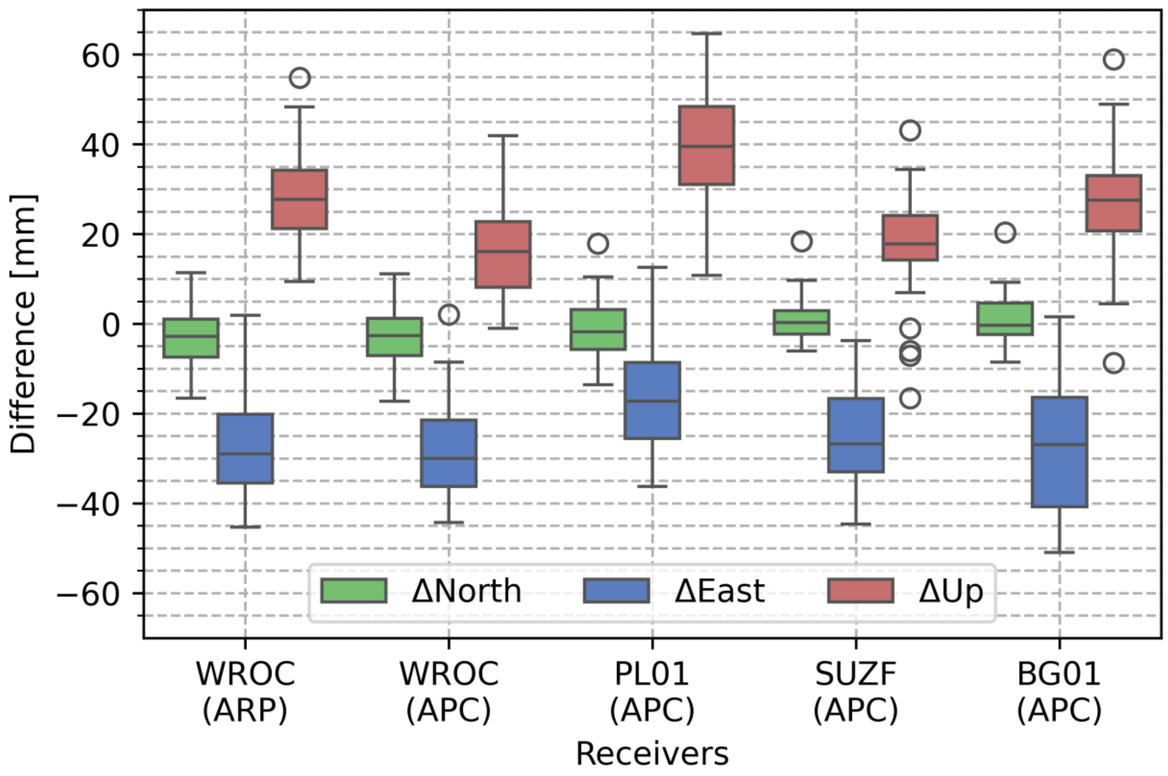
Results: static

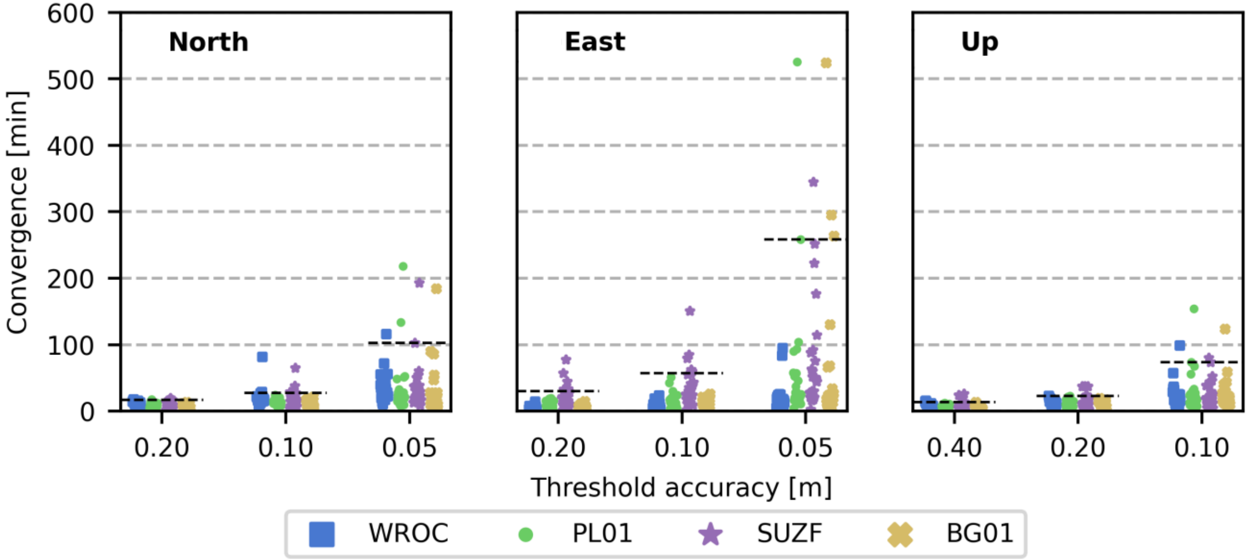
Positioning Accuracy
Standard deviations: 15 mm (North), 26 mm (East), 43 mm (Up) after reaching target accuracy.

Position Bias
Mean bias between estimation and reference was -24 mm and 28 mm for East and Up respectively. For North bias was near to zero.

Position Convergence Time
Mean time needed to achieve target HAS accuracy was 16 min, 30 min and 14 min for North, East and Up respectively.

Observation Quality
Outliers were <0.8% for code and <1.1% for carrier phase observations.





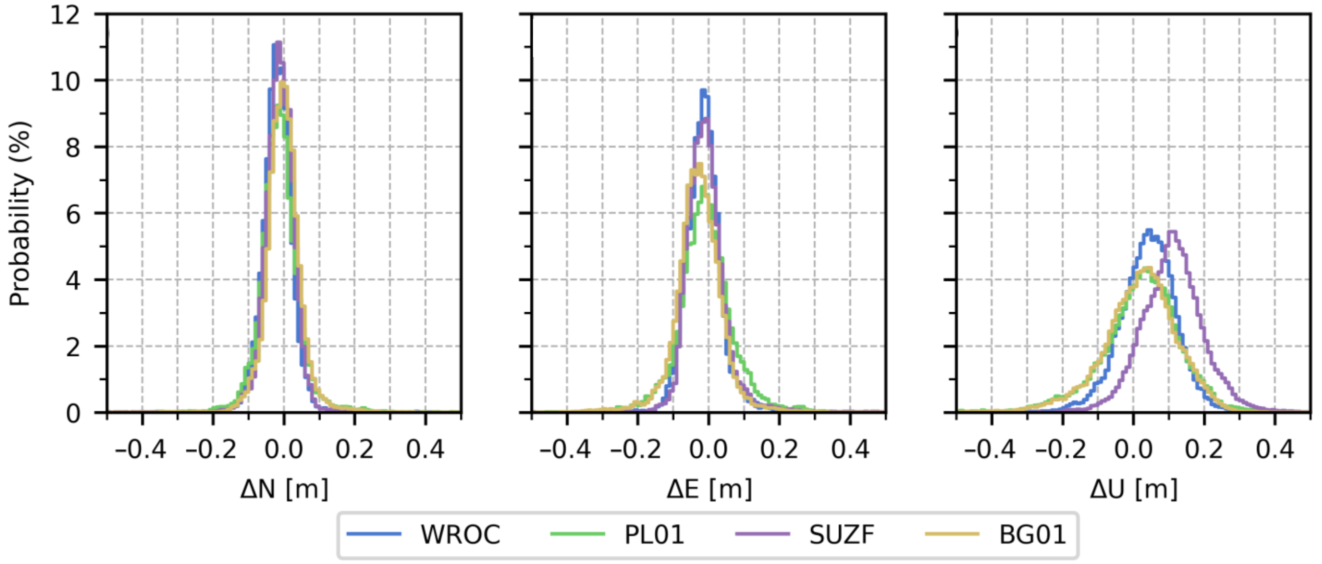
Results: pseudo-kinematic

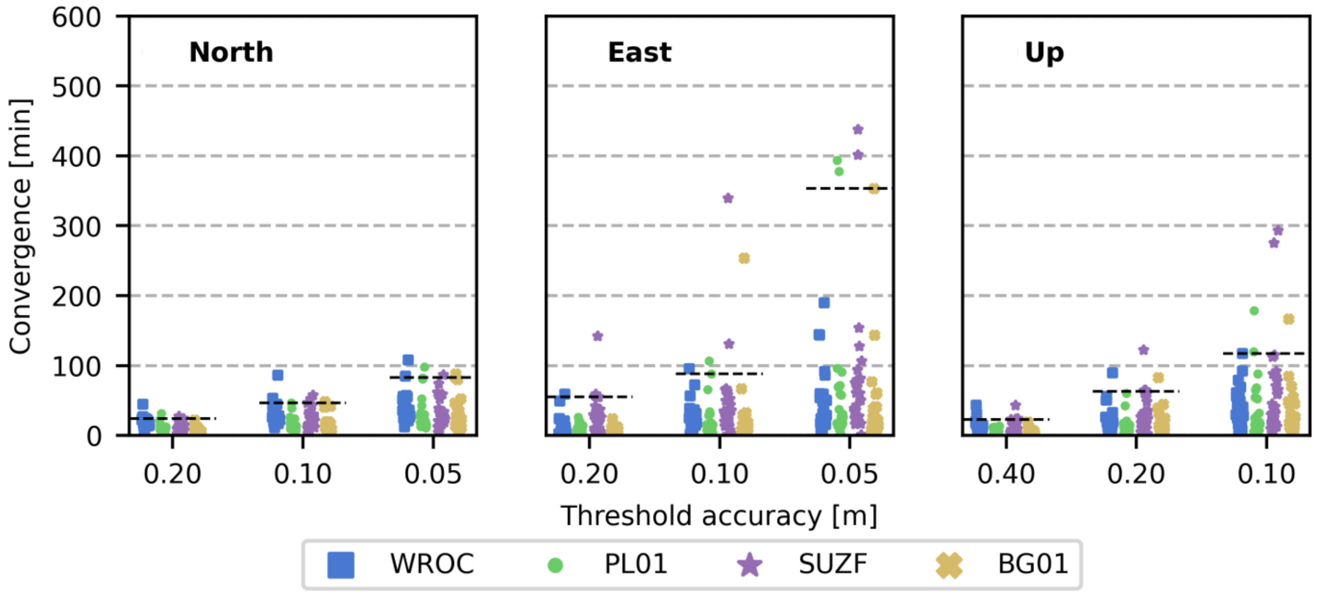
Positioning Accuracy
Standard deviations: 45 mm (North), 44 mm (East), 86 mm (Up) after reaching target accuracy.

Position Bias
Mean bias between estimation and reference was -20 mm for North and East. For Up bias was from 40 mm for PL01, BG01 and WROC, even to 100 mm for SUZF.

Position Convergence Time
Mean time needed to achieve target HAS accuracy was 24 min, 55 min and 23 min for North, East and Up respectively.

Observation Quality
Outliers were <0.5% for code and <1.5% for carrier phase observations.





Experimental setup (UAV flight)

Low-Cost GNSS Receiver

Seagull #GPK2 equipped with **u-blox ZED-F9P** for multi-GNSS tracking (GPS + Galileo).

Flight Place and Time

08:10 – 10:55 UTC

28 April 2023

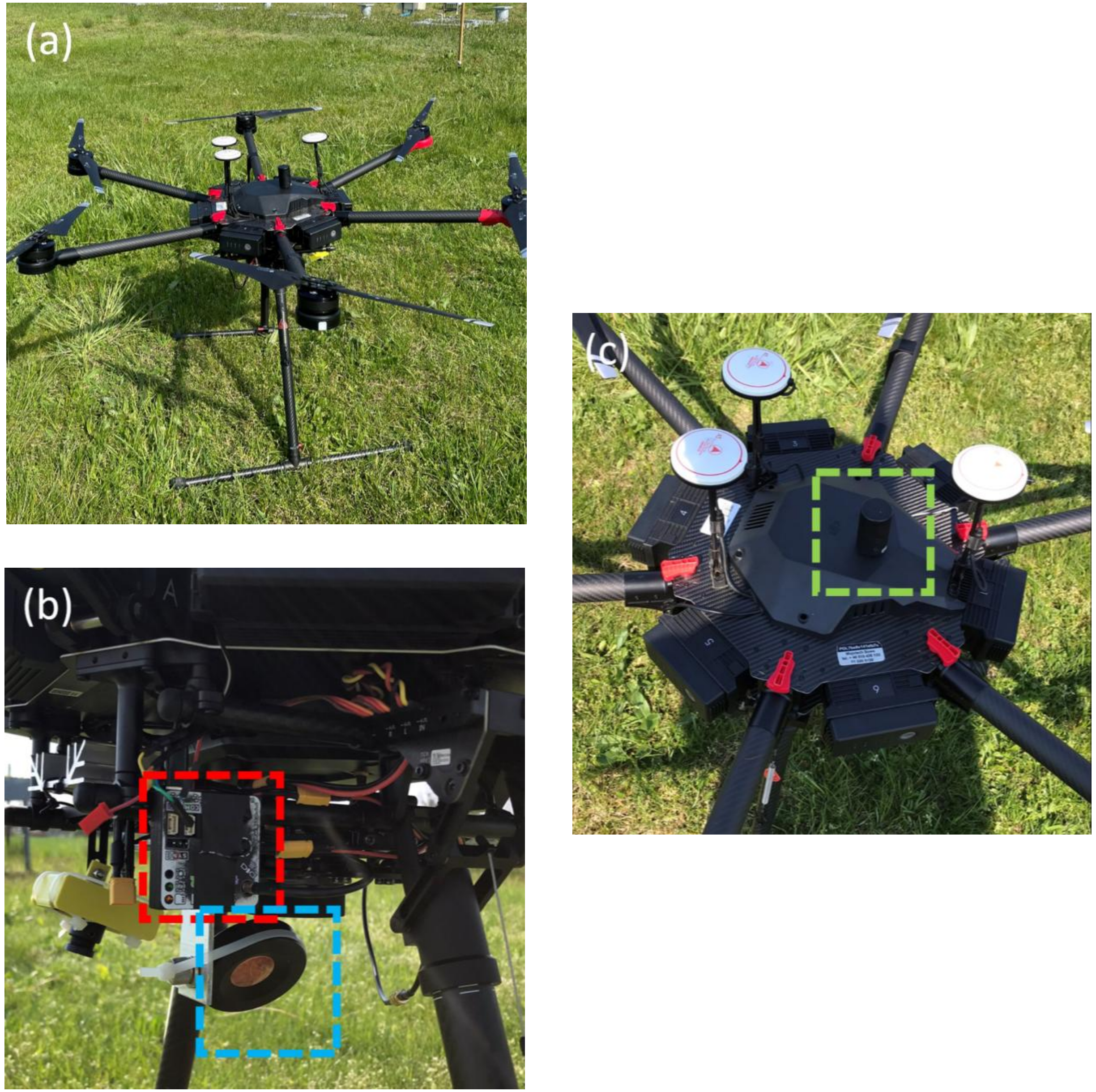
Wrocław, Poland

UAV

DJI Matrice 600 Pro with integrated A3 Pro flight control, and equipped with Leica GMP 104 geodetic retroreflector.

Total Station

Robotic **Trimble** total station was used to control UAV altitude during flight.



Results: UAV flight

Positioning Accuracy

Carrier-phase residuals maximum 5 mm during static initialization and doubled during flight. Code residuals on similar level for both periods (50 cm and 15 cm for 1st and 2nd frequency, respectively).

Position Bias

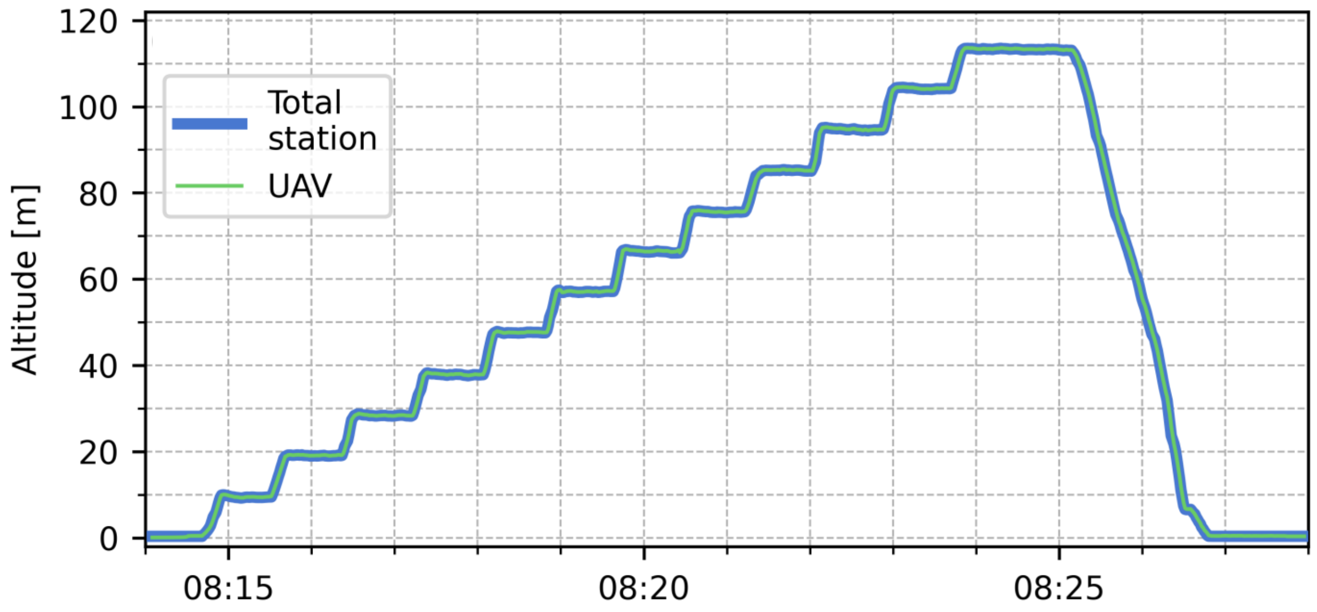
Mean +7.6 cm compared to total station with increasing at 67 m altitude with no clear cause.

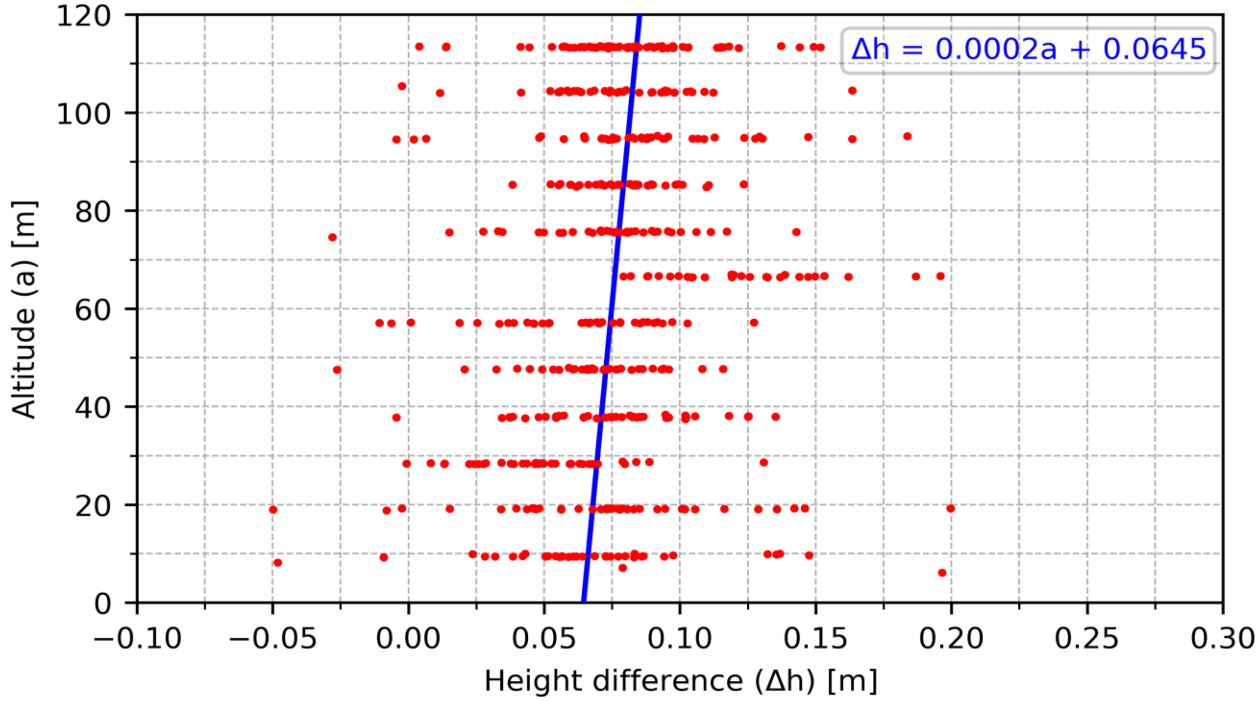
Position Convergence Times

5 mins, 6 mins and 37 minutes for North, Up and East, respectively.

Observation Quality

Outliers were <1.5%.





Summary

- **Proven Feasibility:** Demonstrated that **low-cost GNSS receivers with Galileo HAS** can deliver **high-precision positioning** for real-time static and kinematic, e.g. UAV, applications, which meet Galileo HAS target.
- **Short Convergence Time:** While **convergence times are relatively short,** they **do not fully meet the Galileo HAS target** of achieving accuracy within **300 seconds**, indicating potential for further optimization.
- **Minimal Observation Errors:** Maintained **low observation outlier rates** (<1.5%) with **high-quality code and carrier-phase residuals**, even under dynamic conditions.
- **Reliable Vertical Accuracy:** Strong alignment with total station data confirms suitability for **altitude-sensitive missions** like surveying and mapping.
- **Potential for Broader Applications:** Opens opportunities for **real-time navigation, UAV operations, geoscience monitoring, and deformation analysis** using cost-efficient technology.

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Thank you for your attention!

Full results are available in the **Remote Sensing** under the DOI number: **10.3390/rs16214008**

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