Simulation Trials Data Analysis Results

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ICARUS

INTEGRATED **C**OMMON **A**LTITUDE **R**EFERENCE SYSTEM FOR **U**-**S**PACE

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Abstract

This document represents the deliverable D6.3 "Simulation Trials Data Analysis and Results" of ICARUS project. The main objectives of this document can be summarized as follows:

- To report the verification and validation activities of the project addressed in WP6 considering the Test cases identified and the validation scenarios defined in D6.1 and D6.2
- To provide the coverage of the requirements defined in D6.1 document and report any kind of non-compliance / partial compliance and/or findings generated by the verification and validation activities
- To discuss the lesson learned, the problems solved, and the new questions raised
- To summarize the conclusions of ICARUS validation activities.

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1 Introduction

The ICARUS project proposes an innovative solution to address the challenge of the Common Altitude Reference System for drones in very low-level (VLL) airspace using a GNSS altimetry-based approach, and the definition of a **geodetic-barometric transformation algorithm**, implemented through a dedicated U-space service (U3 service).

The first part of the project was dedicated to the definition of the concept and of the feasibility of the altitude translation services proposed by ICARUS, considering different elements that concur to the final end-to-end (E2E) error. To better understand the problems, five use cases were defined as representative of flight operations where the CAR service is needed. With the help of such use cases, a detailed analysis of the requirements was conducted, and a set of requirements and the related environment type were identified to drive the design of the architecture of the CAR service. This document reports the outcomes of simulations and flight trials considering different GNSS equipment used in mixed configurations (from low-cost GNSS to High-end receivers) in operational environments.

The scope of this document (D6.3) is to provide the results of the test cases identified and the validation report of the operational scenarios defined in D6.1 and D6.2, during the design of flight scenarios and the definition of the operational plan.

The document also provides a description of the test bed environments used for the implementation of the validation scenarios for the Italian and the Polish simulations. Each test bed environment used simulated elements and real components for running the scenarios (i.e. simulated track of GA airplane with barometric altitude sensor generated by Cockpit simulator and real track of a drone using Geometric Altitude). The set-up of testbed environment is tailored to the validation of the suite of microservices studied during the project and implemented in WP5. Such micro services identified, developed and implemented in ICARUS project are the following:

- **VCS (Vertical Conversion Service):** provides automatic translation between barometric height and GNSS altitude (i.e. conversion from a barometric reference system to a geodetic one or vice-versa);
- **VALS (Vertical Alert Service):** Alerts drones and manned aviation over the common geodetic reference system about the current vertical distance to the ground (or other drone traffic), when such a distance becomes too small.
- **RGIS (Real Time Geographical Information Service)**: provides accurate cartography and 3D DTM / DSM of ground obstacles during the execution of a flight, to provide real-time information on the vertical distance to the ground, including above taller obstacles.

Moreover, for the verification activities some specific tests (both dynamic and static) were performed to provide a clear and accurate assessment about the translation errors from barometric to geometric systems used by UAS and GA airspace users.

The document is structured as follows:

- Section 1: Introduction and approach to verification and validation activities
- Section 2: Verification and Validation Setup
- Section 3: Test cases results
- Section 4: Validation Report

- Section 5: Traceability Matrix
- Section 6: Conclusions

The approach used for verification and validation activities is presented in D6.1; however, the operational details for the plan of each simulated (or real flight) exercise are presented in D6.2, which is intended as an operational document for supporting both operational and simulation trials. The outcome of the verification and validation campaign are presented in this document.

1.1 Applicable Reference material

The following documents are considered applicable reference material:

[1] Grant Agreement-894593-ICARUS
[2] ICARUS Consortium Agreement
[3] SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4), available at http://ec.europa.eu/research
[4] Project Handbook of SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4) (Programme Execution Guidance), edition 03.00.00, 14th March 2019
[5] D3.1 – ICARUS concept definition: state of the art, requirements, gap analysis
[6] D4.1 – Design and Architecture of the ICARUS system & service
[7] D5.1 – UTM Platform architecture
[8] D5.2 – Cockpit Simulator Architecture
[9] D5.4 – External I/F test
[10]D-Flight USSP ICD - https://www.d-flight.it/new_portal/2021/06/24/nasce-il-manifesto-per-lo-spazio-aereo-dei-droni-d-flight-in-campo-per-il-decollo-del-settore/
[11]ICARUS_Requirements_v1.3
[12]D6.1 – Validation Scenario Design
[13]D6.2 - Simulation Trials Execution Plan

1.2 Acronyms

Acronyms	Signification
AMSL	Above Mean Sea Level
ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CARS	Common Altitude Reference System
DSM	Digital Surface Model
DTM	Digital Terrain Model
E2E	End to End
EFB	Electronic Flight Bag
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
GA	General Aviation
CARA	Common Altitude Reference Area

GBAS	Ground Based Augmentation System
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
HPL	Horizontal Protection Level
ISA	International Standard Atmosphere
MCMF	Multi Constellation Multi Frequency
MFMC	Multi Frequency Multi Constellation
QFE	Query Field Elevation
QNH	Query Nautical Height
RGIS	Real Time Geographical Information Service
RNP	Required Navigation Performance
RPAS	Remotely Piloted Aircraft System
RMS	Root Mean Square
SBAS	Satellite Based Augmentation System
SFMC	Single Frequency Multi Constellation
SiS	Signal in Space
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
USSP	U-Space Service Provider
UTM	Unmanned Traffic Management
VALS	Vertical Alert Service
VCS	Vertical Conversion Service
VLL	Very-Low-Level
VPL	Vertical Protection Level

Table 1-1 – Acronyms' list

1.3 Approach to verification and validation activities

The micro-services developed in ICARUS (VALS, VCS, RGIS) have been defined according to the following methodology:

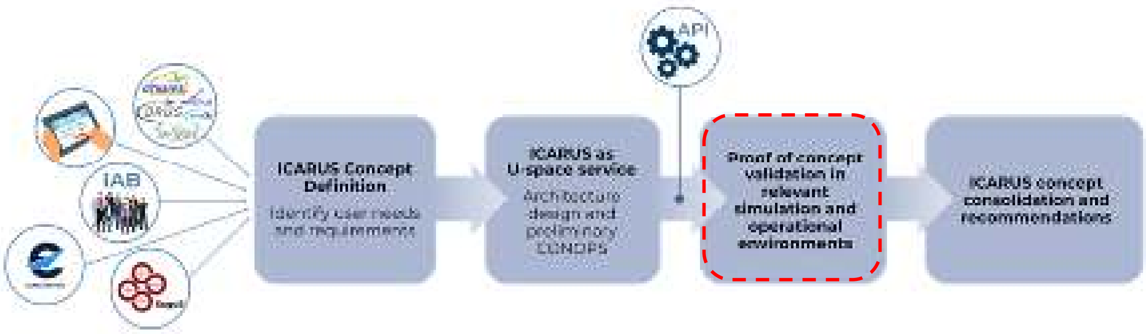


Figure 1-1 – Methodology: focus on verification and validation activities

For the verification activities, these services have been tested in this phase with a mixed approach involving both simulations in labs and verification activities in real operational scenarios, involving drones and manned aircraft flying at different heights. GA flights and taxi-drone flights were simulated with UAS flights and ultralight flights operated in a real scenario. The main objectives of the verification activities can be summarised as follows:

- to stress the differences in the different altitude measurement systems with different height / altitude settings
- to recognise the importance of the concept underpinning the micro-services proposed in terms of E2E accuracy and other KPIs;
- to provide a limited number of test cases that enable the full coverage of the requirements defined in D3.1
- to provide flight logs, data and external references (benchmarks) for data analysis and interpretation of the results[1]

Afterwards, the validation of ICARUS prototype services, put in place with the testbed described, is addressed with reference to the final E2E performance achieved. The validation was supported by two actual USSPs:

- D-Flight (Italy https://www.d-flight.it/new_portal/) with the support of Telespazio and TopView;
- PansaUTM (Poland https://www.pansa.pl/en/pansautm/) with the support of Droneradar;

1 ICARUS project promotes re-use of scientific data knowledge to help researchers, innovators and EU institutions. For this reason, free access to data collected during verification and validation activities will be given to U-space and H2020 communities.

As a final step, the validation outcomes will be presented to both UAS pilots and GA / ultralight pilots to provide feedback on the ICARUS micro-services developed. This activity will be put in place when presenting ICARUS outcomes to the member of the Advisory board for the third and last meeting.

The verification and validation methodology can be organised as shown in *Figure 1-2*. This diagram illustrates the process followed for verification and validation activities (WP6).

Figure 1-2 – Organisation of information-related verification and validation activities

1. **ICARUS requirements (Use Cases):** Relevant use cases for ICARUS were defined in Section 6 of D3.1. This set of five use cases was defined to support the definition of the requirements used to drive the design of the ICARUS micro-service architecture and the flight trials (simulated and real) for the assessment of the performance and the validation of the concept. The requirements will be used as the input to the other activities.
2. **Verification and Validation Plan:** This is described in D6.1, taking the project schedule into account. In this section the test cases, the test procedures, and the naming convention will be identified and coded. The Chapter 3 of this document provides the results of the Test cases defined in D6.1 and implemented in this document.
3. **Validation Scenario Design:** The validation scenario design is described in D6.1 where different scenarios (both simulated and real) were described, with particular reference to the ICARUS micro-services that will be queried during the validation campaign and the target users that will be engaged in the validation (e.g. GA pilots, drone pilots, USSP operators).
4. **Operational Activities and Simulations:** These activities were described in D6.2. This provides operational details about the validation campaigns and exercises that were conducted, considering the particular areas where trials will take place. In this document the operational plan for execution of real flights and the **simulation trials** was described.
5. **Data Analysis and Results:** This information is described in this document (D6.3). In this document, all the data collected during the flights (simulated and real) are described and

analysed for final results and recommendations. The test results, from the test cases and test procedures defined in Section 2 of the D6.2 document, are finally presented here (D6.3).

6. **Requirements coverage:** The final step is a final check of the coverage of the requirements defined in D3.1. A traceability matrix will be used to support this stage (D6.3), with additional comments and findings.

2 Verification & Validation Setup

This chapter presents the architecture of the Testbed used for Verification and Validation activities.

2.1 Testbed Architecture

The testbed architecture is composed by different elements interconnected with physical or logical interfaces. The main scope of this testbed is to realize a suitable architecture to interconnect the ICARUS microservices developed with the “clients” (i.e. Ground Control Station for Drones and EFB devices for Manned airplanes, “consumers” of such services) and to provide an objective means of logging for data analysis in post processing.

Finally, the devices used to exploit the services, aims also at providing to users of ICARUS services (Drone pilots and Manned pilots) a modality for evaluate the user experience a provide feedback from an operational perspective.

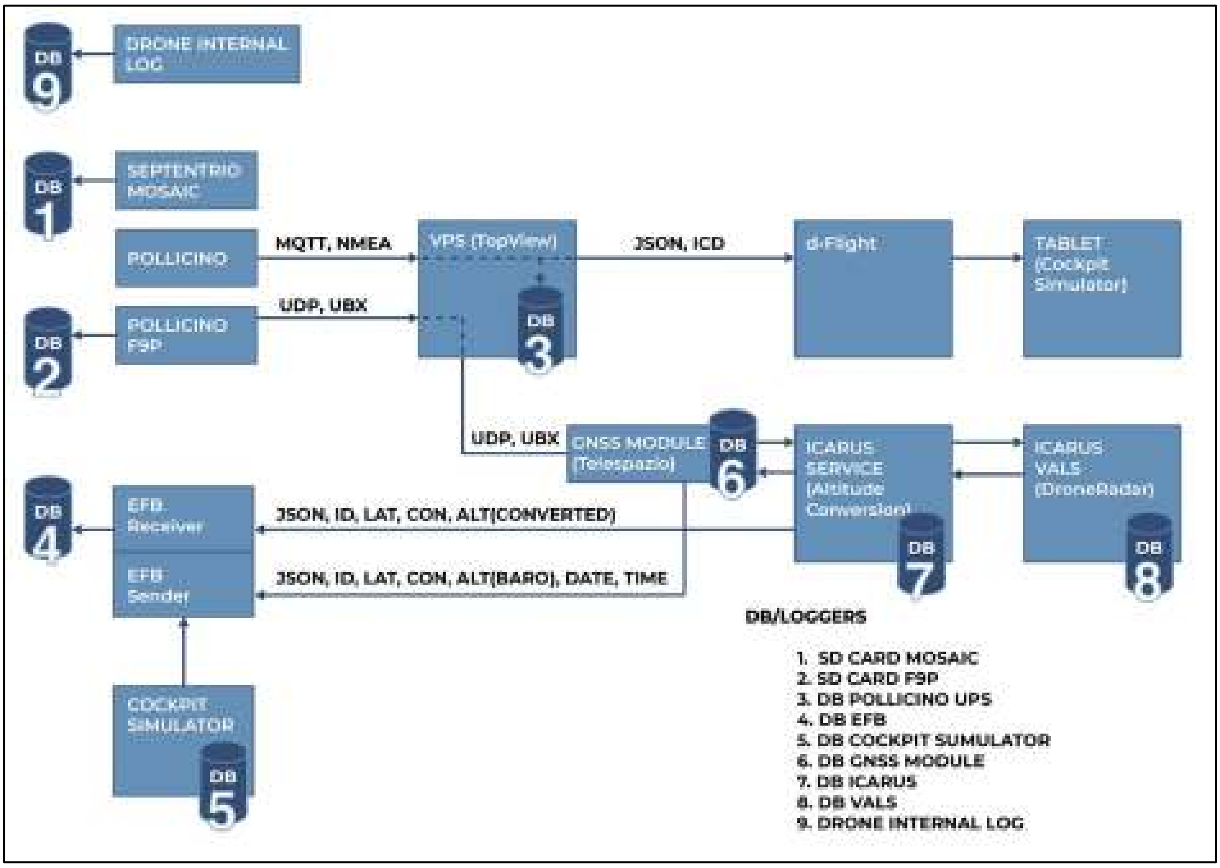


Figure 2-1 – Testbed architecture

The main elements of the architecture are the following:

- **Multicopter Drones**: Three small drones were used for the tests. In most of the test cases the platform DJI M300 RTK was used for the possibility to generate a reliable and accurate reference RTK DFMC GNSS trajectory already hybridized with data of other internal sensors (IMUs, barometer, Ultrasonic and vision sensors). In other cases, additional drones were used in parallel to test specific test cases (as comparison of converted heights). The internal drone data loggers were used to analyse data in post processing (DB9: Drone Internal Log). When used in combination with a private GNSS station, the trajectory of drone is very accurate and repeatable. It is not possible however to get GNSS raw measurement from drone internal loggers, although the final trajectory results already filtered and augmented with an RTK solution and internal sensors data fusion resulted very accurate.

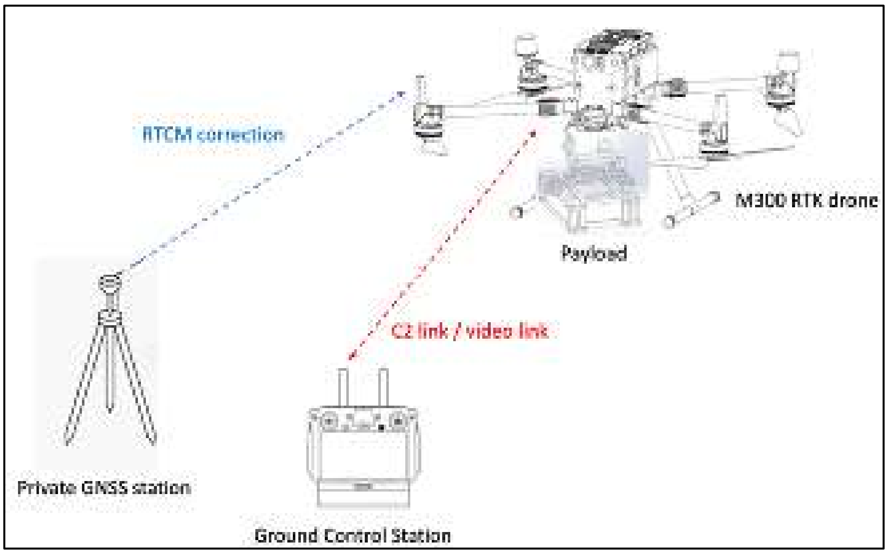


Figure 2-2 – UAS architecture for tests

- **GNSS / Barometer Payload:** A specific Payload was built as prototype just for measuring GNSS data and barometric data during the flights. In some tests an ADS-B Transponder was also added as additional payload for data comparison and conversions. The payload realized is composed by three independent GNSS receivers (2 High-end receivers: Septentrio Mosaic X5 and U-Blox F9P connected to the same Antenna) and a low-cost GNSS receiver (embedded in Pollicino transponder) for comparing the data acquired. With respect to the Testbed Architecture in ***Figure 2-3***, this payload logs data on SD cards (DB1, DB2) and feeds at the same GNSS Raw data to ICARUS microservices, logged on a Virtual Private Server (VPS, DB3)

Figure 2-3 – ICARUS prototype payload

- **GNSS Module:** This module gets in input the GNSS raw measurements received by the GNSS receiver U-Blox F9P and transmitted through 4G internet connection. In this way this element of the ICARUS testbed is capable to provide the integrity assessment of the GNSS signal using other elements (EDAS, ARAIM algorithm, Ground monitoring stations,) for both the vertical axis and the horizontal plane. During the tests data was stored on a local DB (DB6). Finally, this module dispatches the calculation of ICARUS microservices to the “clients” (Drones GCS and airplane’s EFB) subscribers of the services.

- **ICARUS Service:** This module represents the main digital interface for the ICARUS vertical conversion service (VCS). In the testbed architecture the same interface was used to access and query also the VALS service. The output of ICARUS microservices are dispatched to the clients through the GNSS module.

- **Cockpit Simulator:** The cockpit simulator was used in the simulation trials as validation platform. The EFB device developed was installed as an add-on of the platform to provide to pilots’ information about the presence of drones limited to 5 NM. The EFB displays in a very simple and intuitive way the direction of local drone traffic and their converted height. The EFB is one "client” of the Testbed architecture intended as “consumer” of ICARUS VCS microservice. Just for simulation reasons, some data generated by the Cockpit simulator as Attitude, Barometric altitude and airplane Position feeds directly the EFB for calculations. The real device should calculate this data autonomously. The cockpit simulator and the EFB logs data locally (DB4 e DB5).

Figure 2-4 – Cockpit Simulator and EFB used for verification and validation activities

For validation scenarios two separate platforms were used for visualization in real time and play back of the scenarios run.
Since Altitude translation is implemented in real time in these platforms, they were used also as additional element of the Ground Control Stations of the drone Pilots to present different measured and translated altitudes/heights.

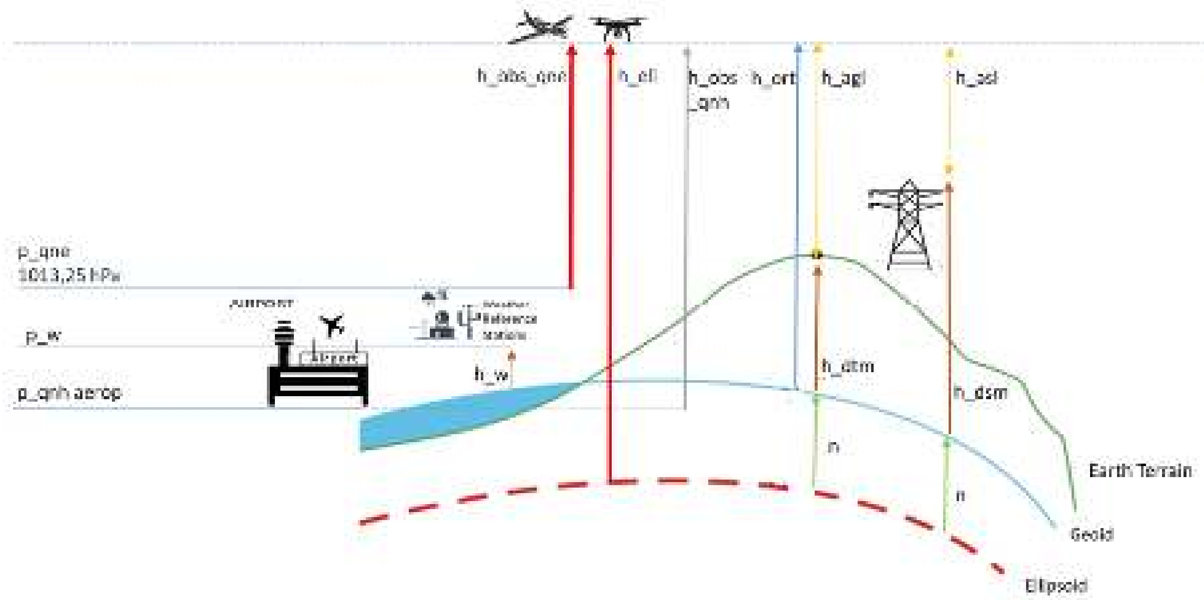
Figure 2-5 – VALS service visualised on Droneradar web application. Caution: The exlemation on DJI mobile app is graphically animated

For full VALS demo, please watch following movie:
https://www.youtube.com/watch?v=5PvYjxk4CTA

2.1.1 E-Geos visualization platform

The prototype developed by Telespazio and e-Geos to provide ICARUS services is able to receive the input data necessary for the operation of the 4 implemented microservices (VCS-VALS-RGIS-GNSS).
Data sent by the drone is used to track and provide the GNSS monitoring services necessary for the integrity calculation.
Once the data has been received, coming from the drone or the manned aircraft, the RGIS service is activated, and it calculates the DSM and DTM height value at the point where the manned and unmanned aircraft is located.
VCS service recalls the pressure value from the input barometric sensors and from weather services.
At this point The VCS has all the necessary values available to carry out the conversion.
From the converted data, VALS is ready, by matching, positions, altitude / height and integrity values, it is able to generate alerts if a collision with the ground, surface or obstacles is possible.

Some details of the parameters in input and output calculated by the platform are presented in the following pictures.



Input:

- vehicle_type has to be equal to 0 if the request is coming from a drone, or equal to 1 for airplanes' requests.
- h_obs_qne the observed height over QNE in meters *(in case of an airplane request)*
- h_ell the ellipsoidal height in meters *(in case of a drone request)*
- p_w is the pressure in hectopascal (hPa) of the weather station nearest to the vehicle which is asking for conversion
- h_w is the ortometric height of the weather station nearest to the vehicle which is asking for conversion
- p_qnh_airport is the average QNH pressure in hectopascal (hPa) for the region in which the airport is located
- h_dtm the DTM height (in meters)
- h_dsm the DSM height (in meters)
- n is the *geoid undulation* in meters (height of the geoid relative to a given ellipsoid of reference)

Output:

- h_ort the orthometric height of the requesting vehicle in meters
- h_obs_qnh the orthometric height of the requesting vehicle respect the QNH of the runway (in meters)
- h_agl the orthometric height of the aircraft respect the DTM (in meters)
- h_asl the orthometric height of the aircraft respect the DSM (in meters)
- h_obs_qne the orthometric height of P respect the QNE in meters (only for drones' requests)
- h_ell the ellipsoidal height of P requesting vehicle in meters (only for airplanes' requests)

Figure 2-5 –TPZ-E-GEOS SW Platform used for visualization of converted altitudes/heights and data analysis.

2.1.2 Droneradar visualization platform

In order to verify the system operation correctness as well as to capture the contextual nature of the information, CARS was integrated and visualized on two Droneradar platforms:

- A standalone web application using a WebSocket connection
- The CARS altitude converter was integrated into the PansaUTM/Droneradar UTM within GOF2 project.

For the purposes of smooth visualization the maximum flying object refresh rate was set to 5Hz (5 position updates per second).

Two tests installations were used for the verification: mobile and stationary. Stationary environment was used to perform large scale tests. In stationary scenarios, the ADS-B IN stream **was taken from** the receiver located at Warsaw Babice TWR (EPBC). The ADS-B receiver "has seen" signals at a distance of about 180NM, receiving in peaks approx. 60 airplanes at the same time. Both the VCS converter used in the project and the Web visualizer (WWW application) were efficient enough to handle online conversions of all aircraft.

Mobile installation was used to perform ad-hoc tests with UAS flying in relatively close vicinity.

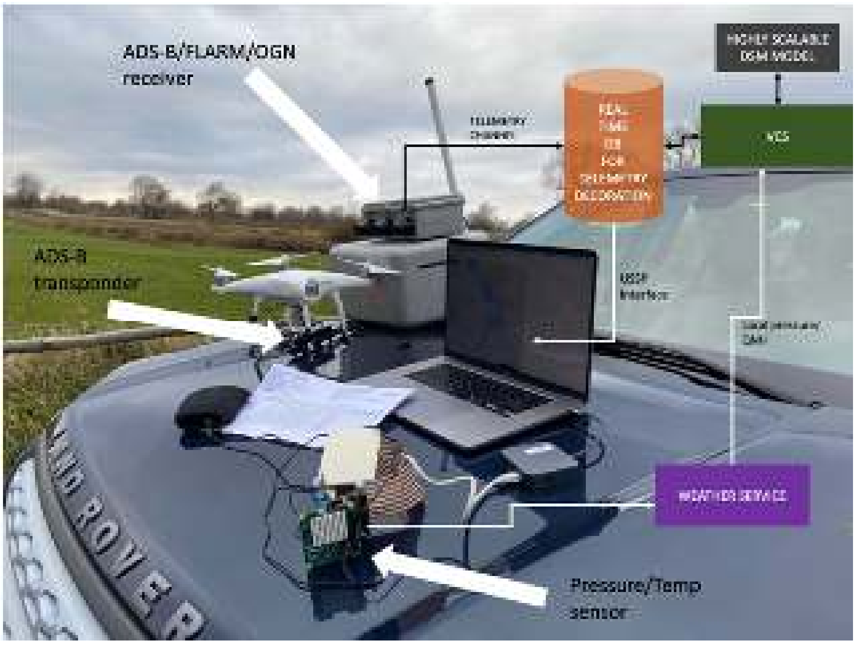


Figure 2-7 – Droneradar Mobile installation: On-site setup including Meteo Station Sensor

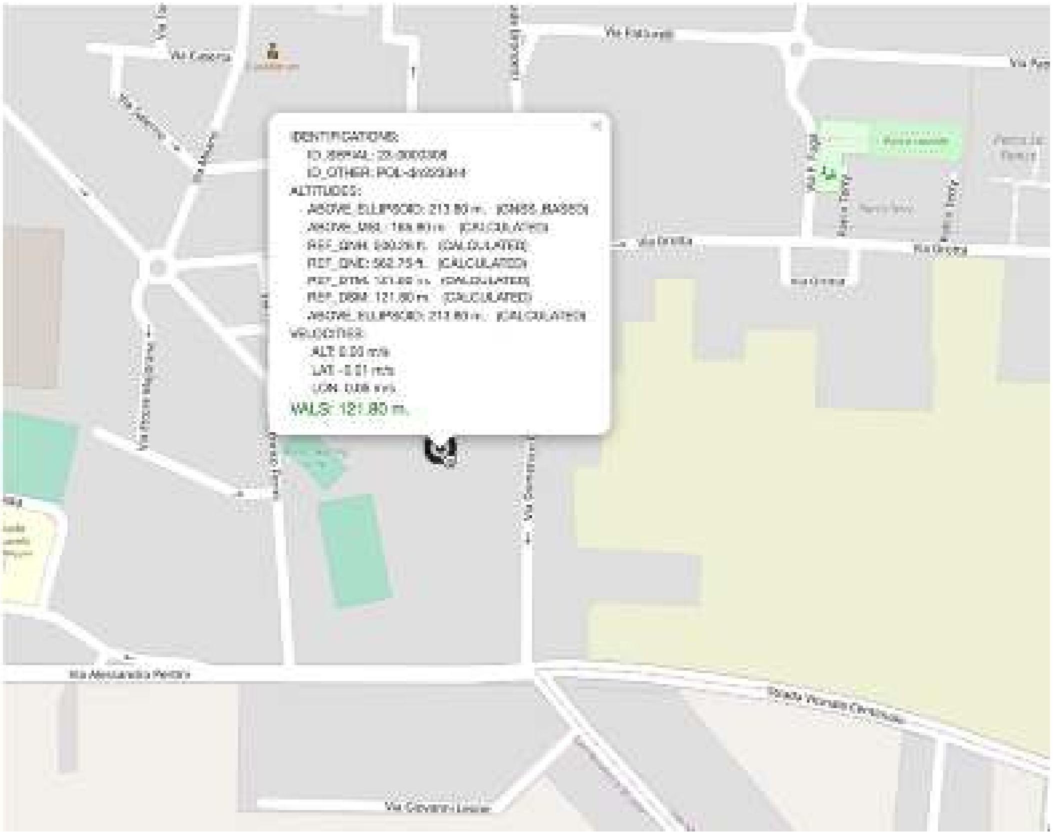


Figure 2-8 – Example of Droneradar standalone visualization. In this example GNSS receiver was used as a source of location and altitude

Figure 2-9 – Droneradar Platform used for visualization of converted altitudes/heights and data analysis. Left screen shows conversion from BARO (ADS-B OUT transponder) to GNSS. Right screen shows conversion from GNSS (3G/LTE tracker equipped with GNSS receiver) to BARO. Both examples show conversion in reference to the DTM/DSM.

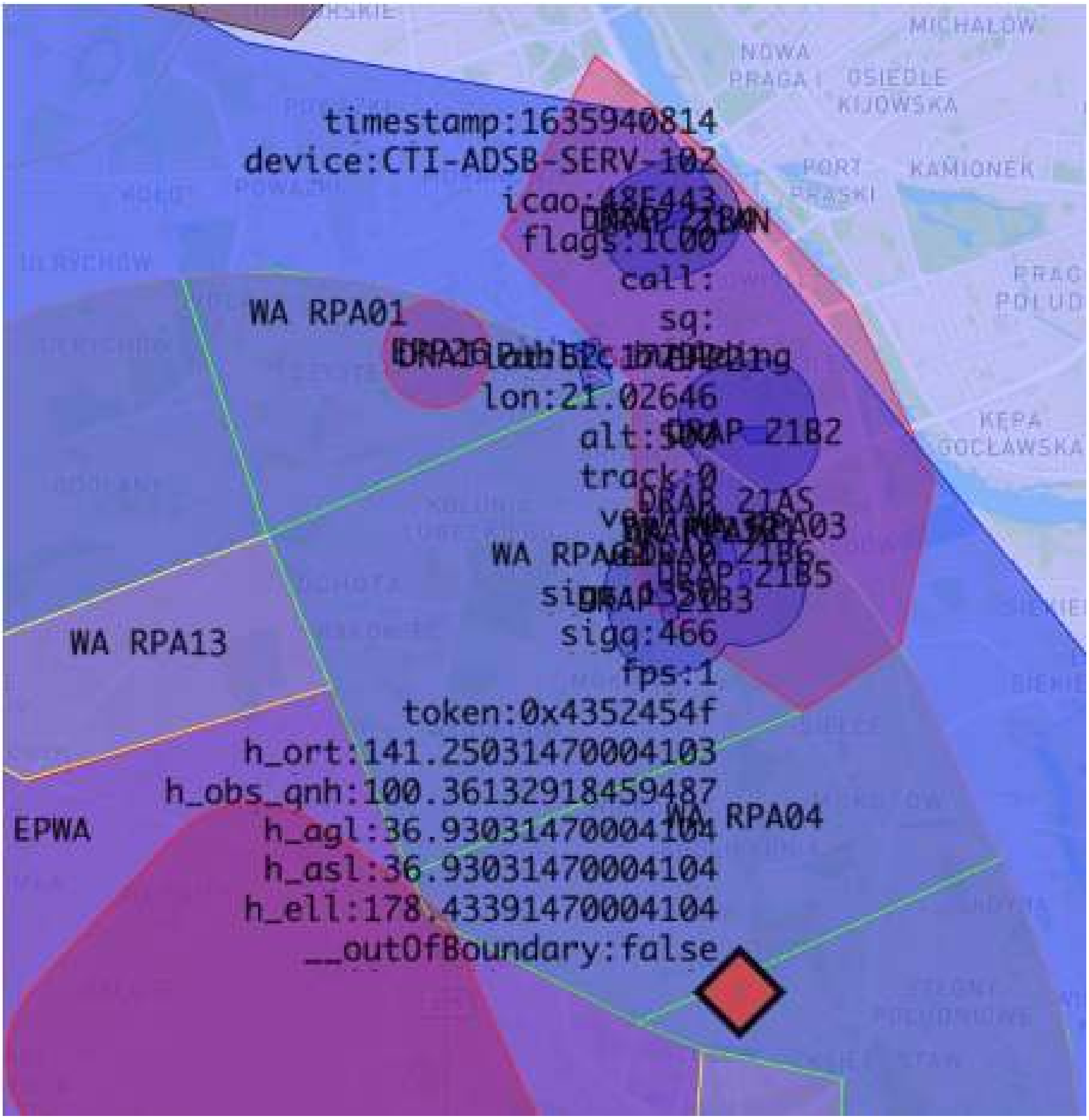


Figure 2-8 – PansaUTM and Droneradar Platform used for visualization of converted altitudes/heights and data analysis within GOF2 project

3 Test cases results

In this chapter the results of test cases are presented. A summary for each test objective is also reported.

3.1 TEST_OPS.GNSS.10 – UAS-UAS altitude reference (urban)

3.1.1 Description and objective of test

UAS-UAS altitude reference (Urban)	
Test code	**TEST_OPS.GNSS.10**
Objective	The objective of this test is to verify the performance of different GNSS Receivers (from low cost SFMC to high end MFMC GNSS receivers) for UAS-UAS common altitude reference in urban environment.
Description	For the present test a UAS Multicopter will be used. The drone will be equipped with a custom payload composed by different GNSS receivers. The payload is composed by one unique Triple frequency antenna, working in the bands E1, E5, E6 feeding 2 or 3 GNSS receivers coupled with a GNSS signal splitter. In particular, the receivers that will be used are: ✓ Septentrio GNSS Development Board Mosaic X5 (Triple band with Galileo E5 AltBoc enabled); ✓ U-Blox F9P GNSS receiver dual frequency constellation receiver ✓ Pollicino low cost GNSS receiver, single frequency multiconstellation GNSS Receiver This payload will allow GNSS raw data (and NMEA data) to be stored onboard and used for post processing analysis. The main goal is to gather meaningful GNSS Rx data to assess the vertical accuracy achievable with each GNSS receiver with respect to a reference trajectory The Drone will perform different flights (tentatively 5) of about 30 minutes with the same configuration using but at different time slots: ✓ **Ground Control Station** with a mission planning software for a simple 3 waypoint automatic loop mission at a given Height of 25 m AGL in suburban environment. ✓ **Private GNSS RTK station:** To augment the UAS position and navigation performance during the flight for the determination of the reference trajectory.
Required data	✓ GNSS raw data of Septentrio X5 GNSS Receiver ✓ GNSS raw data of U-Blox F9P GNSS Receiver ✓ NMEA data of "Pollicino" GNSS Receiver ✓ GNSS raw data of the permanent private GNSS RTK station; ✓ Drone Trajectory data (hybridized/augmented positions) used as reference trajectory

Expected Output	✓ Accuracy (mu, sigma) of the vertical axis and horizontal plane w.r.t. the reference drone trajectory for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Precision (mu, sigma) of the vertical axis w.r.t. the mean vertical height for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Integrity figures (mu, sigma for VPL) for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Integrity figures (mu, sigma for HPL) for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino;
Pass / Fail criteria	The test is passed if any of the GNSS devices will ensure at least an accuracy of: ✓ 9 meters for the vertical accuracy (req. ICARUS-D31-0310) ✓ 1,5 meters for the vertical accuracy in static tests (req. ICARUS-D31-0240) ✓ 1,0 meters for the horizontal accuracy in static tests (req. ICARUS-D31-0240) and for integrity: ✓ 27 meters for the VPL level when flying at 15 m/s (req. ICARUS-D31-0320)

Table 3-1 **–TEST_OPS.GNSS.10 description**

3.1.2 Test implementation

Different sessions were performed to collect significant data samples with the aim of:

- assessing the performance of different GNSS Receivers for UAS-UAS common altitude reference in urban environment.
- verifying which GNSS architecture /configuration is the most suitable for UAS-UAS CAR in urban environment
- assessing whether the GNSS technology alone is capable to provide UAS-UAS CAR common altitude reference in urban environment.

Most of the tests were made in the period of April 2022-May 2022. Some examples of data collected are reported.

In the first part of the test different flight sessions were made with one drone only equipped with ICARUS payload. The second part of test was made with the two drones taking off from the same home point, climbing together at different heights.

Equipment

The following equipment was used for this test:

- ✓ Payload composed by 3 GNSS Receivers.
- ✓ DJI M300 RTK drone / DJI M210 drone
- ✓ Ground Control Station with software for automatic mission planning.
- ✓ GNSS Private RTK station (Geodetic Grade);
- ✓ Spare batteries and Recharging station for batteries.

Test Environment

The area of the test identified is in nearby TopView premises.

Figure 3-1 – Area of test and equipment used

3.1.2.1 GNSS Receivers performance Comparison

Figure 3-2 – UAS used for test

One of the key visual output to provide the goodness of the GNSS is the Stanford Diagram. For each of the test performed, a Stanford diagram has been done.

This Diagram uses an all-in-view approach (i.e. all GPS satellites in view with valid differential corrections available) for computing the error/protection level pair (HPE, VPL) to plot for each time sample. A misleading information event occurs when, being the system declared available, the position error exceeds the protection level but not the alert limit.

A hazardously misleading information event occurs when, being the system declared available, the position error exceeds the alert limit.

The diagonal axis separates those samples in which the position error is covered by the protection level, above the diagonal, from those, below the diagonal, in which the protection level fails to cover the position error. Stanford plots allow an easy and quick check that integrity holds, just by making sure that all sample points lie on the upper side of the diagonal axis.

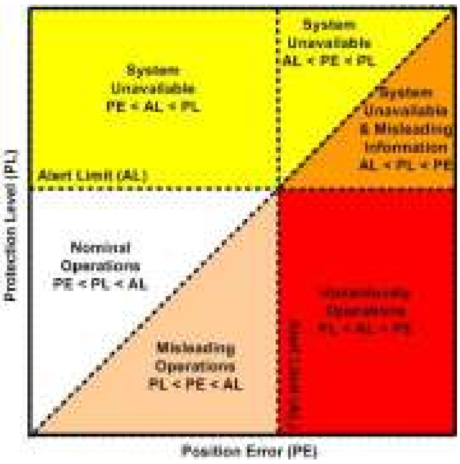


Figure 3-3: Stanford Diagram Explanation

3.1.2.1.1 UBLOX F9P

The following analysis have been done:

1) U-blox F9P in nominal ARAIM configuration (dual frequency ion-free multiconstellation combination) [data at 0.5 Hz]

2) U-blox F9P in degraded ARAIM configuration (single frequency E1 / L1 multiconstellation) [data at 0.5 Hz]

Here are reported the graph explaining the analysis done and the results obtained:

<u>Dual Frequency</u>

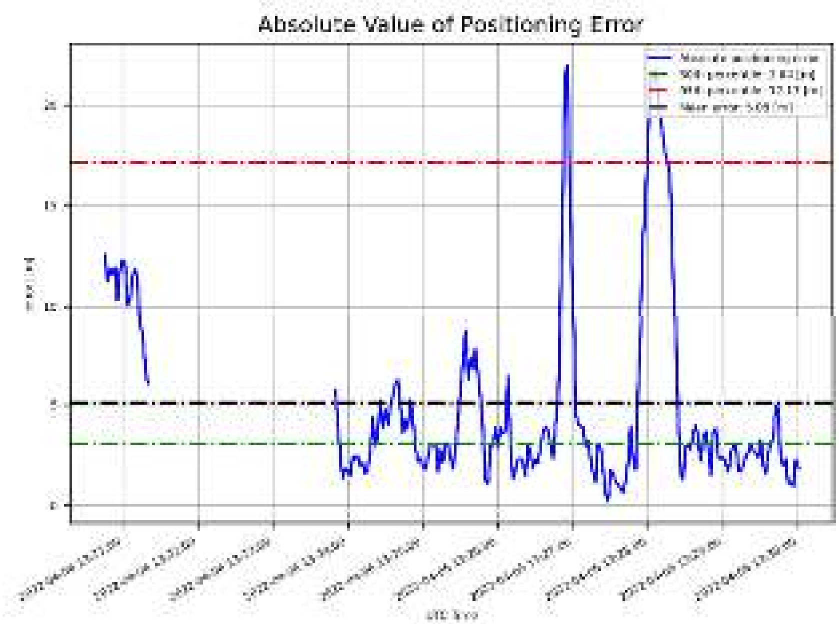


Figure 3-4: Absolute value of Positioning Error- F9P-ARAIM Dual Frequency

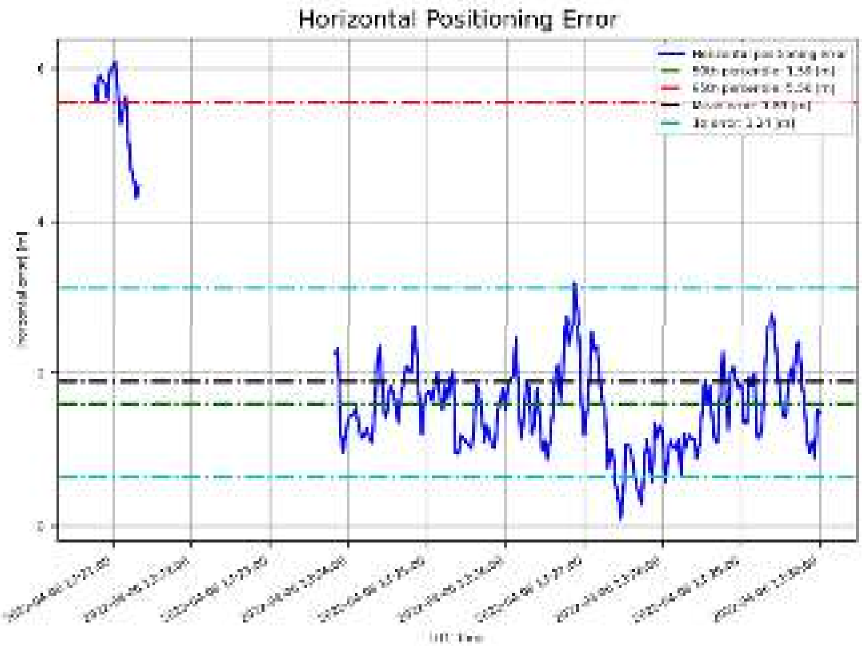


Figure 3-5: Horizontal Positioning Error- F9P-ARAIM Dual Frequency

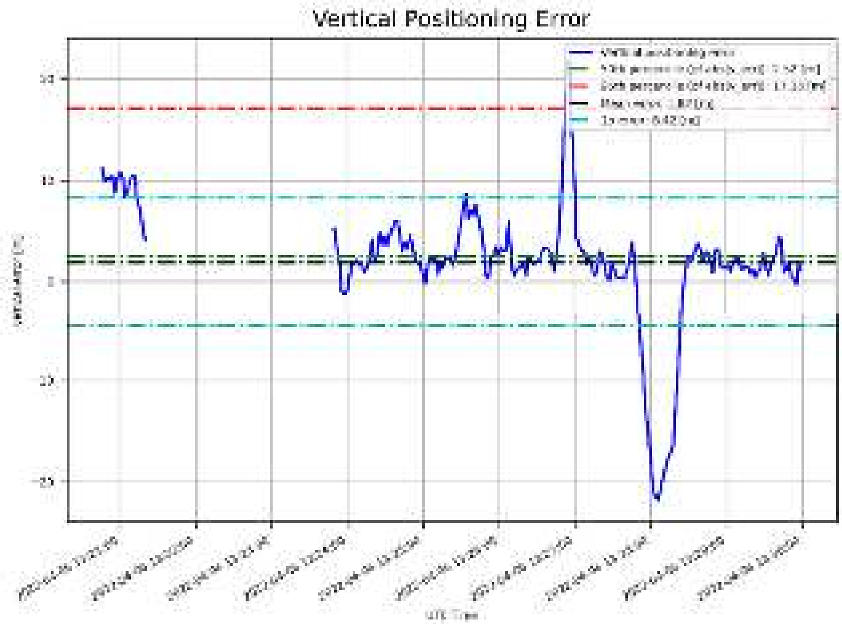


Figure 3-6: Vertical Positioning Error- F9P-ARAIM Dual Frequency

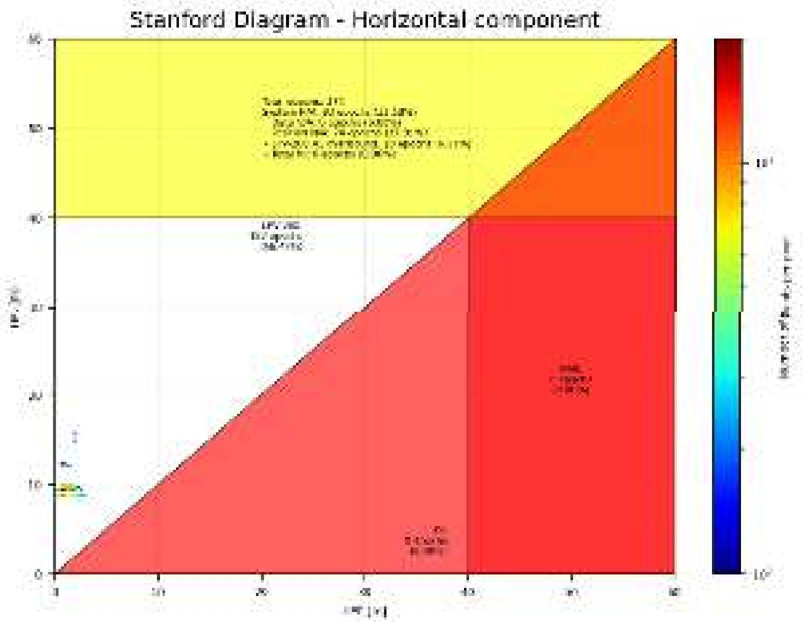


Figure 3-7: Stanford Diagram-Horizontal Component- F9P-ARAIM Dual Frequency

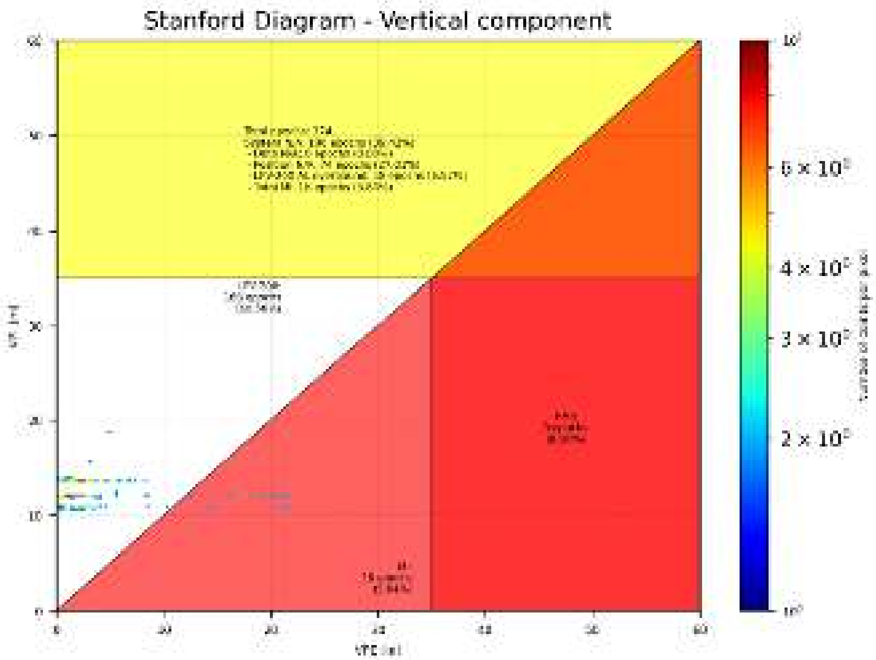


Figure 3-8: Stanford Diagram- Vertical Component- F9P-ARAIM Dual Frequency

Single Frequency

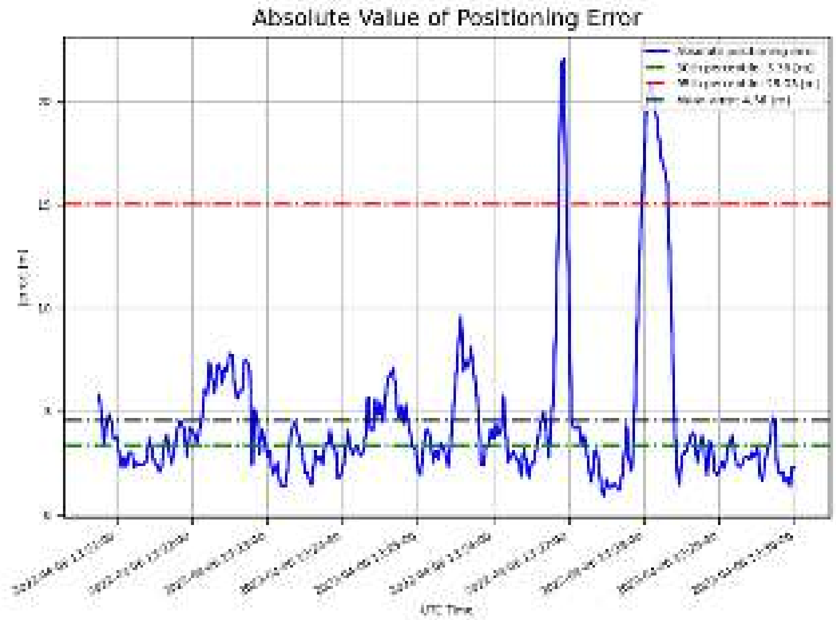


Figure 3-9: Absolute value of Positioning Error- F9P-ARAIM Single Frequency

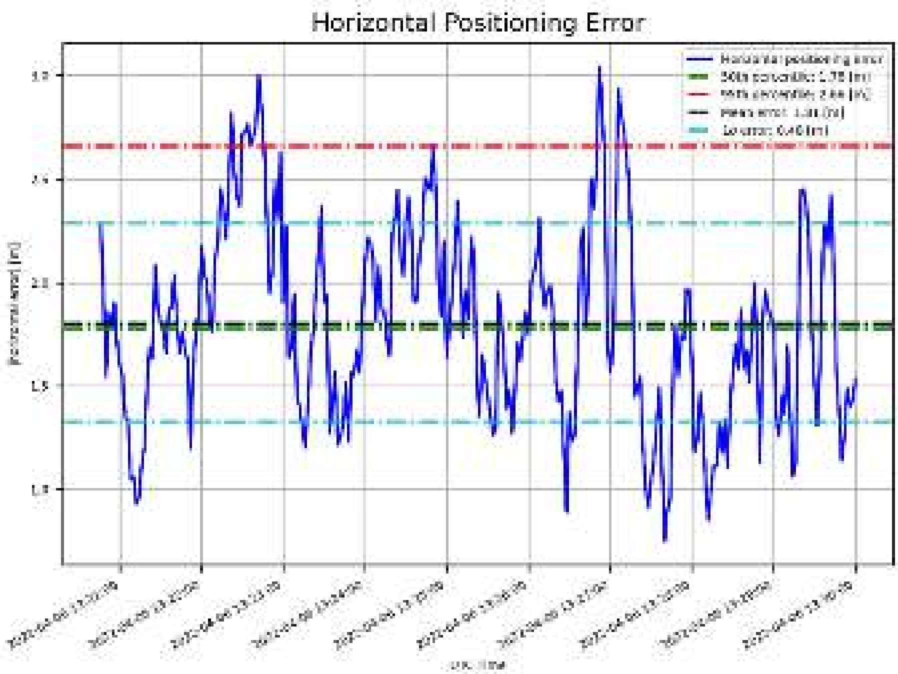


Figure 3-10: Horizontal Positioning Error- F9P-ARAIM Single Frequency

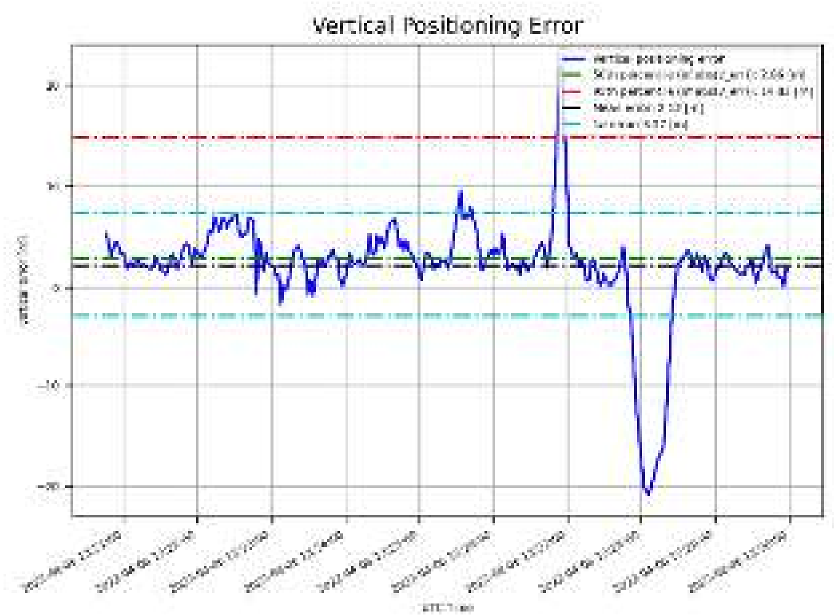


Figure 3-11: Vertical Positioning Error- F9P-ARAIM Single Frequency

3.1.2.1.2 **Septentrio MOSAIC X5**

The following analysis has been done:

1) MOSAIC Septentrio in nominal ARAIM configuration (dual frequency ion-free multiconstellation combination) [data at 1 Hz]

2) MOSAIC septentrio in degraded ARAIM configuration (single frequency E1 / L1 multiconstellation) [data at 1 Hz]

3) Processing SBAS (EGNOS) using the MOSAIC as the base receiver and the EGNOS messages (SBAS at present is based exclusively on the measurements on L1 of the constellation GPS)

Here are reported the graph explaining the analysis done and the results obtained:

3.1.2.1.2.1 ARAIM ALGORITHM

<u>Dual Frequency</u>

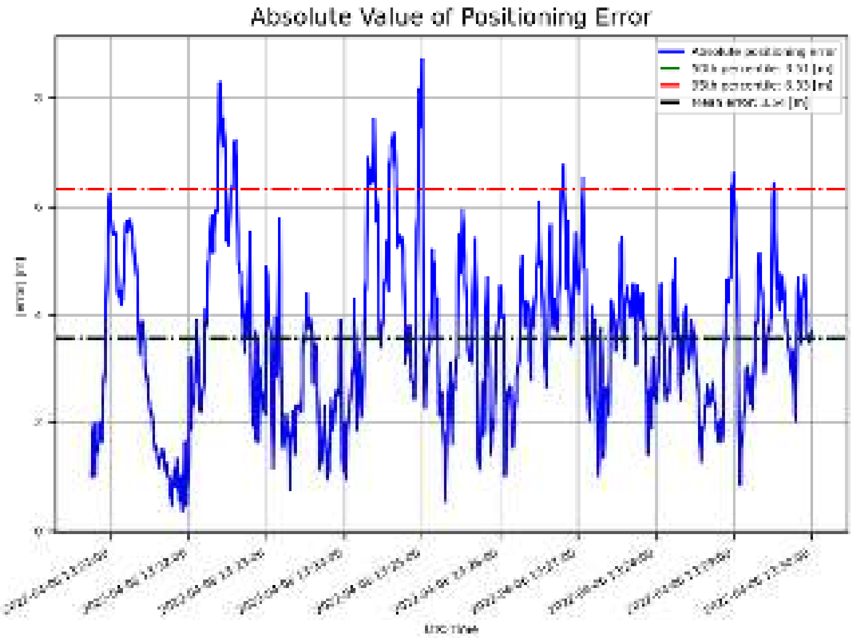


Figure 3-12: Absolute value of Positioning Error- Septentrio- ARAIM Dual Frequency

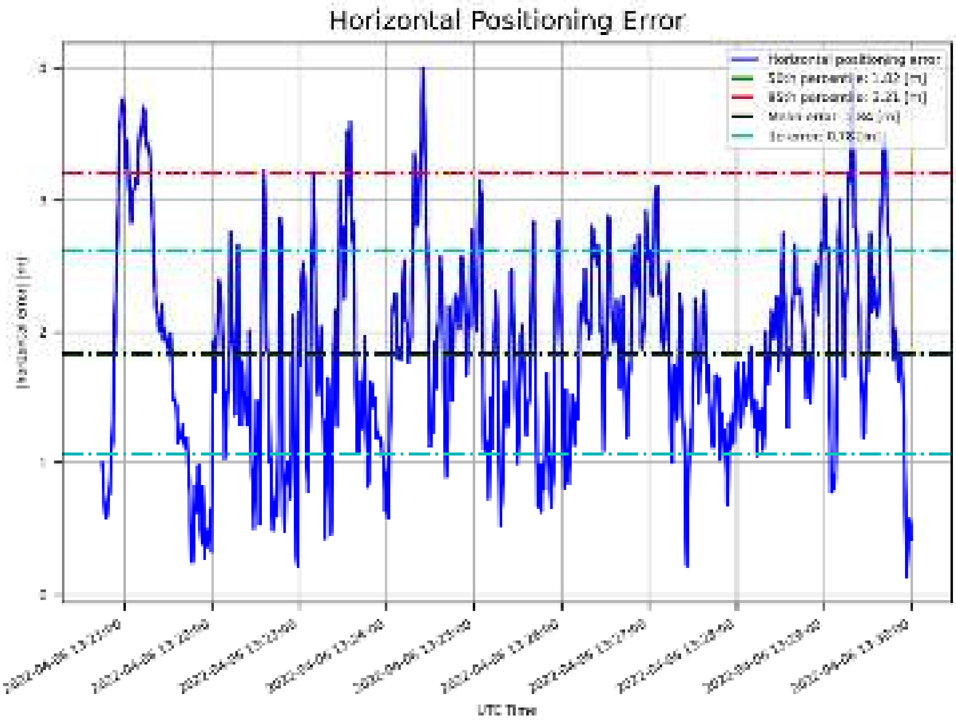


Figure 3-13: Horizontal Positioning Error- Septentrio-ARAIM Dual Frequency

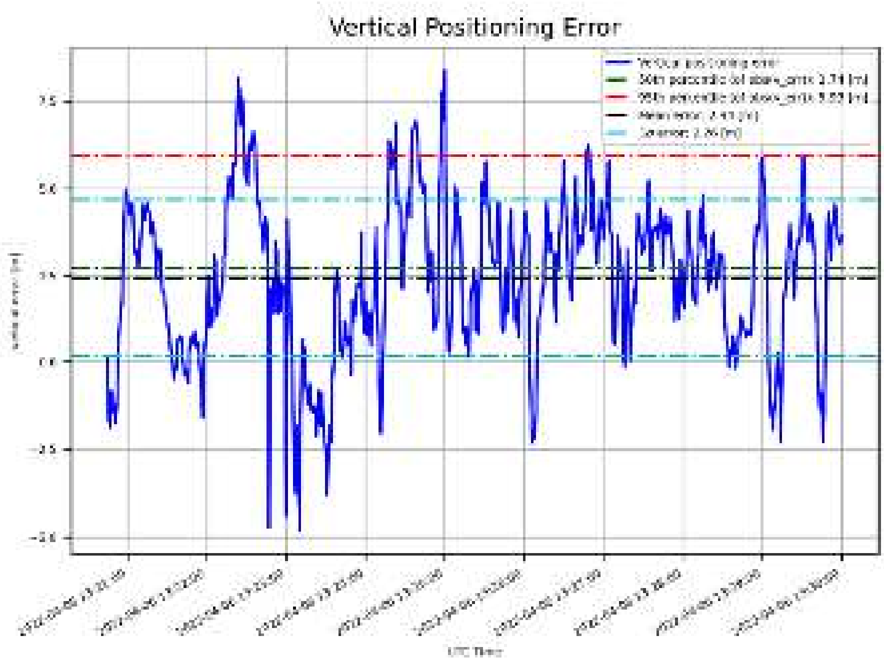


Figure 3-14: Vertical Positioning Error- Septentrio-ARAIM Dual Frequency

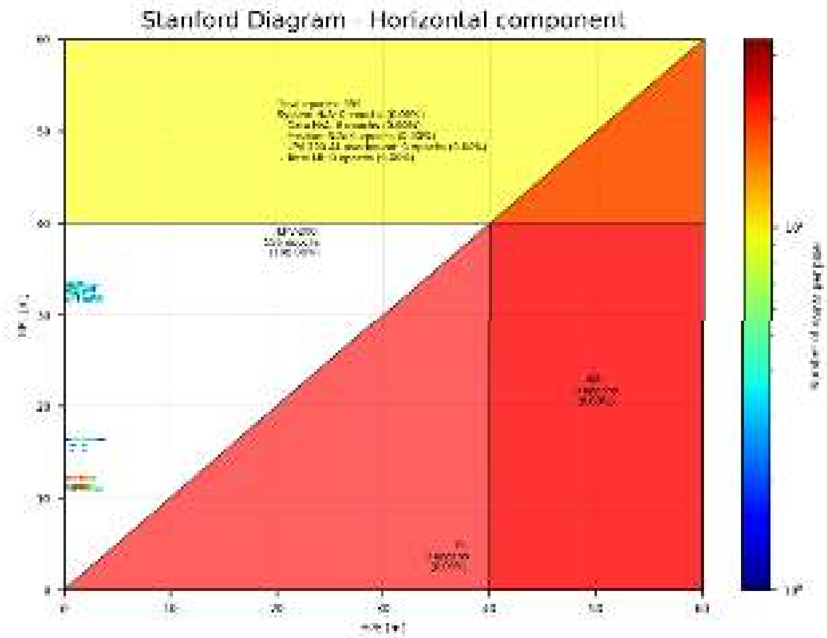


Figure 3-15: Stanford Diagram-Horizontal Component- Septentrio-ARAIM Dual Frequency

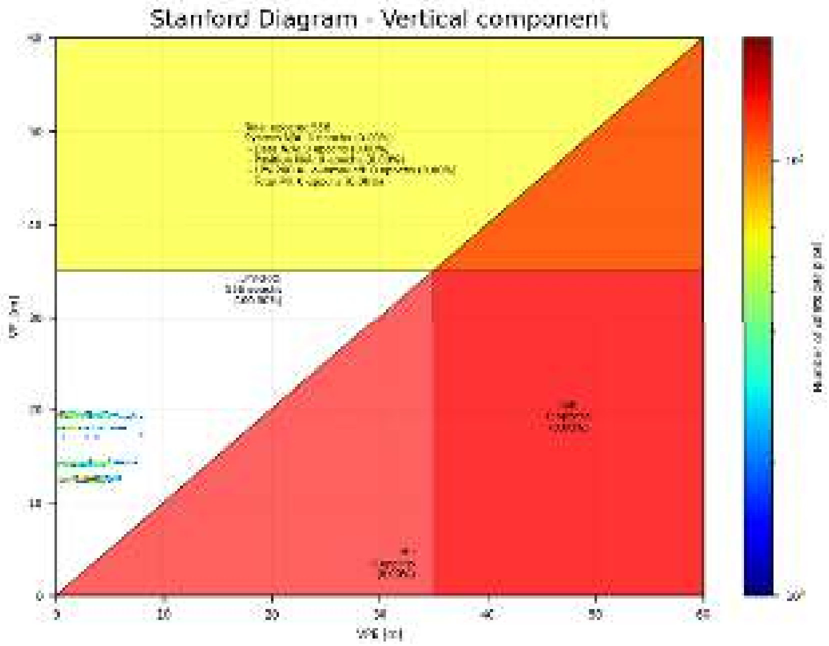


Figure 3-16: Stanford Diagram-Vertical Component- Septentrio-ARAIM Dual Frequency

<u>Single Frequency</u>

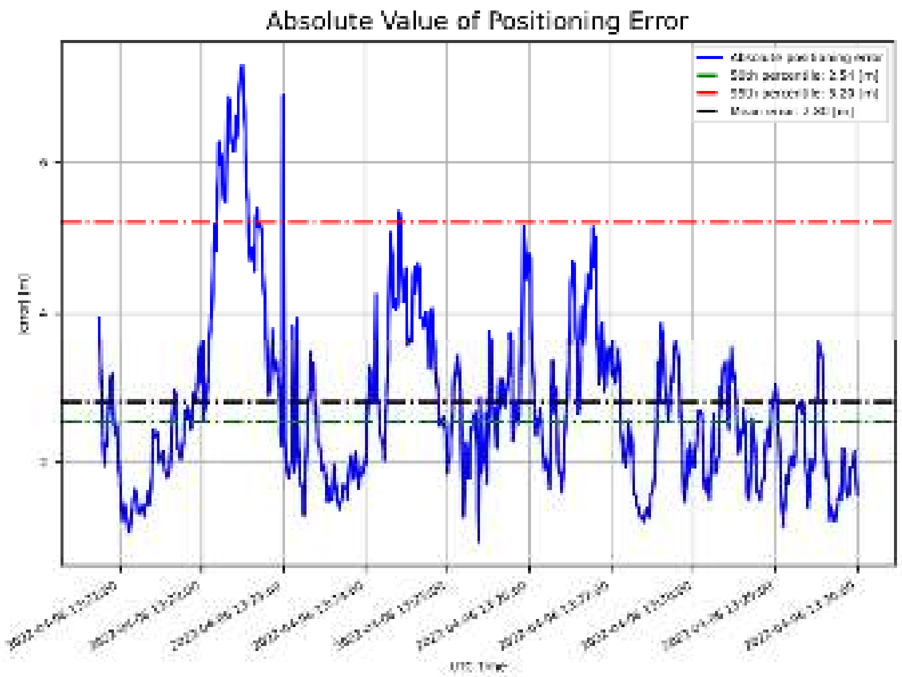


Figure 3-17: Absolute value of Positioning Error- Septentrio- ARAIM Single Frequency

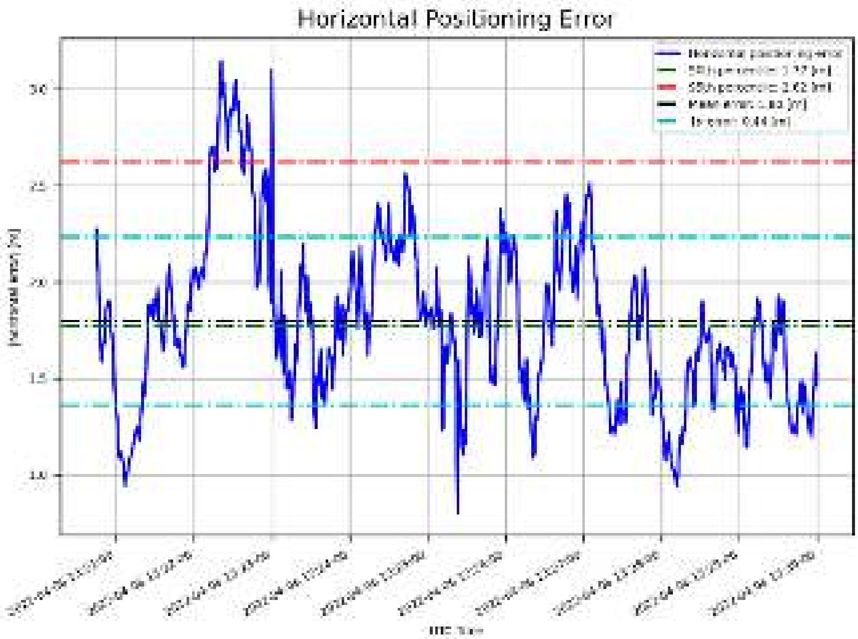


Figure 3-18: Horizontal Positioning Error- Septentrio-ARAIM Single Frequency

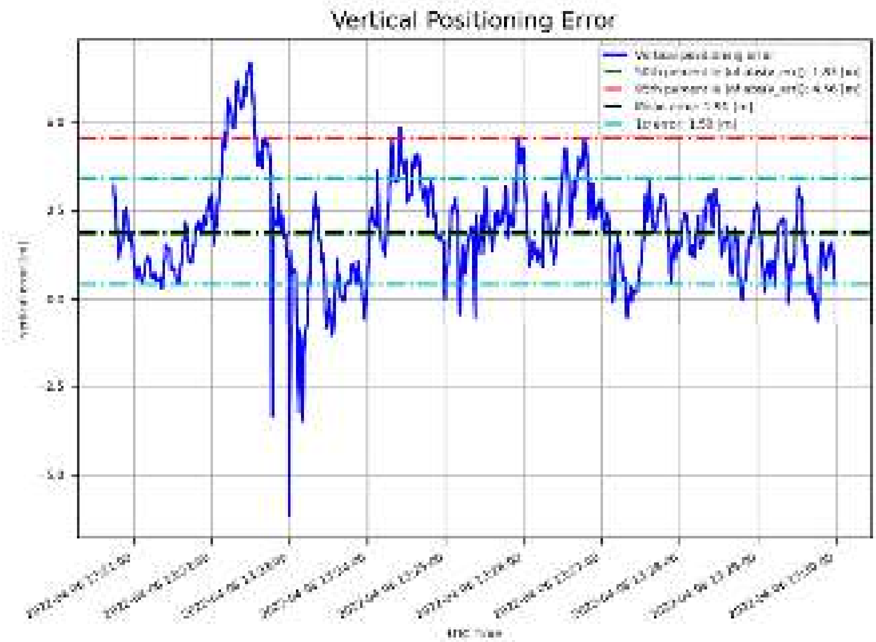


Figure 3-19: Vertical Positioning Error- Septentrio-ARAIM Single Frequency

3.1.2.1.2.2 SBAS (GPS+EGNOS) ALGORITHM

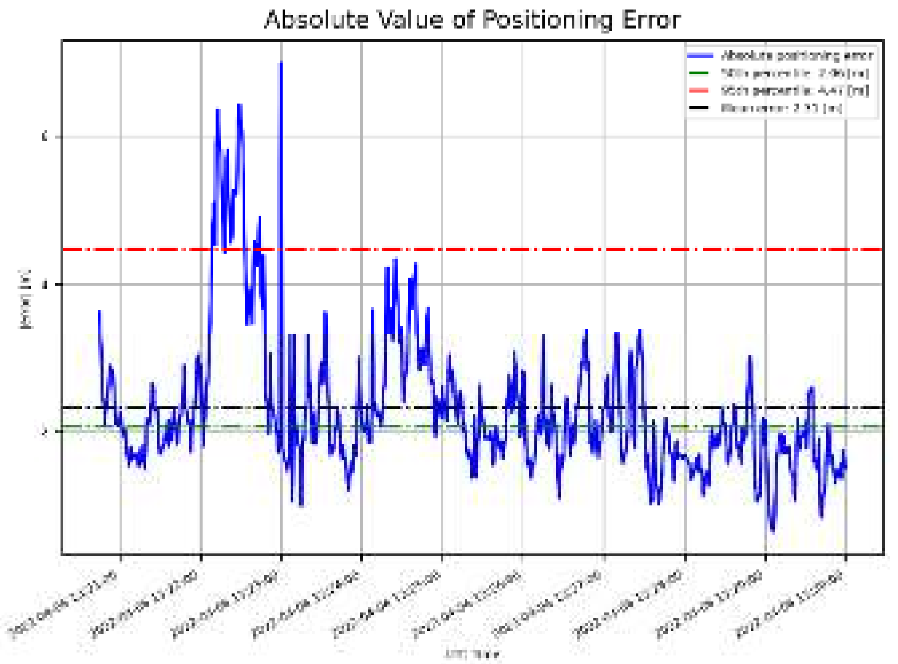


Figure 3-20: Absolute value of Positioning Error- Septentrio - SBAS

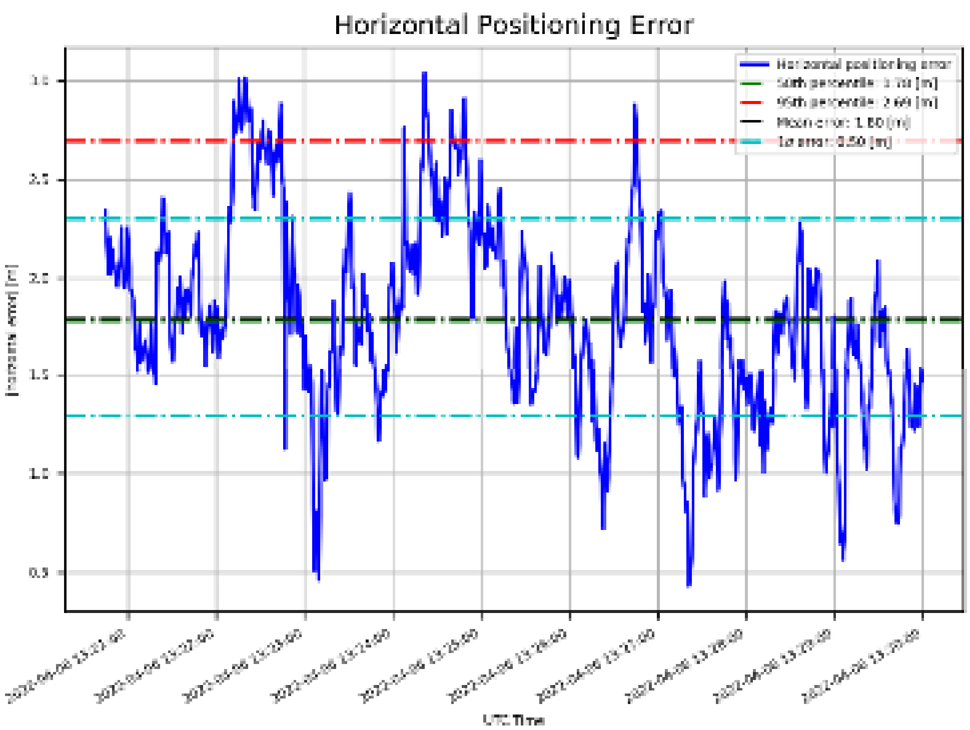


Figure 3-21: Horizontal Positioning Error- Septentrio-SBAS

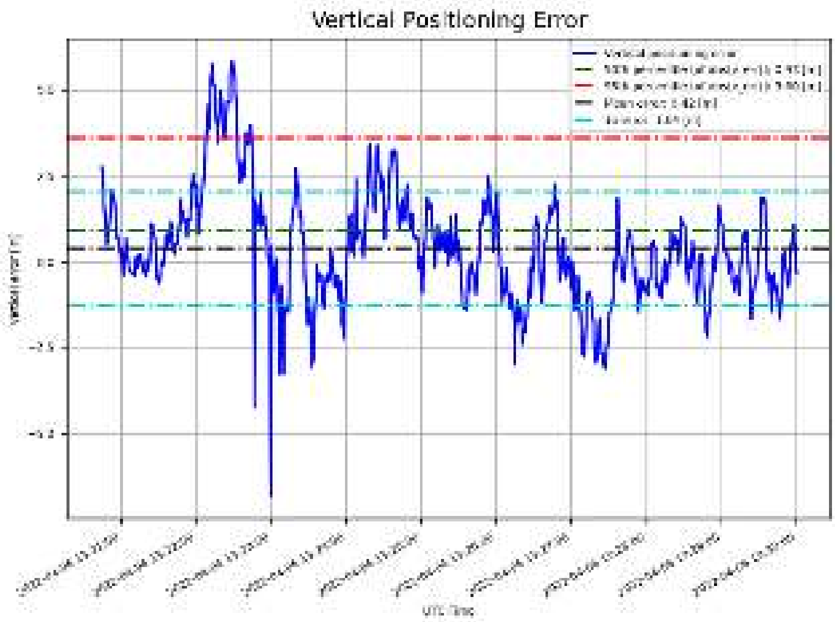


Figure 3-22: Vertical Positioning Error- Septentrio-SBAS

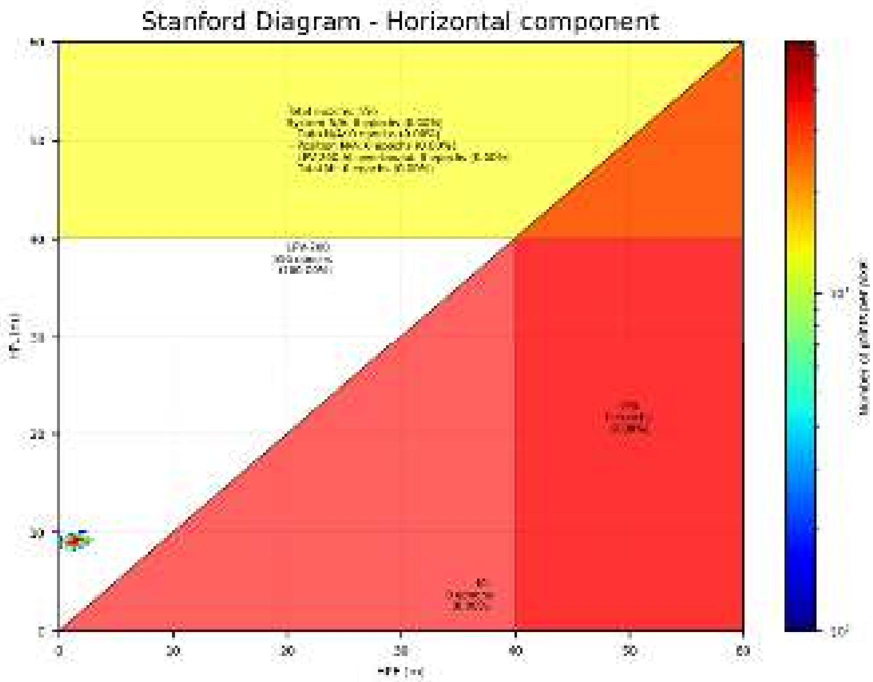


Figure 3-23: Stanford Diagram-Horizontal Component- Septentrio-SBAS

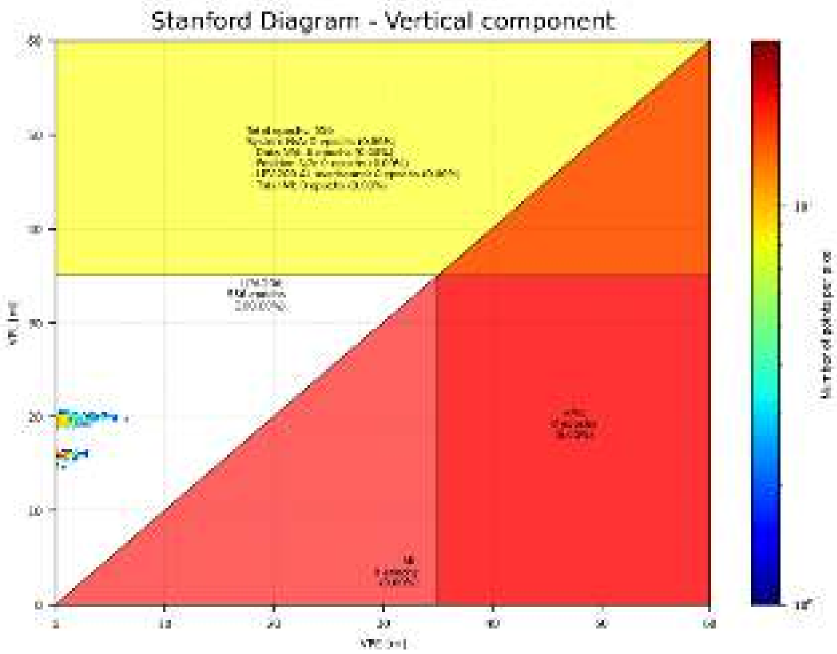


Figure 3-24: Stanford Diagram-Vertical Component- Septentrio-SBAS

3.1.2.2 UAS-UAS vertical accuracy comparison (GNSS)

The consortium got the chance to make and additional test for UAS-UAS vertical accuracy comparison thanks to the presence of 2 UAS flying concurrently.

In this test the Ground Control Stations of each drone were used as reference for height measurement, having fixed the same home point (same altitude over the ellipsoid) for both drones.

The objective is to evaluate any discrepancy in height measurement considering the GNSS raw measurement onboard measured by the payload and the data presented on the Ground Control Station.

For this test both drones, taking off at the same home point, climbed synchronously at different heights at steps of 10 meters from 10 m AGL to 120 m AGL. For each step the drones stand in hovering for about 1 minute

Figure 3-25 – ICARUS Payload installed on DJI M300 RTK UAS

Figure 3-26 – Second Drone DJI M210 used for test

Figure 3-27 – Implementation of test for UAS-UAS vertical accuracy comparison.

In the following tables and graphs, it is reported the HAE (Height Above Ellipsoid) values measured by each drone internal GNSS receiver (hybridized position) against ZED-F9P U-blox receiver (raw data).

Step	Min (m)	Max (m)	Mean (m)	Measured step (m)
1 (10 m)	102,915	103,296	103,106	10,306
2	112,683	113,080	112,882	9,776
3	122,379	122,893	122,636	9,754
4	132,486	132,838	132,662	10,026
5	142,372	143,004	142,688	10,026
6	152,45	153,654	153,052	10,364
7	162,116	163,085	162,601	9,549
8	172,648	173,075	172,862	10,261

9	182,285	183,005	182,645	9,783
10	192,568	193,053	192,811	10,166
11	202,264	202,734	202,499	9,688
12	212,4	212,753	212,577	10,078

***Table 3-2* –GNSS U-Blox F9P Precision**

In the previous table the U-Blox F9P navigation solution was reported with the max, min and mean value calculated against each hovering step (10 meters). The precision of the GNSS Receiver is very good with a dispersion around the mean value of less than 50 cm at 70 meters AGL (step 7). However the precision information might be insufficient without comparison with another measurement (dissimilar, independent or provided by a higher grade instrument). For this reason, the same table was generated for the Septentrio Mosaic X5 and for both drones hybridized vertical positions.

Step	Min (m)	Max (m)	Mean (m)	Measured step (m)
1 (10 m)	103,847	104,886	104,367	11,567
2	112,680	113,098	112,889	8,522
3	122,442	123,237	122,840	9,951
4	132,558	133,129	132,844	10,004
5	142,172	143,24	142,706	9,862
6	152,897	153,182	153,040	10,334
7	160,909	163,188	162,049	9,009
8	172,243	172,731	172,487	10,438
9	182,643	183,16	182,902	10,415
10	192,358	192,722	192,540	9,638
11	201,706	202,305	202,006	9,466
12	211,352	212,133	211,743	9,737

***Table 3-3 – Septentrio* Mosaic X5 Precision**

In the previous table the Septentrio Mosiac X5 navigation solution was reported with the max, min and mean value calculated against each hovering step (10 meters). The precision of the GNSS Receiver looks more dispersed around the mean value. This result might be related to better algorithms and filtering used by U-Blox.

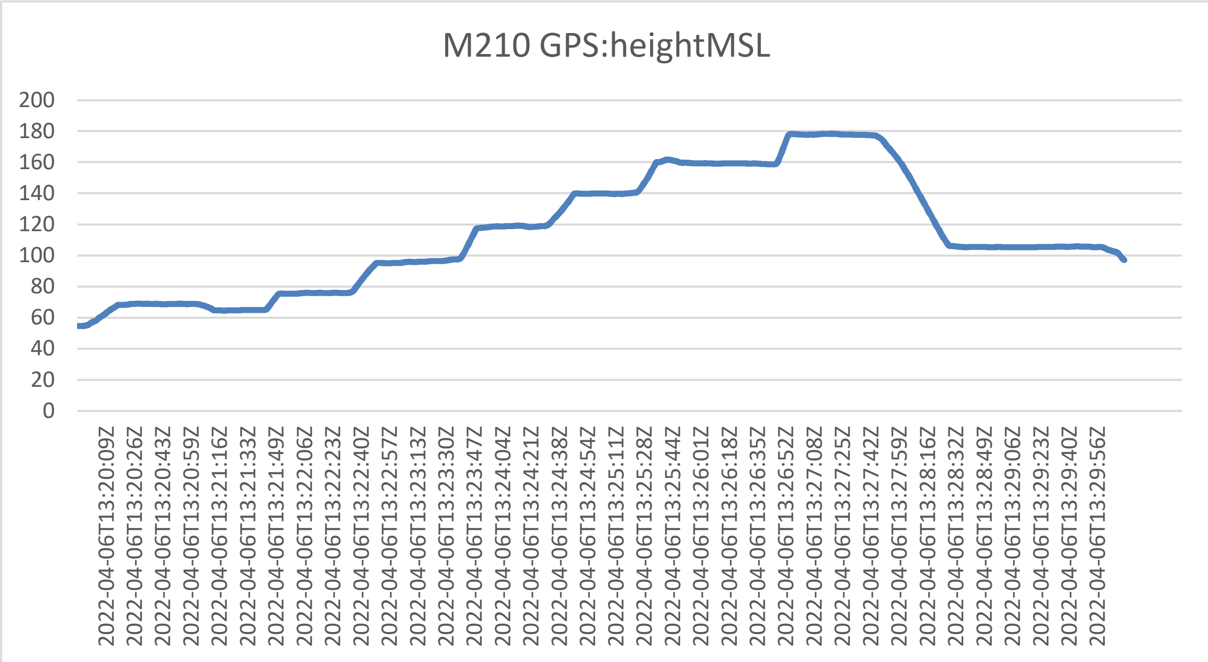


Figure 3-28 – DJI M210 Height MSL parameter (hybridized position)

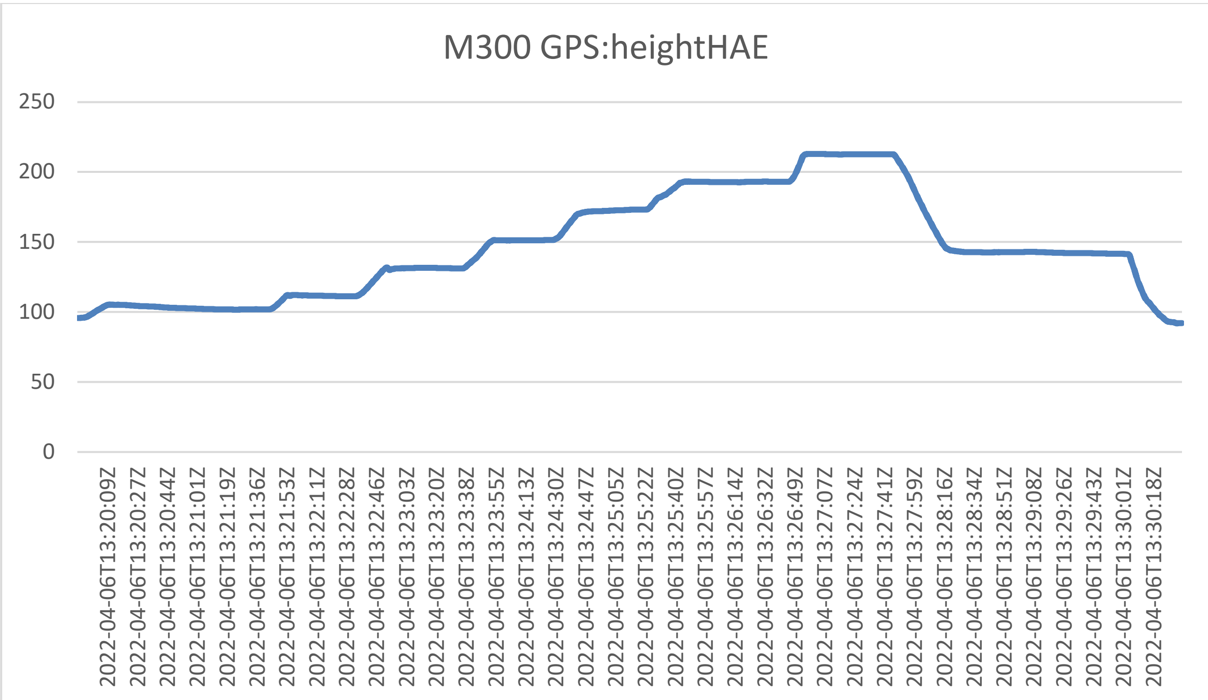


Figure 3-29 – DJI M300 Height above ellipsoid parameter (hybridized position)

The navigation data collected by the drones internal showed the same mission profile flown, however the DJI 210 (older drone) had the possibility to output only the Hight above geoid, therefore considering the fixed point of test, an offset of about 41 meters was added to compare on both drones the orthometric distance (ellipsoid).

The comparison of the F9P Receiver with the hybridized data of both drones presents the following accuracies for the first 70 meters.

	DJI M210	U-Blox F9P	
STEP	mean msl (m)	mean msl (m)	Difference (m)
1	64,7	62	2,7
2	75,9	71,8	4,1
3	96,2	92,4	3,8
4	119,1	112	7,1
5	139,8	131,6	8,2
6	159,2	151,8	7,4
7	177,9	172,4	5,5

***Table 3-4 – Accuracy of* M210 drone hybridized solution against F9P GNSS receiver**

	DJI M300 RTK	U-Blox F9P	
STEP	mean HAE (m)	mean HAE (m)	Difference (m)
1	101,6	102,4	0,8
2	111,6	113,2	1,6
3	131,2	133,1	1,9
4	151	152,4	1,4
5	172,6	173,5	0,9
6	192,5	192,8	0,3
7	212,4	213,3	0,9

***Table 3-5 – Accuracy of* M300 RTK drone hybridized solution against F9P GNSS receiver**

The results clearly states that the presence of GNSS Hybridized solution, augmented by RTK technology provide an outstanding level of overall accuracy also on the vertical axis. The difference in meters up to 70 meters has a maximum difference of 1.9 meters with the DJI M300 RTK drone and more than 8.2 meters with a non RTK drone (DJI M210).

This difference shall be intended also for this case as a Total System Error, even if calculated in a controlled and simplified environment.

3.1.3 Test Results

TEST_OPS.GNSS.10- UAS-UAS altitude reference (Urban)	
Test Result	**Passed*** **This test is passed with limitation to the data set acquired and analyzed.** This test was performed with 3 GNSS Receivers used in different configurations in a dynamic test. It must be considered that the errors calculated must be intended as Total System Error of the UAS even if the movement of the UAS was very simple (climbing and descending only). In this case the GNSS Error contributes only for a certain amount of the error. Indeed, several algorithms in post processing were analyzed starting from the Raw data of acquired by the receivers and the requirement of vertical accuracy (9 m@2 sigma) was met in **3 cases over 5 configurations.** In particular, the best results were achieved by the Septentrio Mosaic X5 receiver in Single frequency configuration and in SBAS / EGNOS configuration. In this case the vertical accuracy achieved is 1.50 m @1 sigma (ARAIM Single frequency) and 1.64 m@1 sigma (GPS/EGNOS) definitely in line with the requirement ICARUS D31-0310. However, when another GNSS receiver is selected with less capabilities (U-Blox F9P), The requirement is not met (5,27 m @ 1 sigma). On the other hand, both GNSS receivers showed an outstanding accuracy on the horizontal plane (less than 1 meter @1 sigma for both receivers.) Finally, the VPL and HPL levels are also within the requirements given for most of the samples acquired, however additional tests are needed to better assess the GNSS integrity with the exploitation of a Ground based network for Navigation signal monitoring. The following tables present additional information of the test performed.
Pass Criteria	The is test is passed if any of the GNSS devices will ensure at least an accuracy of: ✓ 9 meters for the vertical accuracy (req. ICARUS-D31-0310) ✓ 1,5 meters for the vertical accuracy in static tests (req. ICARUS-D31-0240) ✓ 1,0 meters for the horizontal accuracy in static tests (req. ICARUS-D31-0240) and for integrity: ✓ 27 meters for the VPL level when flying at 15 m/s (req. ICARUS-D31-0320)
Remark	ARAIM algorithm are demanding, it worth exploring also additional onboard lighter Integrity check performed with other dissimilar sensors.

	Hybridized GNSS solution of vertical axis, augmented by RTK technology for drone positioning, seems to be the most promising configuration to achieve outstanding vertical measurement over a common reference.

3.1.3.1 UBLOX F9P ARAIM Algorithm Results

Dual Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	3.04	17.17	5.08	
Horizontal Positioning Error	1.59	5.56	1.89	1.24
Vertical Positioning Error	2.52	17.13	1.82	**6.42**
Horizontal Protection Level (rms)	10.030 m			
Vertical Protection Level (rms)	12.871 m			
Single Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	3.36	15.03	4.58	
Horizontal Positioning Error	1.78	2.66	1.81	0.48
Vertical Positioning Error	2.66	14.82	2.12	**5.27**

Table 3-6: UBLOX F9P ARAIM Results-URBAN

3.1.3.2 SEPTENTRIO MOSAIC ARAIM Algorithm Results

Dual Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	3.51	6.33	3.54	
Horizontal Positioning Error	1.82	3.21	1.84	0.78
Vertical Positioning Error	2.74	5.93	2.44	**2.26**
Horizontal Protection Level (rms)	19.278 m			
Vertical Protection Level (rms)	15.417 m			
Single Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	2.54	5.20	2.80	
Horizontal Positioning Error	1.77	2.62	1.80	0.44
Vertical Positioning Error	1.93	4.56	1.91	**1.50**

Table 3-7: SEPTENTRIO ARAIM Results-URBAN

3.1.3.3 SEPTENTRIO MOSAIC SBAS Algorithm Results

	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	2.06	4.47	2.31	
Horizontal Positioning Error	1.78	2.69	1.80	0.50

Vertical Positioning Error	0.93	3.60	0.42	1.64
Horizontal Protection Level (rms)	9.392 m			
Vertical Protection Level (rms)	18.583 m			

Table 3-8: SEPTENTRIO SBAS Results-URBAN

3.2 TEST_OPS.GNSS.20 – UAS-UAS Altitude reference (open sky)

3.2.1 Description and objective of test

UAS-UAS altitude reference (Open Sky)	
Test code	**TEST_OPS.GNSS.20**
Objective	The objective of this test is to verify the performance of different GNSS Receivers (from low cost SFMC to high end MFMC GNSS receivers) for UAS-UAS common altitude reference in open sky environment (country side - X,Y Volumes)
Description	For the present test a UAS Multicopter will be used. The drone will be equipped with a custom payload composed by different GNSS receivers spreading from low performance to high performance. The payload is composed by one unique Triple frequency antenna, working in the bands E1, E5, E6 feeding 2 or 3 GNSS receivers coupled with a GNSS signal splitter. In particular, the receivers that will be used are: ✓ Septentrio GNSS Development Board Mosaic X5 (Triple band with Galileo E5 AltBoc enabled); ✓ U-Blox F9P GNSS receiver dual frequency constellation receiver ✓ Pollicino low cost GNSS receiver, single frequency multiconstellation GNSS Receiver This payload will allow GNSS raw data (and NMEA data) to be stored onboard and used for post processing analysis. The main goal is to gather meaningful GNSS Rx data to assess the vertical accuracy achievable with each GNSS receiver with respect to a reference trajectory The following equipment will be used for the test: ✓ **Ground Control Station** with a mission planning software for a simple automatic loop mission ✓ **Private GNSS RTK station:** To augment the UAS position and navigation performance during the flight for the determination of the reference trajectory.
Required data	✓ GNSS raw data of Septentrio X5 GNSS Receiver ✓ GNSS raw data of U-Blox F9P GNSS Receiver

	✓ NMEA data of "Pollicino" GNSS Receiver ✓ GNSS raw data of the permanent private GNSS RTK station. ✓ Drone Trajectory data (augmented positions by RTK GNSS station) used as reference trajectory
Expected Output	✓ Accuracy (mu, sigma) of the vertical axis and horizontal plane w.r.t. the reference drone trajectory for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Precision (mu, sigma) of the vertical axis w.r.t. the mean vertical height for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Integrity figures (mu, sigma for VPL) for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino; ✓ Integrity figures (mu, sigma for HPL) for: ○ GNSS Receiver Septentrio X5; ○ GNSS Receiver UBlox F9P; ○ GNSS Receiver Pollicino;
Pass / Fail criteria	The test is passed if any of the GNSS devices will ensure at least an accuracy of: ✓ 9 meters for the vertical accuracy (req. ICARUS-D31-0310) ✓ 1,5 meters for the vertical accuracy in static tests ✓ 1,0 meters for the horizontal accuracy in static tests and for integrity: ✓ 27 meters for the VPL level when flying at 15 m/s (req. ICARUS-D31-0320) ✓ 46 meters for the HPL level when flying at 15 m/s (req. ICARUS-D31-0330) Although, the same requirements apply for this test, better figures are expected in open sky environment since we did not write a requirement for open sky as we did for the urban environment (ICARUS-D31-0240)

Table 3-9 – **TEST_OPS.GNSS.20 description**

3.2.2 Test Implementation

3.2.2.1 GNSS Receivers performance Comparison

3.2.2.1.1 UBLOX F9P

The following analysis has been done:

3) U-blox F9P in nominal ARAIM configuration (dual frequency ion-free multiconstellation combination) [data at 0.5 Hz]

4) U-blox F9P in degraded ARAIM configuration (single frequency E1 / L1 multiconstellation) [data at 0.5 Hz]

Here are reported the graph explaining the analysis done and the results obtained:

<u>Dual Frequency</u>

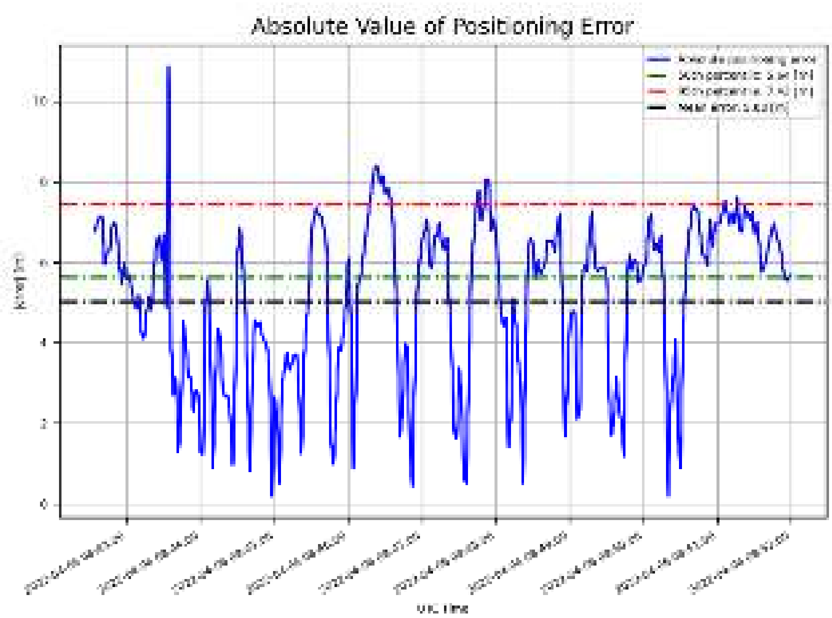


Figure 3-30: Absolute value of Positioning Error- F9P-ARAIM Dual Frequency

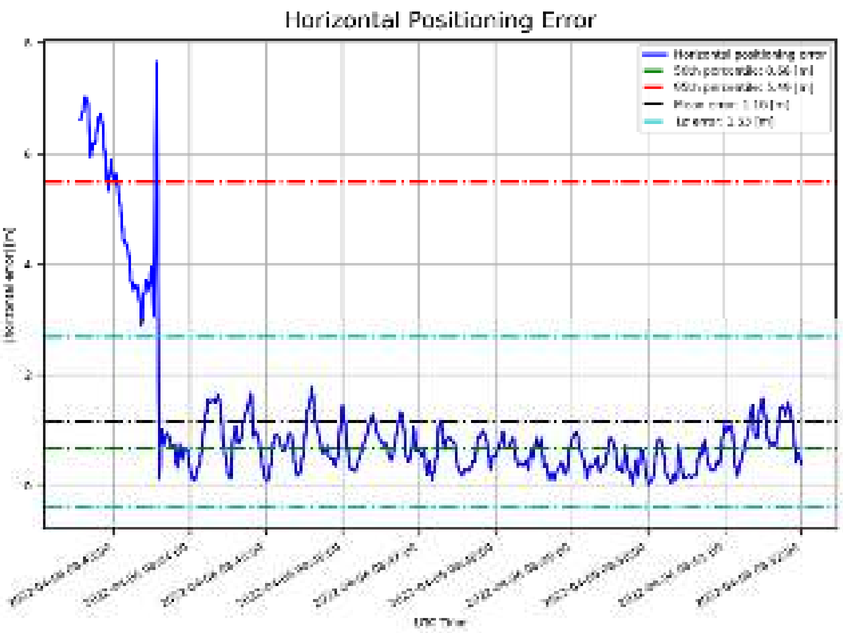


Figure 3-31: Horizontal Positioning Error- F9P-ARAIM Dual Frequency

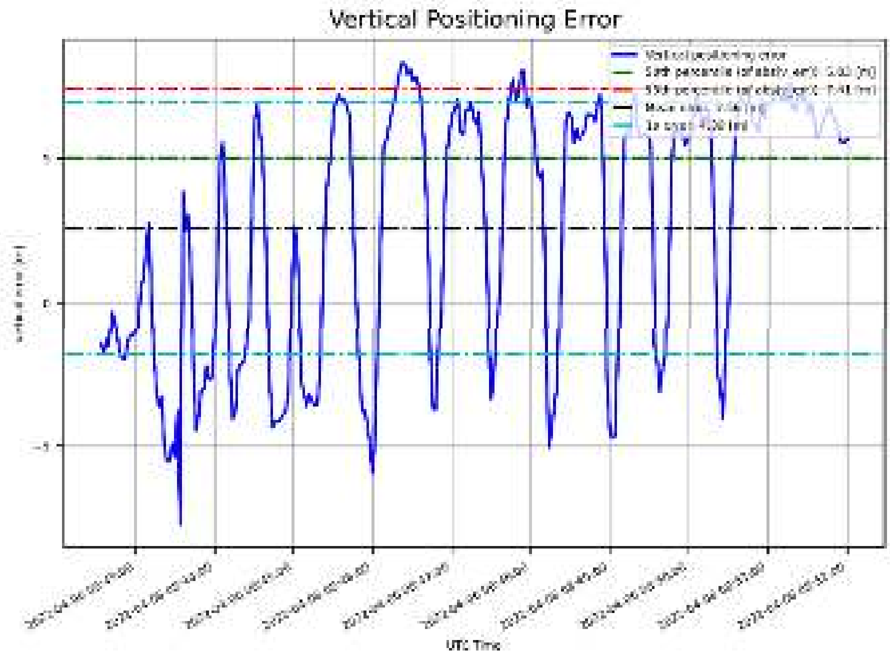


Figure 3-32: Vertical Positioning Error- F9P-ARAIM Dual Frequency

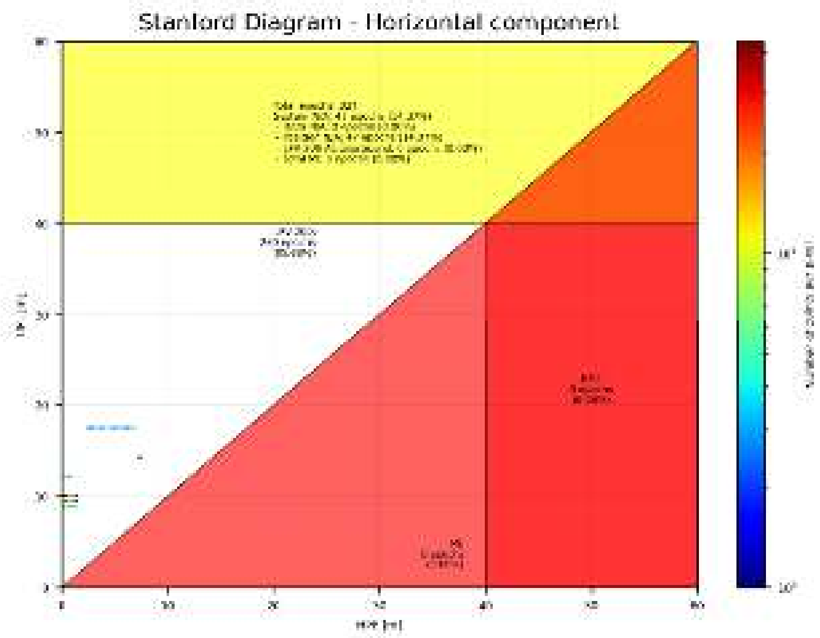


Figure 3-33: Stanford Diagram-Horizontal Component- F9P-ARAIM Dual Frequency

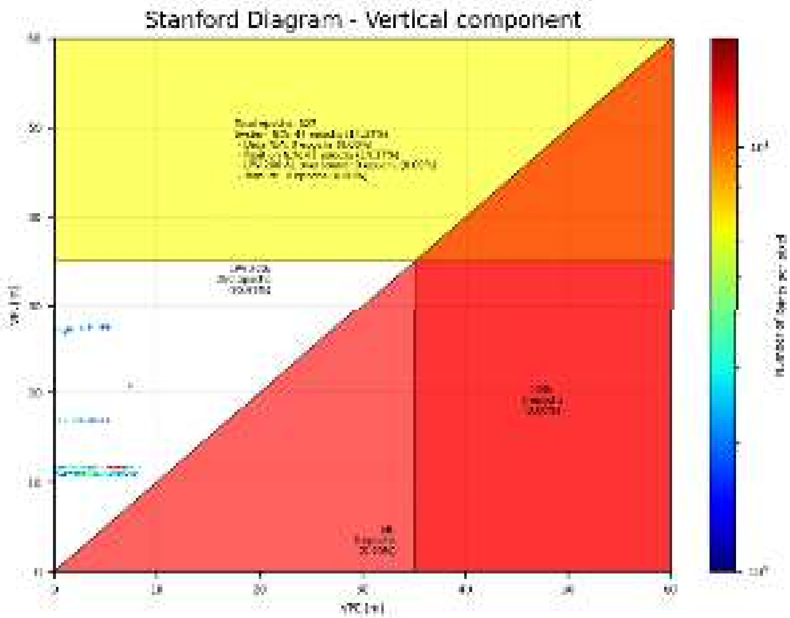


Figure 3-34: Stanford Diagram- Vertical Component- F9P-ARAIM Dual Frequency

<u>Single Frequency</u>

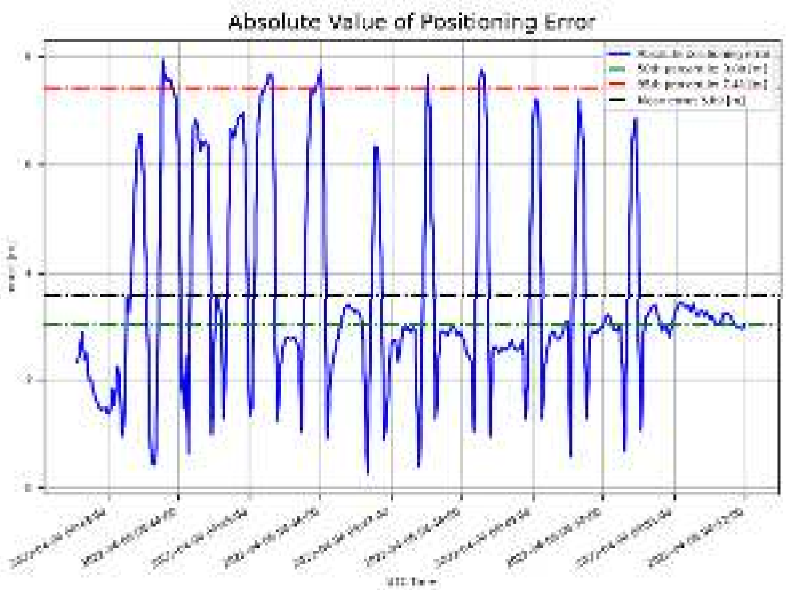


Figure 3-35: Absolute value of Positioning Error- F9P-ARAIM Single Frequency

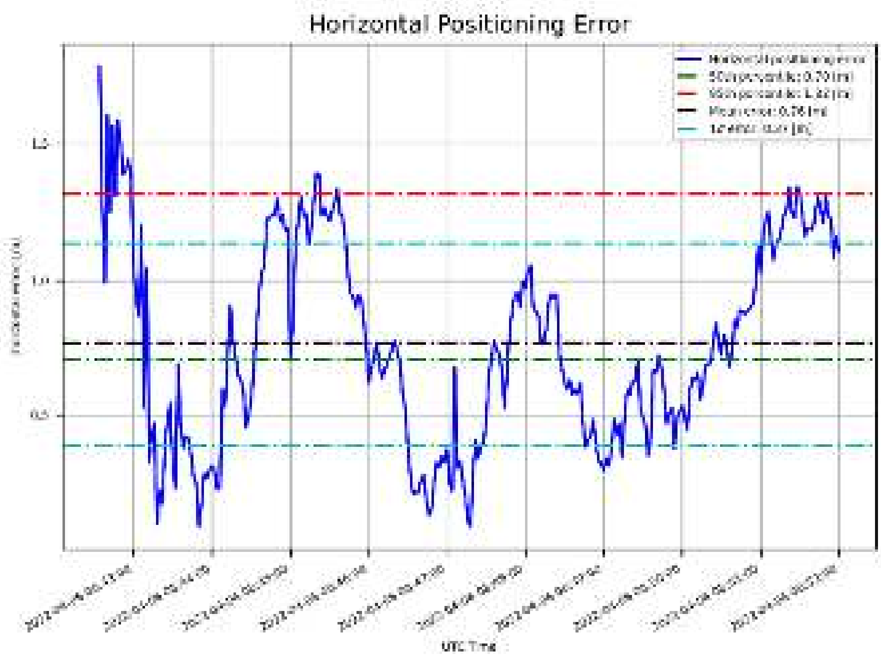


Figure 3-36: Horizontal Positioning Error- F9P-ARAIM Single Frequency

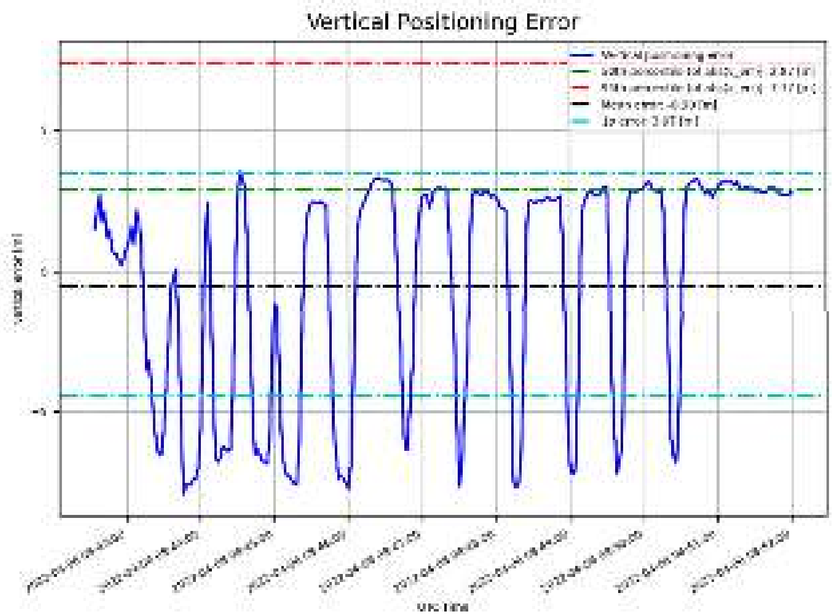


Figure 3-37: Vertical Positioning Error- F9P-ARAIM Single Frequency

3.2.2.1.2 Septentrio MOSAIC X5

The following analysis has been done:

1) Septentrio Mosaic in nominal ARAIM configuration (dual frequency ion-free multiconstellation combination) [data at 1 Hz]
2) Septentrio Mosaic in degraded ARAIM configuration (single frequency E1 / L1 multiconstellation) [data at 1 Hz]
3) Processing SBAS (EGNOS) using the MOSAIC as the base receiver and the EGNOS messages (SBAS at present is based exclusively on the measurements on L1 of the constellation GPS)

Here are reported the graph explaining the analysis done and the results obtained:

3.2.2.1.2.1 ARAIM ALGORITHM

Dual Frequency

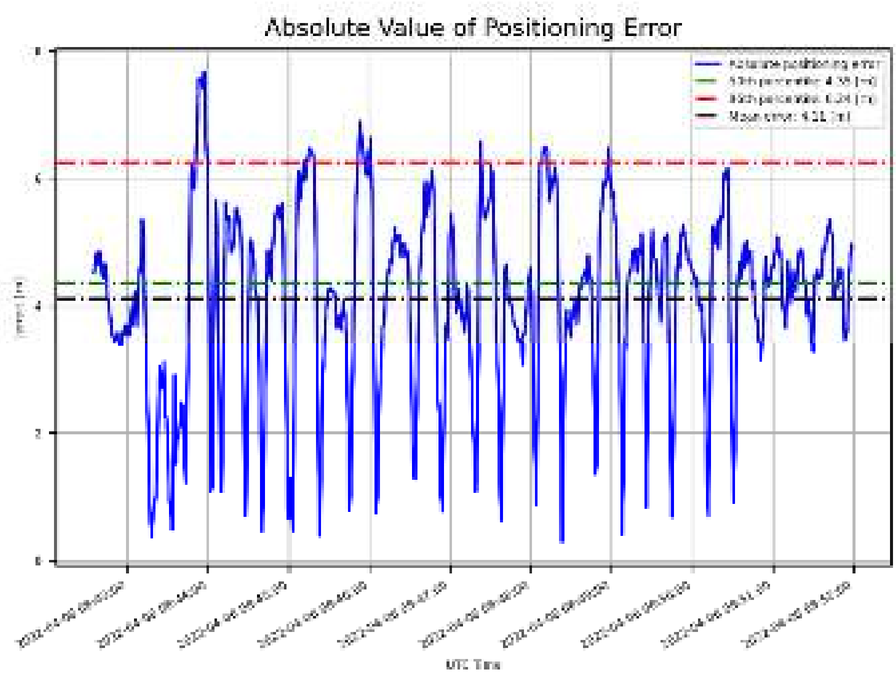


Figure 3-38: Absolute value of Positioning Error- Septentrio- ARAIM Dual Frequency

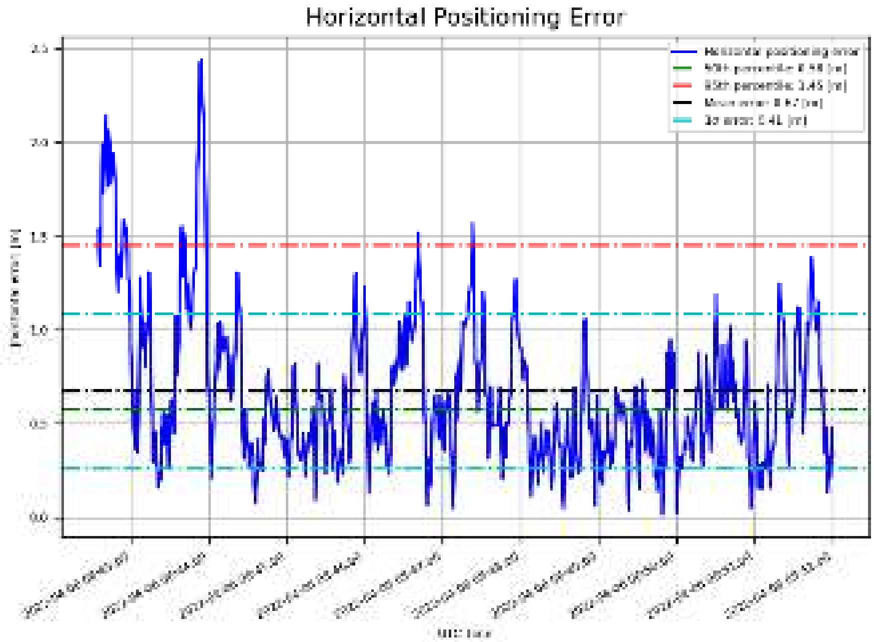


Figure 3-39: Horizontal Positioning Error- Septentrio-ARAIM Dual Frequency

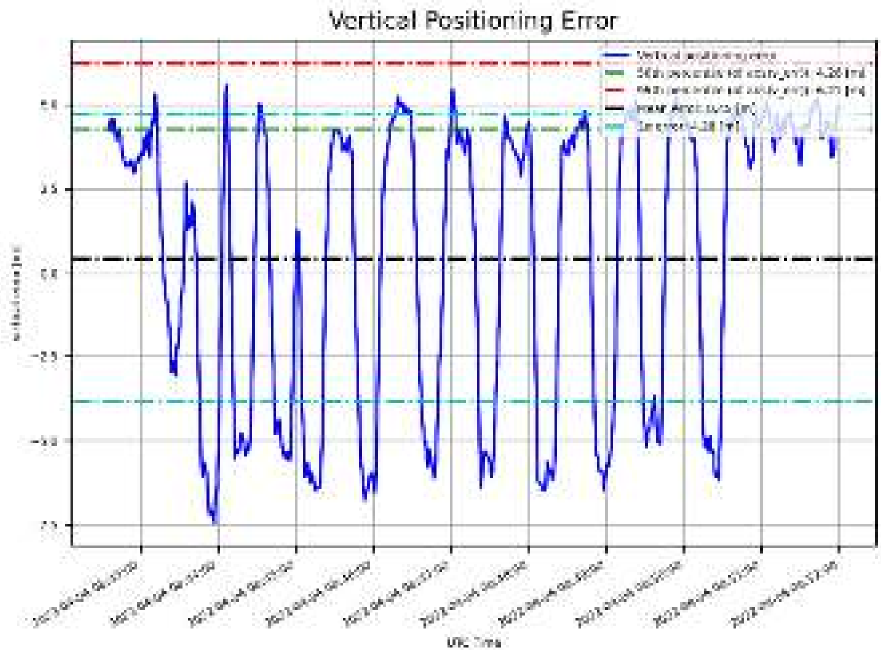


Figure 3-40: Vertical Positioning Error- Septentrio-ARAIM Dual Frequency

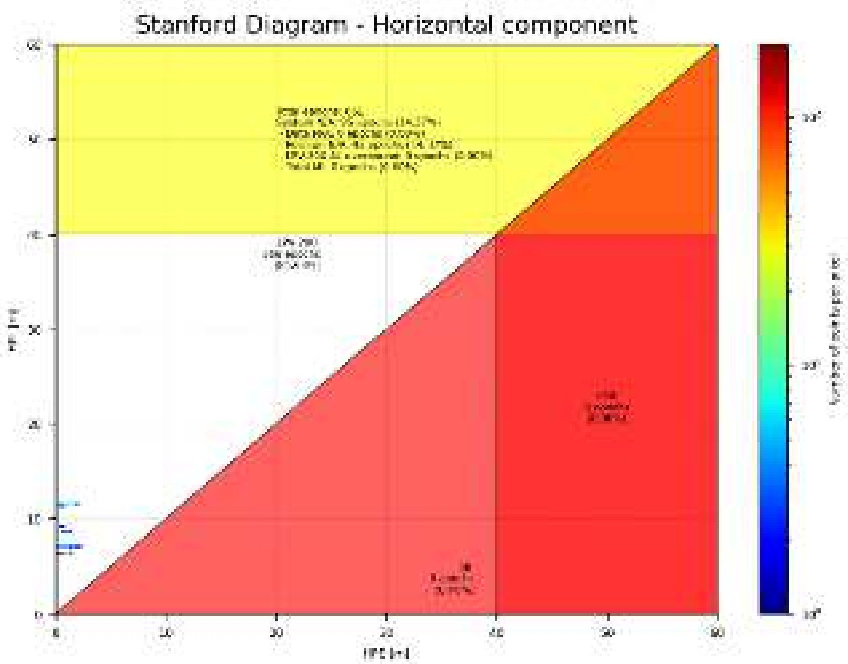


Figure 3-41: Stanford Diagram-Horizontal Component- Septentrio-ARAIM Dual Frequency

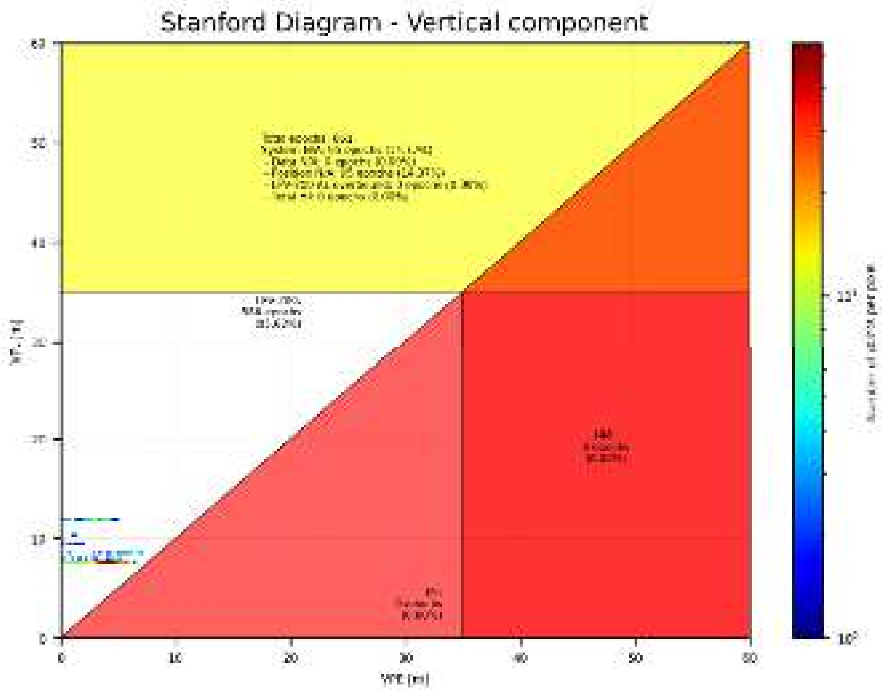


Figure 3-42: Stanford Diagram-Vertical Component- Septentrio-ARAIM Dual Frequency

Single Frequency

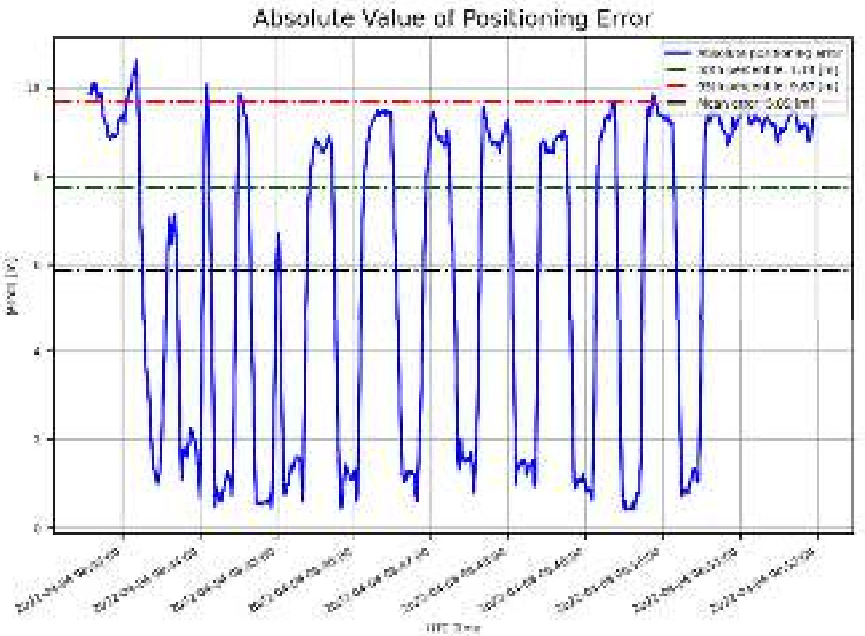


Figure 3-43: Absolute value of Positioning Error- Septentrio- ARAIM Single Frequency

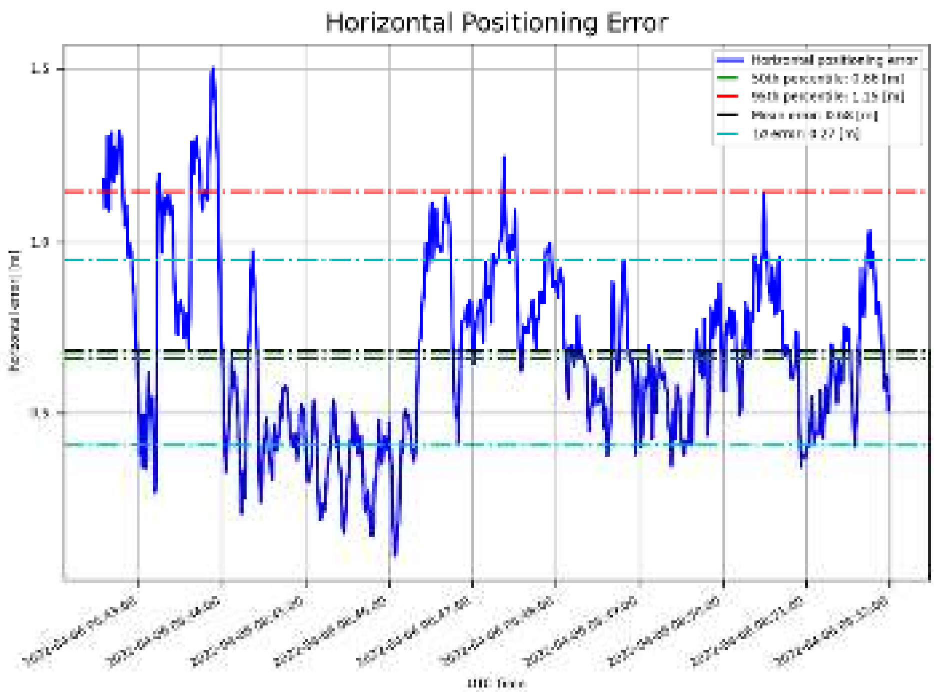


Figure 3-44: Horizontal Positioning Error- Septentrio-ARAIM Single Frequency

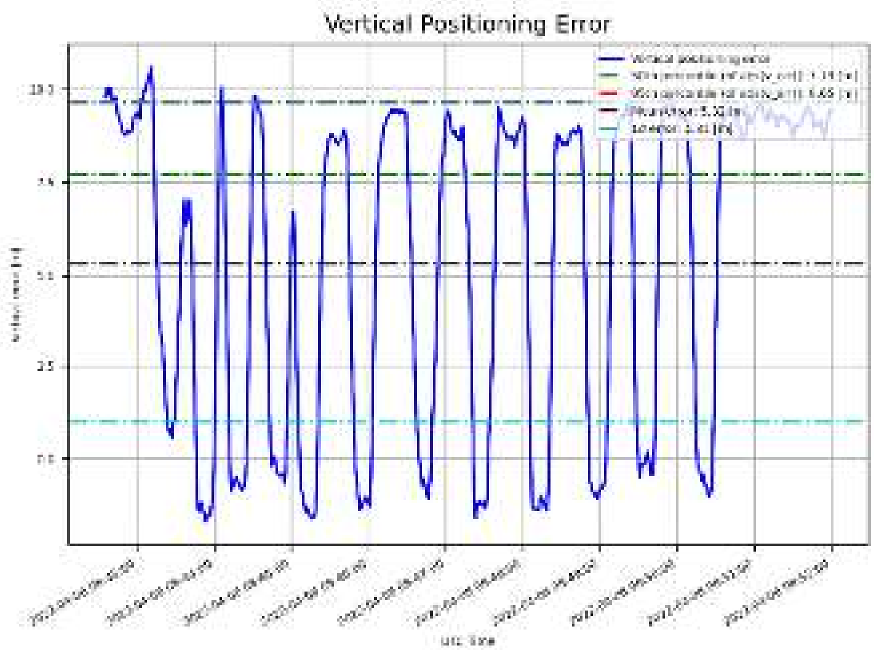


Figure 3-45: Vertical Positioning Error- Septentrio-ARAIM Single Frequency

3.2.2.1.2.2 SBAS (GPS+EGNOS) ALGORITHM

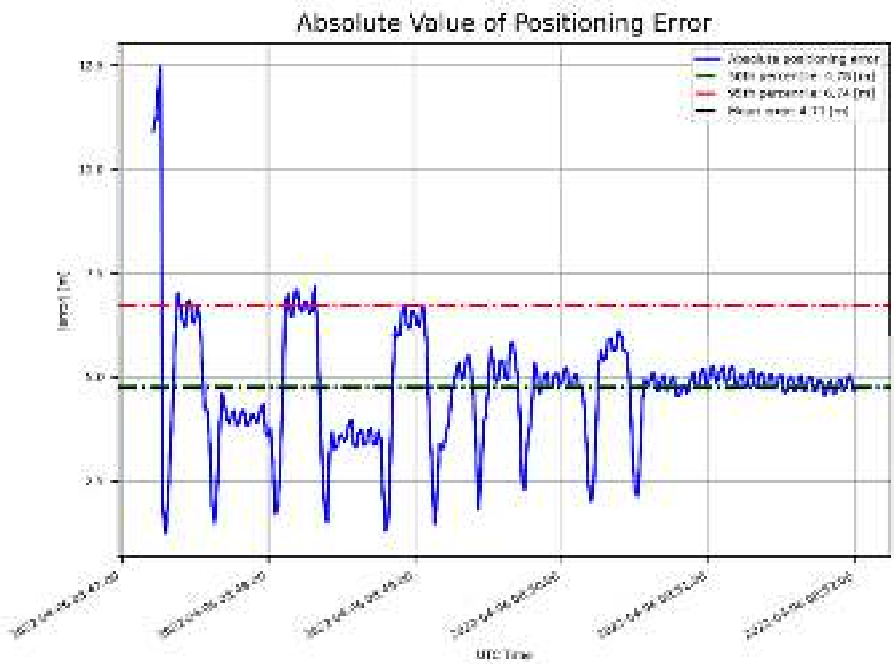


Figure 3-46: Absolute value of Positioning Error- Septentrio - SBAS

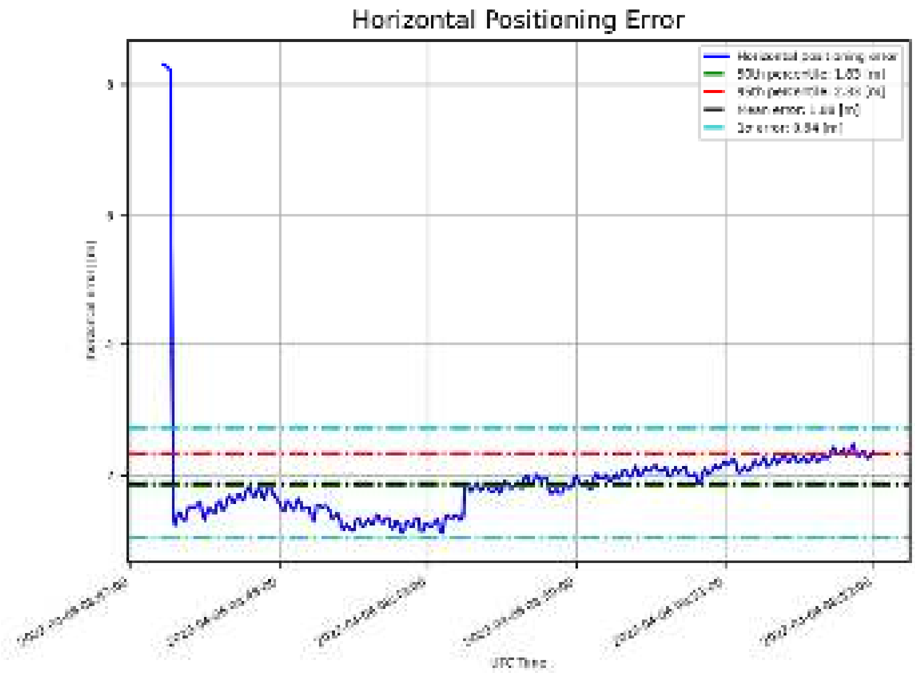


Figure 3-47: Horizontal Positioning Error- Septentrio-SBAS

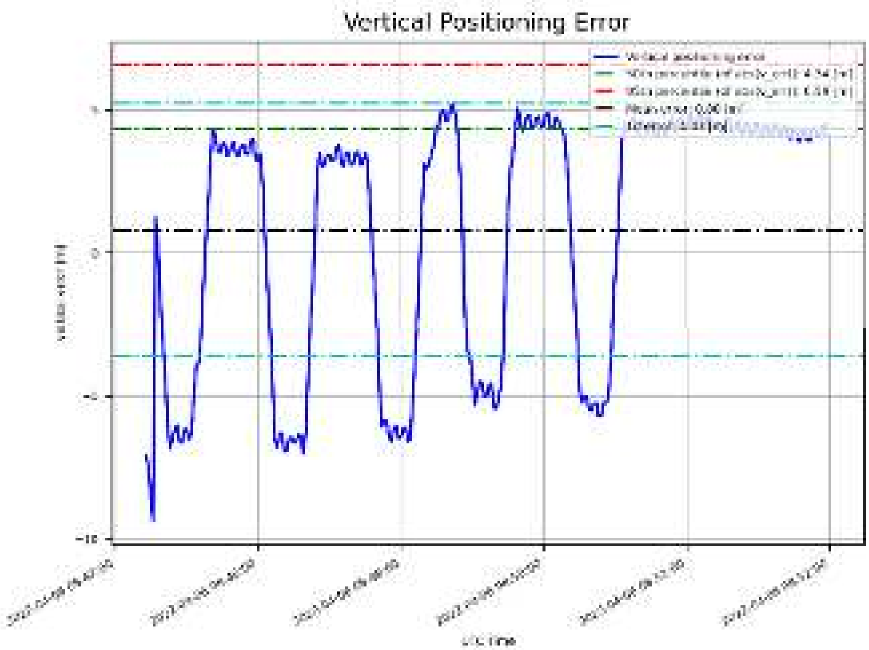


Figure 3-48: Vertical Positioning Error- Septentrio-SBAS

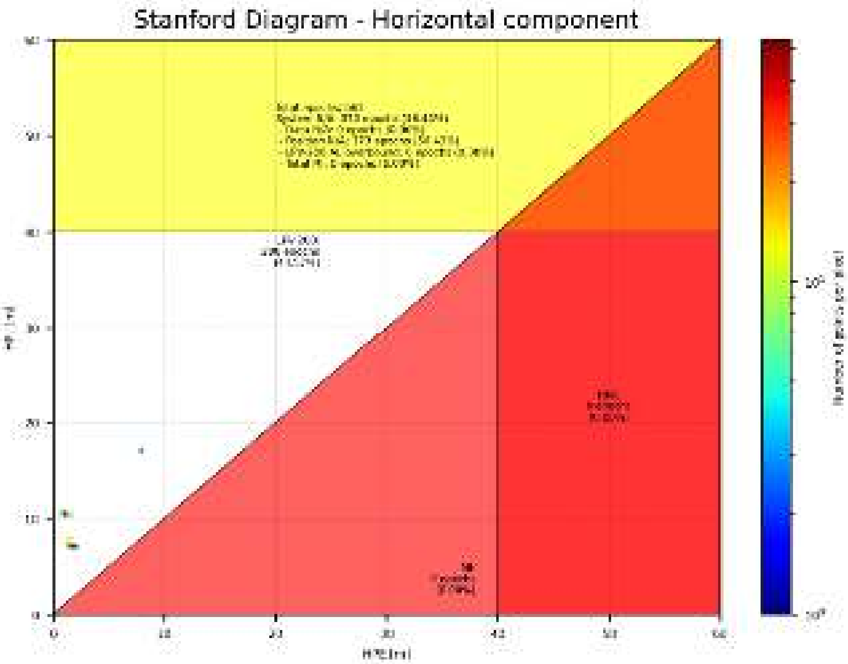


Figure 3-49: Stanford Diagram-Horizontal Component- Septentrio-SBAS

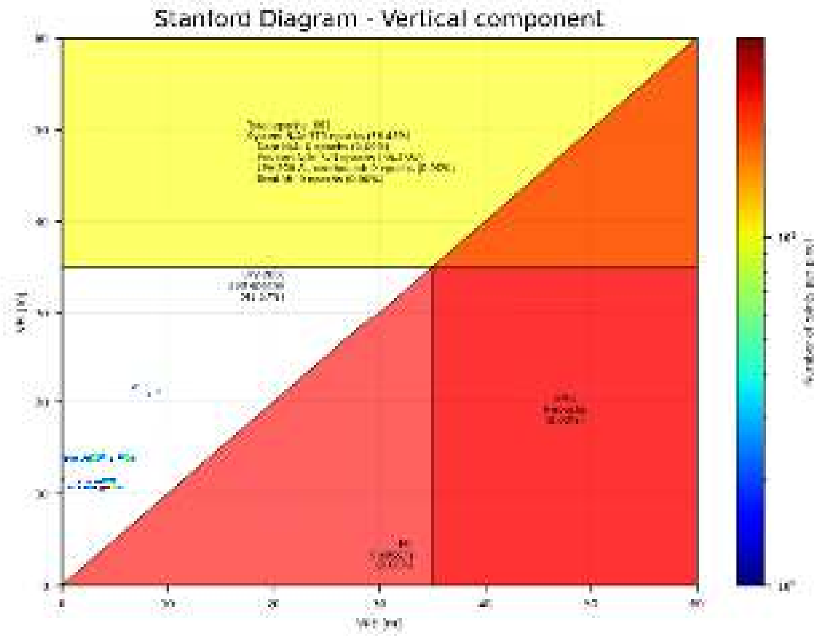


Figure 3-50: Stanford Diagram-Vertical Component- Septentrio-SBAS

3.2.3 Test Results

TEST_OPS.GNSS.10- UAS-UAS altitude reference (Open Sky)	
Test Result	**Passed*** **This test is passed with limitation to the data set acquired and analyzed.** This test was performed with 3 GNSS Receivers used in different configurations in a dynamic test. Even in this case it must be considered that the errors calculated is intended as Total System Error of the UAS even if in simplified and controlled condition. In open sky the results were all (**5 cases over 5 configurations**) below the 9 meters requirement even if the overall performance resulted worse for the Septentrio Mosaic in all configurations. This results confirm the need of local RTK stations providing local correction to the UAS navigation solution Both GNSS receivers showed an outstanding accuracy on the horizontal plane (less than 1 meter @1 sigma for both receivers, in some cases less than 50 cm) as expected for the Open Sky scenario. Finally, the VPL and HPL levels are largely within the requirements given for all the samples acquired, however additional tests are needed to better assess the GNSS integrity with the exploitation of a Ground based network for Navigation signal monitoring. The following tables present additional information of the test performed.
Pass Criteria	The is test is passed if any of the GNSS devices will ensure at least an accuracy of: ✓ 9 meters for the vertical accuracy (req. ICARUS-D31-0310) ✓ 1,5 meters for the vertical accuracy in static tests (req. ICARUS-D31-0240) ✓ 1,0 meters for the horizontal accuracy in static tests (req. ICARUS-D31-0240) and for integrity: ✓ 27 meters for the VPL level when flying at 15 m/s (req. ICARUS-D31-0320)
Remark	This result confirm the need of local RTK stations (possibly in the form of CORS – Continuous Operating Reference Station) providing local corrections to the UAS navigation solution.

3.2.3.1 UBLOX F9P ARAIM Algorithm Results

Dual Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	5.54	7.43	5.03	
Horizontal Positioning Error	0.68	5.49	1.16	1.53
Vertical Positioning Error	5.03	7.41	2.56	**4.39**
Horizontal Protection Level (rms)	12.173 m			
Vertical Protection Level (rms)	16.063 m			
Single Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	3.00	7.41	3.60	
Horizontal Positioning Error	0.70	1.32	0.76	0.37
Vertical Positioning Error	2.87	7.37	0.50	**3.97**

Table 3-10: UBLOX F9P ARAIM Results-OPEN SKY

3.2.3.2 SEPTENTRIO MOSAIC ARAIM Algorithm Results

Dual Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	4.35	6.24	4.11	
Horizontal Positioning Error	0.58	1.45	0.67	0.41

Vertical Positioning Error	4.26	6.21	0.45	**4.28**
Horizontal Protection Level (rms)	8.403 m			
Vertical Protection Level (rmssc)	9.631 m			
Single Frequency				
	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	7.74	9.67	5.85	
Horizontal Positioning Error	0.66	1.15	0.68	0.27
Vertical Positioning Error	7.73	9.65	5.32	**4.31**

Table 3-11: SEPTENTRIO ARAIM Results-OPEN SKY

3.2.3.3 SEPTENTRIO MOSAIC SBAS Algorithm Results

	50 th Percentile [m]	*95 th Percentile [m]*	*Mean Error [m]*	*1 σ [m]*
Absolute Value of Positioning Error	4.78	6.74	4.71	
Horizontal Positioning Error	1.83	2.33	1.88	0.84
Vertical Positioning Error	4.34	6.59	0.80	**4.43**
Horizontal Protection Level (rms)	9.189 m			
Vertical Protection Level (rms)	12.634 m			

Table 3-12: SEPTENTRIO SBAS Results-OPEN SKY

3.3 TEST_OPS.GNSS.30 – UAS-UAS Altitude reference (continuity)

3.3.1 Description and objective of test

UAS-UAS altitude reference (Continuity)	
Test code	TEST_OPS.GNSS.30
Objective	The objective of this test is to verify the performance of Continuity figures with different GNSS Receivers (from low cost SFMC to high end MFMC GNSS receivers) for UAS-UAS common altitude reference in both open sky environment and urban environment.
Description	This test gathers data from the previous experiments (TEST_OPS.GNSS.10 and TEST_OPS.GNSS.20) quantified in about 300 minutes of flight (10 flights x 30 minutes), corresponding roughly to 18.000 position samples at 1 Hz or 180.000 position samples acquired at 10 Hz. Each position sample has an UTC time (epoch) that shall be verified in case of absence of GNSS signal for continuity verification (req. ICARUS-D31-0220).
Required data	All data acquired by the GNSS receivers during tests: ✓ TEST_OPS.GNSS.10 ✓ TEST_OPS.GNSS.20
Expected Output	The output expected is the number of epochs or navigation position solutions without a valid navigation solution with respect to the total data acquired (i.e. 180.000 epochs). This output is expected to be very closed to zero according to req. ICARUS-D31-0220. This requirement will be not strictly demonstrated (Verification per Analysis only), however the data acquired in the previous tests is useful to support the verification of the test per analysis, in combination with Literature review.
Pass / Fail criteria	The test is passed if up to 1 sample over 100.000 results corrupted or not valid.

Table 3-13 – **TEST_OPS.GNSS.30 description**

3.3.2 Test implementation

3.3.2.1 GNSS continuity during test

The continuity of a system is the ability of the total system (comprising all elements necessary to maintain craft position within the defined area) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation.

With this definition in mind, in this test we collected all data acquired by the GNSS receivers during the flight from the moment of the acquisition of the Positioning Fix to the time of switching off the GNSS receiver.
The data collected derives from the following devices:

- Septentrio Mosaic X5 GNSS receiver
- U-Blox ZED F9P GNSS Receiver
- Pollicino GNSS receiver and trandponder
- Internal GNSS of DJI M300 RTK drone
- Internal GNSS receiver of DJI M210 drone
- Private Emlid GNSS Reference Station (RTK)

In the period 1 April - 16 June about 38.000 Samples at 1 Hz were collected together with 120.000 samples (at 10 Hz, internal GNSS receiver of drones).
For all these samples no event of discontinuity is reported. However, some consideration about the continuity of Tracking service foe the Pullicino Transponder were also addressed as described in the following.

3.3.2.2 Tracking service continuity

The Pollicino itself did not present any GNSS discontinuity issue (by analyzing the logs). However, the full traceability chain, that involves also the Network Remote identification service through 4G Network connectity presnt some discontinuity hereafter analyzed.

The tests concerned the transmission of position and the ellipsoid altitude with the "Pollicino" device over the LTE network. The device was mounted on board an ultralight aircraft and two flights were carried out at different altitudes. During the first flight, the aircraft departed from an altitude of 42.9m above sea level and reached an altitude above 700m above mean sea level.

At 10:29:30 the pilot takes off and the aircraft increases its flight altitude. The device stopped transmitting data at 10:34:07 UTC at an altitude of 715.6m and at a distance from the take-off point of 9742.67m.

Figure 3-51: Trajectory flown by the aircraft before losing the Trackign signal transmitted by Pollicino transponder.

The loss of signal is attributable to the altitude reached and not to the poor network coverage as the area is perfectly served as you can see the BTS (Base Transceiver Station) LTE that point right on the interested area.

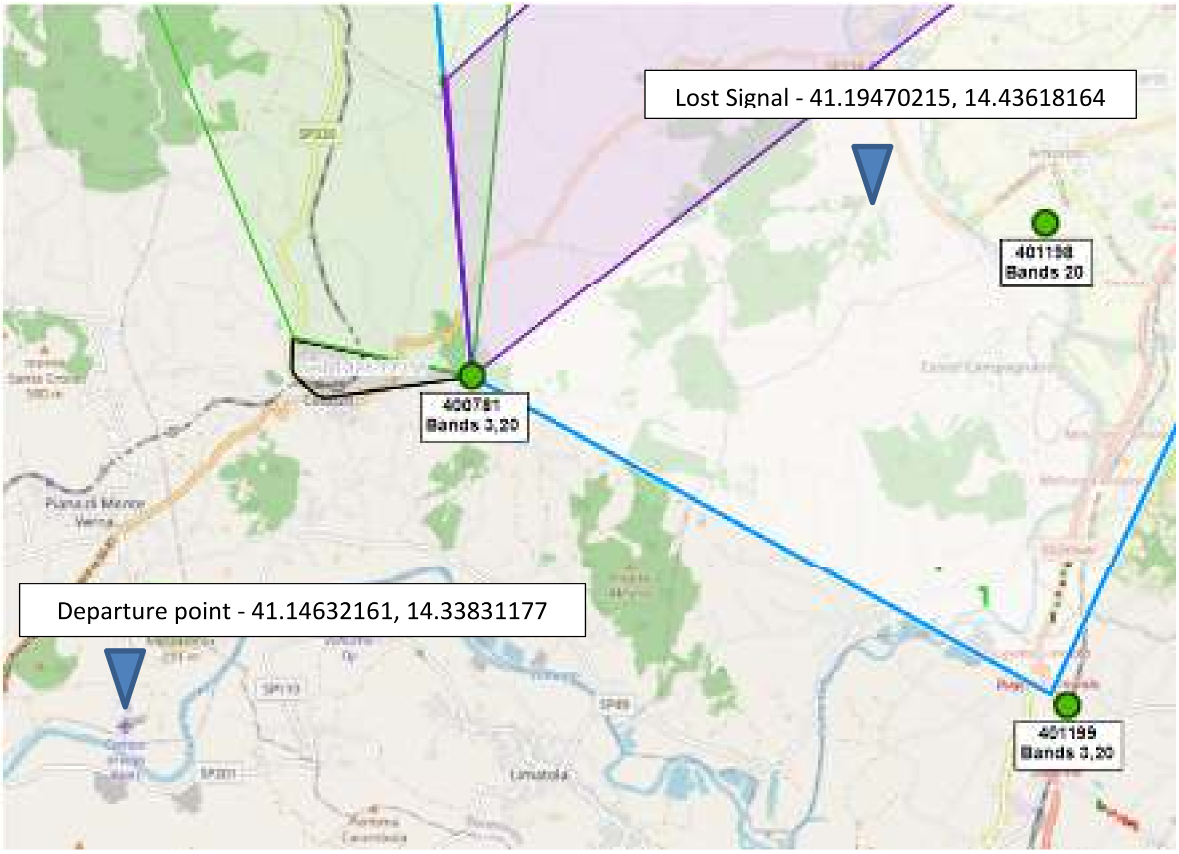


Figure 3-52: Local coverage of LTE Base Stations in coincidence of loss of tracking signal

The device records the first telemetry sample relating to the second flight made at 11:01:41 UTC and constantly reports the position until 11:30:40 UTC.

In this interval the transmission was constantly transmitted and received every 2 seconds, and it is possible to reconstruct the route traveled by the aircraft with the relative maneuvers.

Figure 3-53: Aircraft Profile of mission and significant event (second flight)

1. At 11:07:17 (UTC) the plane leaves the runway to reach an altitude of 365.5 m (msl)
2. At 11:12:44 a first spin maneuver is performed
3. At 11:14:17 a second spin maneuver is performed
4. At 11:16:03 a third spin maneuver is performed
5. At 11:23:00 it settles on an altitude of 125.6 m (msl)
6. Landing on the runway takes place

3.3.3 Test Results

TEST_OPS.GNSS.30- UAS-UAS altitude reference (Continuity)	
Test Result	**Passed*** **This test is passed with limitation to the data set acquired and analyzed.** This test was performed with different receivers. Several samples were collected at both 10 Hz and 1 Hz acquisition providing a good number of samples. The samples acquired never showed any interruption of the service confirming Continuity of data for both internal GNSS receivers of drones and external GNSS receivers of payload and Private GNSS station. The Continuity of U-space Tracking service was also assessed when used in combination with LTE cellular network. The results show a very good coverage of the signal even in the countryside where few Base stations are expected. However, some limitation in height (about 700 meters AGL) are reported, which are still good to serve the VLL airspace. The Tracking service implemented in this way can be used for Traffic information, however redundant mechanism (i.e. e-Conspicuoty at different frequencies) should be also considered.
Pass Criteria	The is test is passed if the number of epochs or navigation position solutions collected by GNSS receivers present valid navigation solution without discontinuity with respect to the total data acquired
Remark	No issue is reported for Continuity; however the data collected my result still small for extensive analysis. Additional data might be useful for additional analysys.

3.4 TEST_OPS.GNSS.40 – UAS-UAS Altitude ref. (Availability)

3.4.1 Description and objective of test

UAS-UAS altitude reference (Availability)	
Test code	TEST_OPS.GNSS.40
Objective	The objective of this test is to verify the performance of Availability of GNSS signal in non-urban environment considering the data acquired from different GNSS Receivers (from low cost SFMC to high end MFMC GNSS receivers).
Description	This test gathers data from the previous experiments (TEST_OPS.GNSS.10 and TEST_OPS.GNSS.20) quantified in about 300 minutes of flight (10 flights x 30 minutes), corresponding roughly to 18.000 position samples at 1 Hz (RF signal used for Continuity). Each position sample has an UTC time (epoch) that shall be verified in case of absence of GNSS signal for SiS availability verification in dynamic conditions (req. ICARUS-D31-0230).
Required data	All data acquired by the GNSS receivers during tests: ✓ TEST_OPS.GNSS.10 ✓ TEST_OPS.GNSS.20 This data acquired in dynamic conditions is needed to verify the availability of GNSS signal (SiS) during turns or UAS maneuvers considered in the tests (automatic plan).
Expected Output	The output expected is the number of epochs or navigation position solutions without a valid navigation solution with respect to the total data acquired (i.e. 18.000 epochs). This output is expected to be very closed to zero according to req. ICARUS-D31-0230. This requirement will be not strictly demonstrated (Verification per Analysis only), however the data acquired in the previous tests is useful to support the verification of the test per analysis, in combination with Literature review.
Pass / Fail criteria	The test is passed if up to 1 sample over 1.000 results corrupted or not valid at GNSS Receiver RF front end (Raw data only).

Table 3-14 – **TEST_OPS.GNSS.40 description**

3.4.2 Test implementation

3.4.2.1 GNSS availability during test

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigation signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities

The availability is usually measured as percentage. Availability will then express the percentage of time that the system is usable by a receiver, user or application.

Particularizations of the availability concept can be made by considering the availability of a usable signal from a specific satellite or by considering the availability of position, velocity and time (PVT) from the full constellation.

The availability of a usable signal from a specific satellite is related with the correct behavior of the satellite. The availability of usable signal for a satellite will only guarantee that the pseudorange to the satellite will be known. For the availability of a PVT it is required that a lock can be made on the signal of at least 3 satellites (for 2D positioning plus time).

When considering the availability of a PVT additional constraints can be added to define when the system is available. If a specific application requires that a PVT is only usable if the expected error is below a certain threshold, it can be said that the system is available only when the error meets that requirement.

Availability can be influenced by several factors being the most important the constellation configuration and its visibility at user location and the surrounding environment (buildings and other obstacles) that might mask part or all of the satellites in the sky.

The same data collected for the previous tests were used to calculate the availability. Even in this case for each sample collected a valid navigation solution was associated for each sample from the time to Fix of Receiver to the time of shutting down the receiver.

3.4.3 Test Results

TEST_OPS.GNSS.10- UAS-UAS altitude reference (Urban)	
Test Result	**Passed*** **This test is passed with limitation to the data set acquired and analyzed.** This test was performed with the same data used for Continuity test. for each sample collected a valid navigation solution was always found and associated to each sample from the time to Fix of Receiver to the time of shutting down the GNSS receiver. The test is passed.

Pass Criteria	The test is passed if up to 1 sample over 1.000 results corrupted or not valid at GNSS Receiver RF front end (Raw data only).
Remark	

3.5 TEST_OPS.DTM.10 – UAS-Ground Obstacle common reference

3.5.1 Description and Objective of test

UAS-Ground Obstacle Common Reference	
Test code	TEST_OPS.DTM.10
Objective	The objective of this test is to verify the **accuracy figures of the DTM/DSM** models used for georeferencing vertically the Ground Obstacles with respect to the same Common altitude reference used by UAS (WGS-84 for BVLOS operations).
Description	The test is structured in the following way: 1. Report the height of the building obtained from public Land Registry or from other certified sources (i.e. project) at the geodetic fiducial point (Hc) 2. Place the GNSS payload at the geodetic fiducial point in a static position for 30 minutes and record GNSS data (Hm). 3. Consider the DTM/DSM model used in the ICARUS prototype service (Dm) 4. Assess the E2E Error considering Error = Hm-Dm-Hc The E2E Error can be filtered of the GNSS Error (previously estimated in TEST_OPS.GNSS.10) to assess the DTM accuracy. This test is useful for ICARUS RGIS service accuracy figures when expressing the Ground Obstacles in the same reference system used by the UAS (WGS-84) during BVLOS operations.
Required data	✓ GNSS raw data of Septentrio X5 GNSS Receiver ✓ GNSS raw data of U-Blox F9P GNSS Receiver ✓ Independent and dissimilar system of measurement.
Expected Output	Converted value of Geometric /Barometric measurements
Pass / Fail criteria	The test is passed if the DTM accuracy, calculated as E2E Error = Hm-Dm-Hc, is on the following ranges: - for urban areas, in the range of [0,50-1,00] m; - for rural areas in the range [5,00 – 10,00] m;

	- for suburban areas [0,50 – 2,00] m, in case of inspection operations; - for suburban areas [5,00 – 10,00] m, in case of transit;

Table 3-15 **–TEST_OPS.DTM.10 description**

3.5.2 Test Implementation

The objective of this test is to verify the **accuracy and resolution of the DTM/DSM models** used for vertically geo-referencing ground obstacles with respect to the same common altitude reference used by UAS (WGS-84 for BVLOS operations).

For ICARUS Validation activities ad hoc DTM and DSM has been generated with a resolution of 1m and 0,6 m respectively, to obtain the best conversion results reducing the amount of total error due to the GIS (Geo Information System) component.

It is important to outline that the **Digital Surface Model (DSM)** is a model of the soil coverage surface (including trees, buildings, bridges and so on) that contains the height of the visible upper level of the objects along a regular grid.

The model is extracted from an aerial photogrammetric survey using auto-correlation, feature matching and other algorithm. This first phase is automatic, but a skilled operator has normally to do some intervention using dedicate hardware (3D stereo) to correct errors mainly due to uniform or repetitive textured areas, shadows and saturation, water.

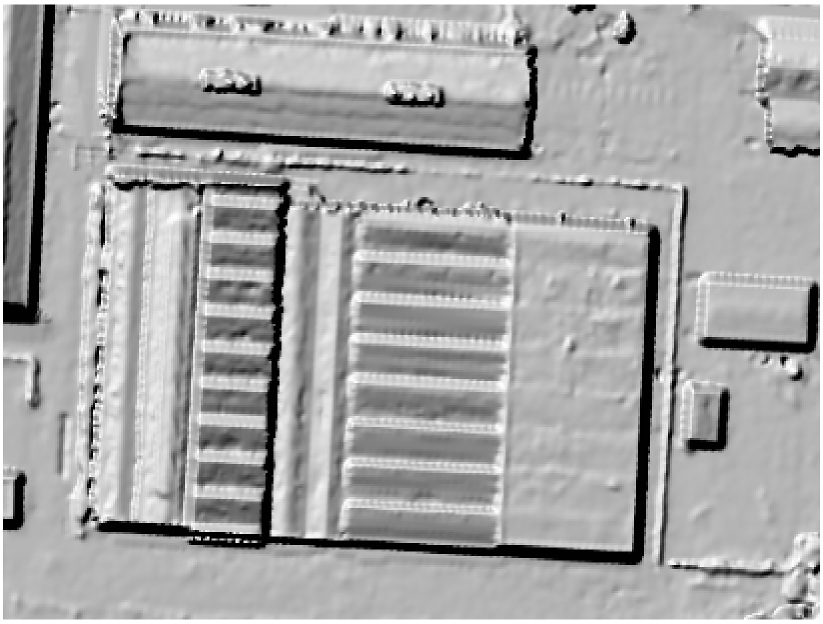


Figure 3-54: DSM Example

To determine if the generated DTM and DSM models, actually had a resolution and an error of 1 m and 0.6 m respectively, the following analyses were carried out:

1) The produced DSM has a resolution (posting) of 2m and was produced using 20cm aerial photos.

The aerial survey was triangulated (geocoded) using high precision ground point (such as IGMI and regionals ones). The residuals (error) of this phase are the following:

	vX/m	vY/m	vZ/m
RMS of GCPs residuals	0.157318	0.155072	0.305234
Avg of GCPs residuals	-0.004007	-0.000451	-0.017076

Table 3-16: residual errors of aerial survey triangulation

After triangulation, a point cloud was automatically produce with a density of 1 measure every 3 image pixel (60cm). A triangular network surface was then modelled to approximate the real surface over the cloud points and sampled at the required output resolution (2m).

In the following there are **extracts** from production software reports:

	Theoretical height accuracy (3D point)	***Estimated internal height accuracy (DTM)***
For DTM 1m	*0.697369 [m]*	*0.227157 [m]*
For DSM 0.6 m	*0.760040 [m]*	*0.107630 [m]*

Table 3-17: DTM-DSM theoretical and estimated height accuracy

Before final sampling, the required editing was performed.

The measurement error for single point is quite small (less than 2 image pixel, < 40cm). The final product accuracy is obviously lower due to the 2m sampling, with a single height value for a 4 square meter cell.

2) To deeply deeply assess the DSM error also in very punctual way the following test was also done:

   1) Put a GNSS payload on the top of a building with access to the rooftop, with the GNSS receiver antenna in open sky.

   2) Determe the height of the building through a Laser Meter, with a certified error through the data sheet

   3) Generate ad hoc DTM/DSM model with the same accuracy and resolution of the one used for the Scenario Validation and the Simulation Trials, so 1 m for the DTM and 0,6 m for the DSM

   4) Estimate the end-to-end error comparing GNSS, laser meter and DSM measured values

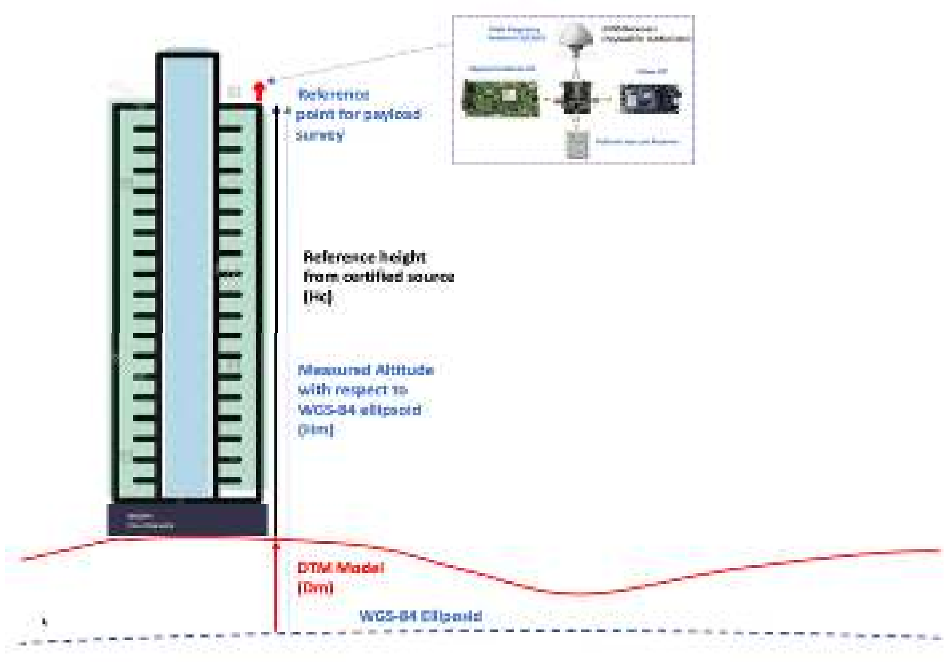


Figure 3-55:Reference test design

For the realization of the test, the following building has been chosen:

- Via Carloforte, 110, 80059 Torre del Greco, NA ("lat": 40.79170833333333, "lon": 14.366172222222222)

Figure 3-56: Real Test case location

To execute the test the following steps has been done:

1) Measure the height of the building through laser meter (independent and dissimilar system) at the reference point (Hc)
2) Place the GNSS payload at the same reference point of the laser meter in a static position for 30 minutes and record GNSS data (Hm).
3) Consider the DTM/DSM model used in the ICARUS prototype service (Dm), using RGIS microservice developed
4) Assess the E2E Error considering error = Hm-Dm-Hc

Figure 3-57: Real test case pictures


```
{
  "data": {
    "status": "success",
    "result": {
      "h_dtm": 51.638,
      "h_dsm": 68.014
    }
  }
}
```


Figure 3-58: RGIS microservice output

3.5.3 Test Results

TEST_OPS.DTM.10- UAS-Ground Obstacle common reference	
Test Result	**Passed** The E2E error calculated in this test by the test: 69.000m-51.639m-17.772m **E2E=0.41 m** Which is even lower than the minimum value of the range identified for urban areas.

Pass Criteria	The test is passed if the DTM accuracy, calculated as E2E Error = Hm-Dm-Hc, is on the following ranges: - for urban areas, in the range of [0,50-1,00] m; - for rural areas in the range [5,00 – 10,00] m; - for suburban areas [0,50 – 2,00] m, in case of inspection operations; - for suburban areas [5,00 – 10,00] m, in case of transit;
Remark	The theoretical and estimated height accuracy is perfectly aligned and coherent with the resolution/accuracy of the model ad hoc provided at 0,6m (DSM).

	Theoretical height accuracy (3D point)	***Estimated internal height accuracy (DTM)***
For DTM 1m	*0.697369 [m]*	*0.227157 [m]*
For DSM 0.6 m	*0.760040 [m]*	*0.107630 [m]*

3.6 TEST_OPS.BARO.10 – Static conversion

3.6.1 Description and Objective of test

Static Conversion	
Test code	TEST_OPS.BARO.10
Objective	The objective of this test is to assess the accuracy of the core **barometric – geometric conversion algorithm**, the main component of the ICARUS VCS microservice. This test does not consider the delivery of the service through the defined software interfaces (D5.1, D5.4), but it aims to evaluate the conversion accuracy only.
Description	This test will use the GNSS Payload implemented for test TEST_OPS.GNSS.10 that will be placed at incremental distances from the given meteorological station's positions. For this test public aeronautical METAR data will be used, but also pressure data from a private network of meteo stations. METAR data represents a certified source of aeronautical meteorological data, however the resolution might not be enough for the calculations. For this reason, a private network of Meteo stations is considered with 0.1 HPa of resolution. This test does not consider any flight operations and will address the following steps:

	The GNSS payload will be placed nearby a Meteorological station (i.e. 100 meters) identified of given position identified, taken from the private meteo station network. Data of Meteo station will be logged with the epoch and made available for post processing activities. 1. In the same way, pressure data from 2 neighbor meteo stations will be read and stored with their epochs. 2. The GNSS payload will be moved 1 Km, 5 km 10, 20 km, 50 km away from the stations. The positions calculated by the payload will be stored with their epoch with the altitude information. The measurement made 20 km at 50 km away should differ of hundreds meters in height (i.e. 300 m) to better assess the algorithm performance. 3. For each position of the GNSS payload a table will be constructed with the positions measured by the payload and the **position calculated** by the algorithm considering one or more meteo station data interpolation. METAR data will be used for reference only.
Required data	The following data is needed for the test: ✓ GNSS raw data/NMEA data acquired by the payload (position, epoch) ✓ Pressure data acquired by 3 meteo stations in the proximity (up to 50 km) of the GNSS payload (pressure of each station, epoch), provided by a trusted meteorological station
Expected Output	The output of the test case is: ✓ Altitude Measured (WGS-84) versus Altitude calculated from pressure data;
Pass / Fail criteria	The test is passed if the vertical conversion service does not introduce an error higher than 10 meters per 1 hPa.

Table 3-18 **–TEST_OPS.BARO.10 description**

3.6.2 Test Implementation

The following Figure 3-59 and Figure 3-60 illustrate the exercise performed to test the accuracy and performance of the CARS translations. Tests were executed in the field with UAV climbing from ground up to 120m above ground level and hoovering at levels: 10, 20, 40, 60, 80, 100 and 120 meters. Drone was equipped with reference RTK device used to determine the mentioned hoovering levels. At each level drone was hoovering for few seconds and then ascended to the next level.

All tests were performed in identical conditions: air temperature was 18,5C, measured pressure was 1004 hPa and airport pressure was 1010 hPa

3.6.2.1 Barometric to Geometric Conversion

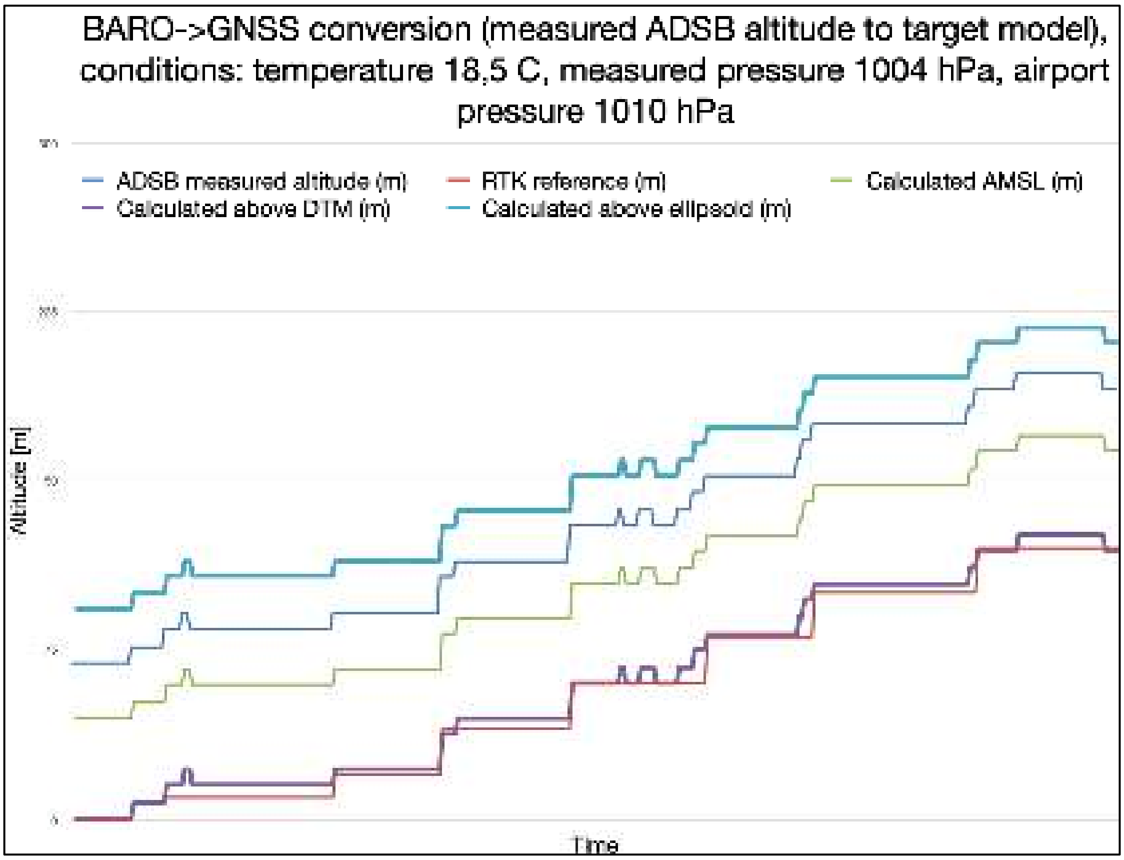


Figure 3-59: BARO->GNSS conversion tests (flight to levels 10, 20, 40, 60, 80, 100, 120 meters above ground)

In the test summarized on above chart, Altitude was measured by ADSB device attached to the drone. The measurements are represented by “ADSB measured altitude” line. The reference height values for height measurements were provided by RTK and they are represented by “RTK reference” line. Remaining plots show values calculated by CARS: “Calculated AMSL”, “Calculated above ellipsoid”, “Calculated above DTM”.

The step shape of the ADSM measurements chart and visible spikes are caused by the accuracy of the ADSB device. It’s precision equals to 25 feet (approx. 7,62m), so therefore there is minimum difference between measured altitude levels only between 7 and 8m and there are occasional spikes of reported data (meaning that ADSB qualified the measurement to the neighbour level).

3.6.2.2 Geometric to barometric conversion

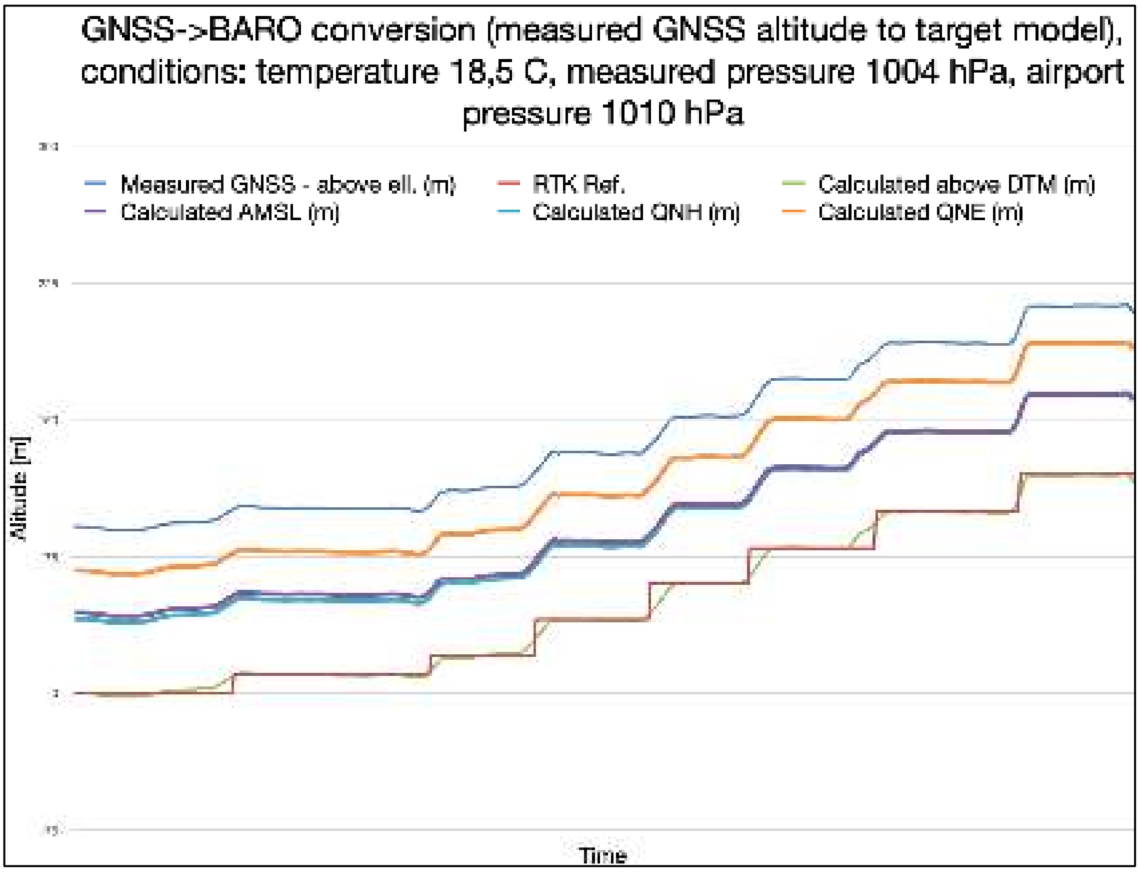


Figure 3-60: GNSS->BARO conversion tests (flight to levels 10, 20, 40, 60, 80, 100, 120 meters above ground)

In the test summarized on above chart, height was measured by GNSS device attached to drone. The measurements are represented by “Measured GNSS – above ell.” line. The reference height values for height measurements were provided by RTK and they are represented by “RTK ref” line. Remaining plots show values calculated by CARS: “Calculated QNE”, “Calculated QNH”, “Calculated above DTM”

Figure 3-61: Preparation of drones and RTK GNSS station on the test site (300 m AMSL)

3.6.2.3 Conversion error analysis

The following analysis provides the information on the impact of introduced measurement errors of temperature, pressure, and sensor height readings on calculated (transformed) altitude calculations. The measurement error can be introduced by environmental conditions. Also, sensor's sensitivity and measurement resolution can introduce further errors. This study do not focus on the evaluation of the source of the error. It evaluates the impact - regardless of its primary source - of the error scale of different input parameters like extreme temperature or pressure measurement on the magnitude of the error for calculated altitudes. The goal is to provide the answer, which input's parameter error has the biggest impact on the translation error.

The analysis is divided into 2 main parts:

- One part is dedicated to the translations of heights from GNSS to BARO
- Second part is dedicated to height translations from BARO to GNSS

The analysis is based on the series of experiments simulating different types of errors:

- Pressure sensor errors
- Pressure sensor elevation error
- Temperature sensor error

performed in various atmosphere conditions:

- Cold temperature condition (-15C)
- Normal temperature condition (15C)
- High temperature condition (30C)
- Low pressure (980hPa)
- Standard pressure (1013hPa)
- High pressure (1040hPa)

The error is calculated for 16 steps above and beyond reference value, each step corresponds (in respective series) to:

- Pressure change of 0,5 hPa error
- Sensor height change of 1m error
- Temperature change of 1C error

3.6.2.4 Impact of pressure sensor error on height calculations (GNSS to BARO conversion)

The simulation's results are presented on the following chart showing the correlation of UA height position error and pressure reading error in different conditions. It contains 9 plots representing combinations of all temperature (cold/normal/high) and pressure (low/standard/high) variations.

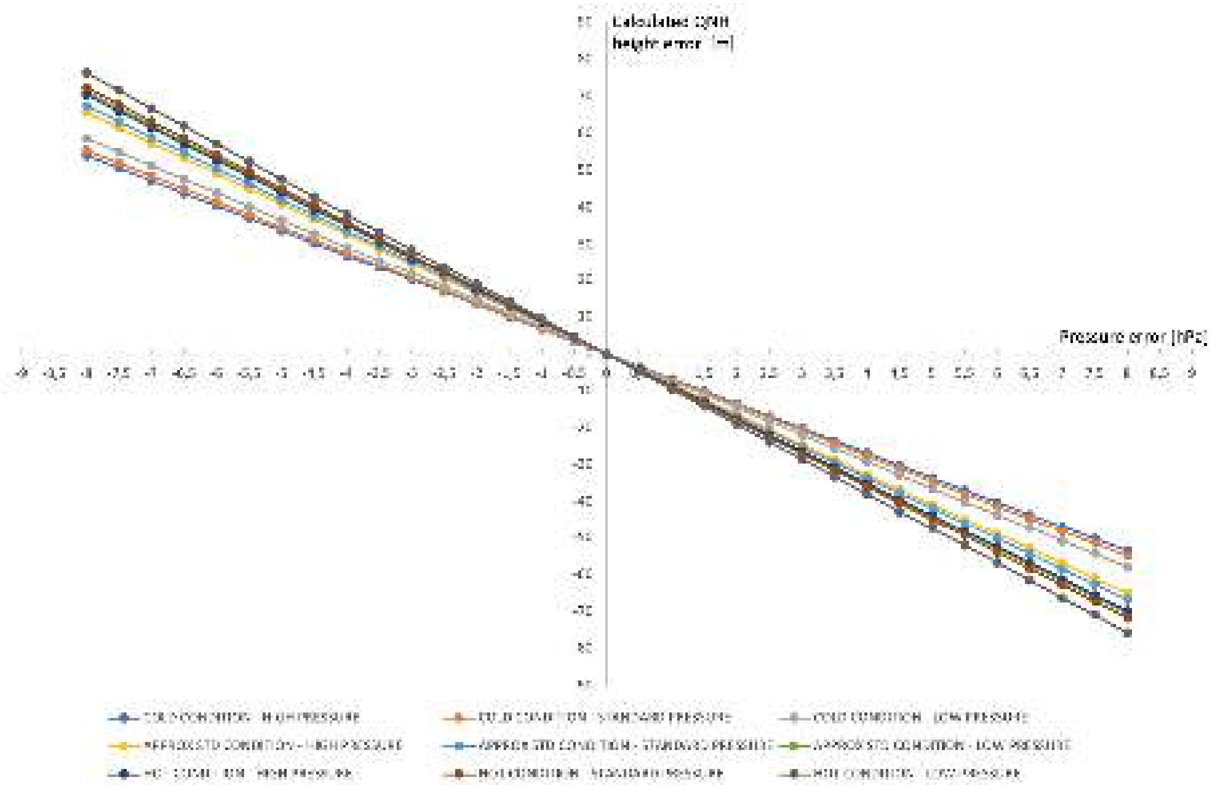


Figure 3-62: *Impact of pressure error on height calculation (GNSS->BARO)*

From the above chart it can be concluded that the error in height calculations is linear in relation to pressure error. The highest error is observed for hot condition combined with low air pressure, whereas the lowest (for the same pressure reading error) is for cold condition combined with high pressure.

The pressure reading error has the biggest and most significant impact on height's error: 1hPa (approx. 0,1%) variation from the actual value introduces the height calculation error of approx. 7-9,5m.

3.6.2.5 Impact of sensor's height error on UAV height calculations (GNSS to BARO conversion)

The simulation's results are presented on the below chart illustrating the correlation of UAV height position error and sensor's height reading error in different conditions. It contains 9 plots representing combinations of all temperature (cold/normal/high) and pressure (low/standard/high) variations.

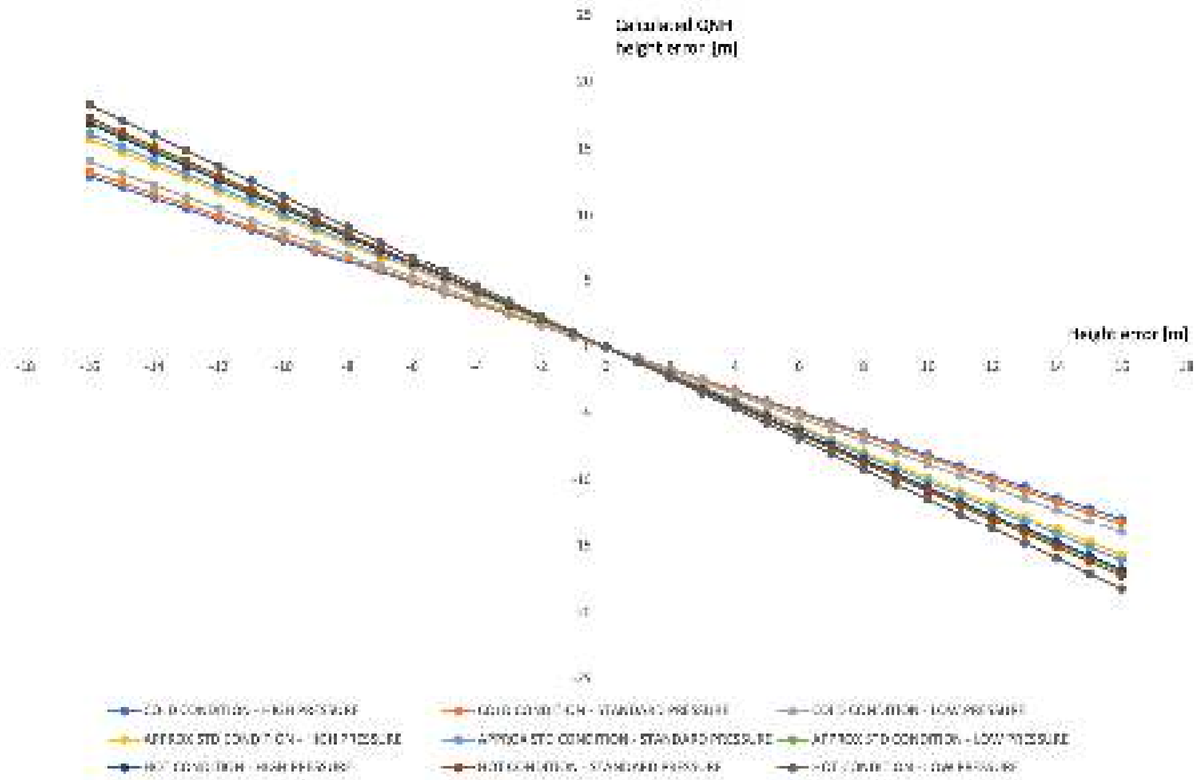


Figure 3-63: ***Impact of sensor's height on height calculation (GNSS->BARO)***

From the above chart it can be concluded that the error in height calculations is linear in relation to sensor's height reading error. The highest error is observed for hot condition combined with low air pressure, whereas the lowest is for cold condition combined with high pressure.

The sensor's height reading error has the minor impact on height's error: 1m (approx. 1%) variation from the actual value introduces the height **calculation error of approx. 0,8-1m.**

3.6.2.6 Impact of temperature sensor error on height calculations (GNSS to BARO conversion)

The simulation's results are presented on the following chart showing the correlation of UAV height position error and temperature error in different conditions. First conclusion is that height calculation error caused by temperature reading error is independent from temperature conditions – in all simulated temperature conditions (cold/normal/high), the error remains the same. So, the chart contains only 3 plots representing different pressure (low/standard/high) variations.

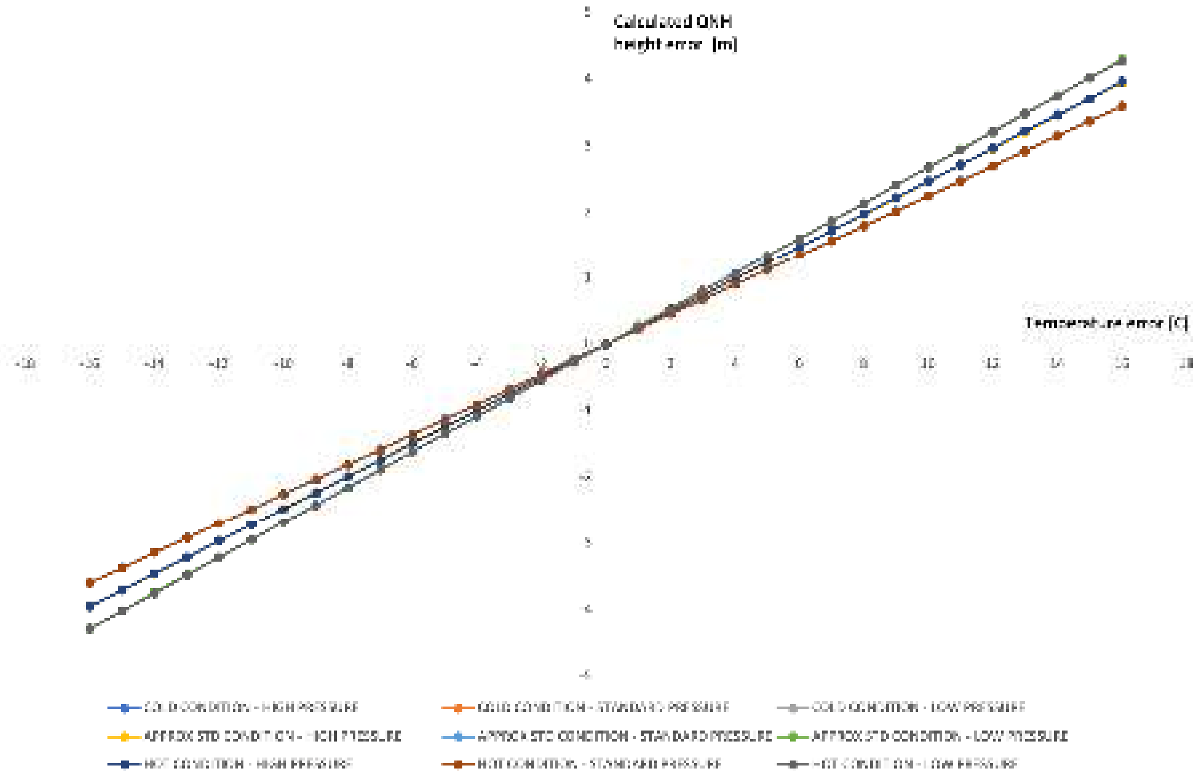


Figure 3-64: *Impact of temperature error on height calculation (GNSS->BARO)*

From the above chart it can be concluded, that the error in height calculations is linear in relation to temperature reading error. The highest error is observed for low air pressure, whereas the lowest is for standard pressure.

The sensor's temperature reading error has the smallest impact on error height's error: 1C deg variation from the actual value introduces the **height calculation error of approx. 0,22-0,27m.**

3.6.2.7 Impact of pressure sensor error on elevation calculations (BARO to GNSS conversion)

The simulation's results are presented on the following chart showing the correlation of UA elevation error and pressure reading error. As the results are the same, there is only one plot common to all combinations of all temperature (cold/normal/high) and pressure (low/standard/high) variations.

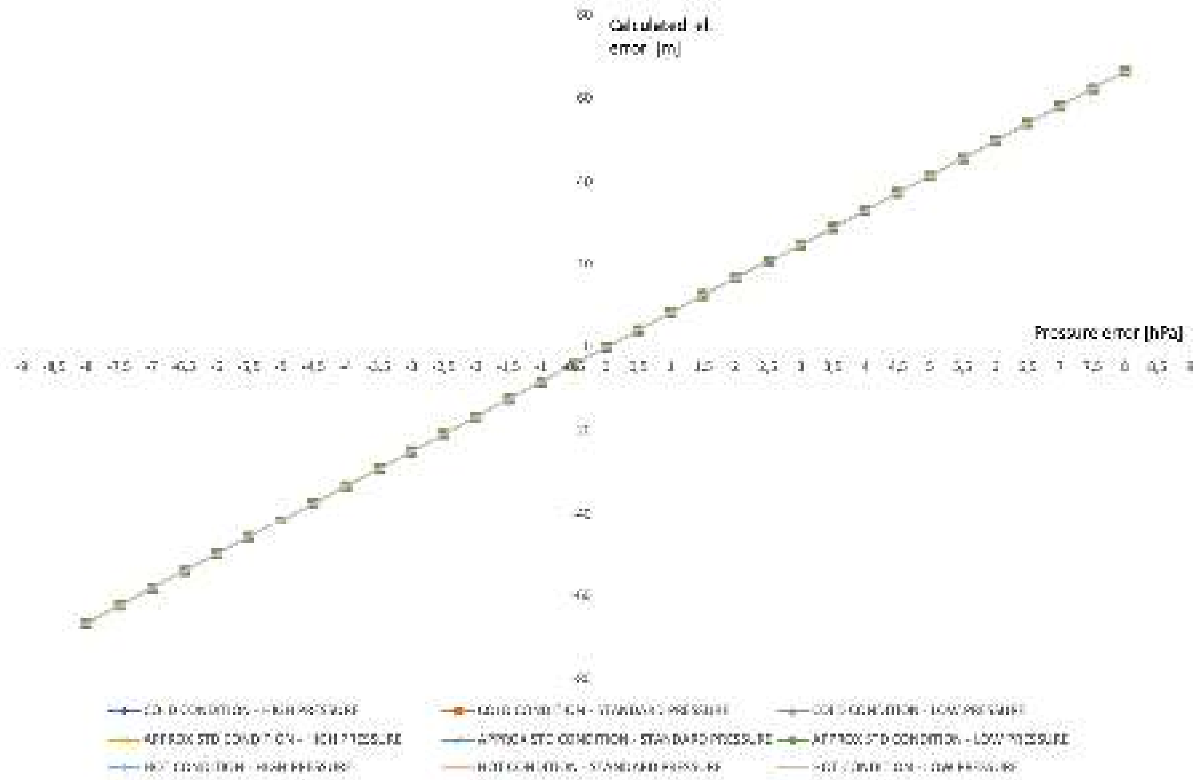


Figure 3-65: *Impact of pressure error on elevation calculation (BARO->GNSS)*

From the above chart it can be concluded that the error in elevation calculations is linear in relation to pressure error. For this type of calculation combination of temperature and pressure conditions has no impact on the result.

The pressure reading error has the biggest and most significant impact on elevation's error: **1hPa (approx. 0,1%) variation from the actual value introduces the elevation calculation error of 8,3m.**

3.6.2.8 Impact of sensor's height error on elevation calculations (BARO to GNSS conversion)

The simulation's results are presented on the following chart showing the correlation of UA elevation error and sensor's height error. As the results are the same, there is only one plot common to all combinations of all temperature (cold/normal/high) and pressure (low/standard/high) variations.

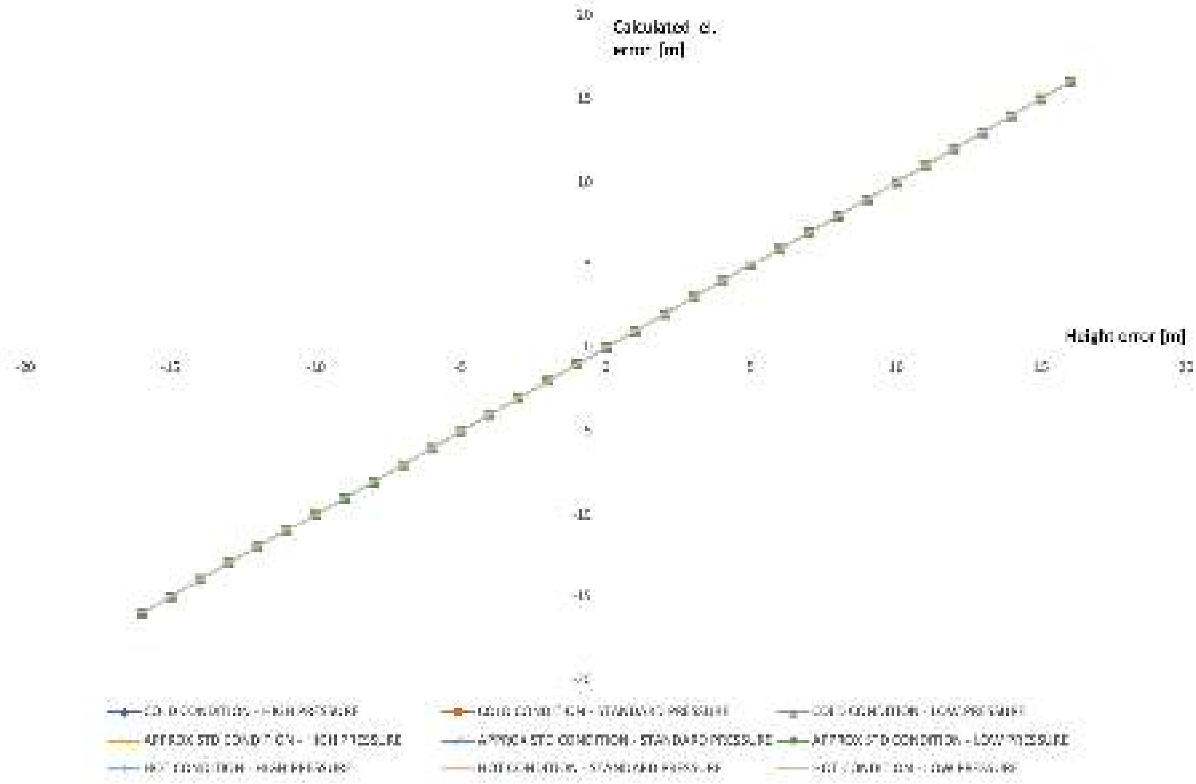


Figure 3-66: ***Impact of height error on elevation calculation (BARO->GNSS)***

From the above chart it can be concluded that the error in elevation calculations is linear in relation to pressure error. For this type of calculation combination of temperature and pressure conditions has no impact on the result.

The pressure reading error has the minor impact on elevation's error: **1m variation from the actual value introduces the elevation calculation error of the same 1m.**

3.6.2.9 Impact of temperature sensor error on elevation calculations (BARO to GNSS conversion)

The simulation's results are presented on the following chart showing the correlation of UA elevation error and temperature error in different conditions. First conclusion is that height calculation error caused by temperature reading error is independent from the pressure conditions – in all simulated pressure conditions (low/standard/high), the error remains the same. So the chart contains only 3 plots representing different temperature (cold/standard/hot) variations.

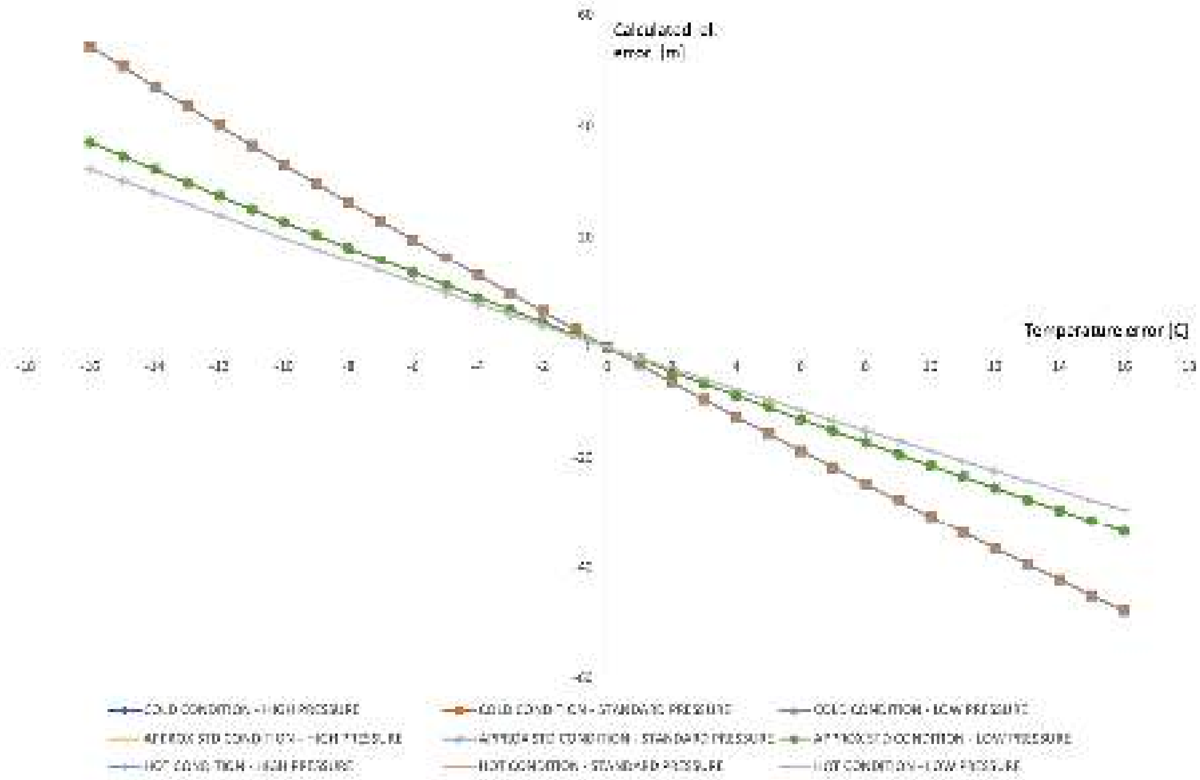


Figure 3-67: ***Impact of temperature error on elevation calculation (BARO->GNSS)***

From the above chart it can be concluded that the error in elevation calculations is linear in relation to temperature reading error. The highest error is observed for cold condition, whereas the lowest is for hot condition.

The sensor's temperature reading error has the minor impact on elevation error: **1C deg variation from the actual value introduces the elevation calculation error of approx. 1,9-3,2m.**

3.6.3 Test Results

Below table summarizes absolute values of errors measured or calculated for flights described above. For calculation only hoovering periods were taken into consideration. Measurements and calculations performed during climbing up were removed.

Measured data is represented by ADSM readings from onboard drone ADSB sensor and GNSS receiver respectively for BARO->GNSS and GNSS->BARO conversions.

Error of measured data is derived from measurement's instruments (ADSB or GNSS) accuracy. For the ADSB the accuracy is 25 feet and thus the measurement step is 7 or 8m. For GNSS device the measurement accuracy is provided by manufacturer.

To calculate the measurement error we referred the CARS above DSM results to RTK measurements.

As can be expected, the BARO->GNSS conversion provides bigger calculated error (compared to reference measurements provided by RTK). But even in this case, at least for tested scenarios, the errors in value were smaller than the accuracy of ADSB sensor. It means, that conversion provided very accurate results. The median value of error was 3,76m

For the GNSS->BARO conversion, as expected, the accuracy is much better. The median value of error was 0,5m.

Type of conversion	**Measured data**		**Calculated data**	
	Altitude [m]	**Error [m]**	**Above DTM [m]**	**Error (min/max/avg) [m]**
BARO->GNSS	69 - 198 (ADSB)	+/-7…8	0,84 - 125,89	0,25 / 5,89 / 3,30
GNSS->BARO	89,8 - 212,1 (GNSS)	N.A.	-2,2 - 120,1	0 / 2,2 / 0,58

Table 3-19: Errors of measured and calculated altitudes

TEST_OPS.BARO.10- Static conversion	
Test Result	**Passed** This test has showed an E2E error of considerably less than 10 meters @1 HPa during conversions from barometric measurement to Geometric measurement and viceversa. Impact on pressure, temperature as well as analysis on the error has been performed.
Pass Criteria	The test is passed if the vertical conversion service does not introduce an error higher than 10 meters per 1 hPa.
Remark	

4 Validation Report

4.1 Scenario 1

This paragraph describes the activities performed in the first validation scenario (S1), concerning concurrent UAS and GA aircraft operations.

This scenario combined the real flight of a UAS and simulated manned aircraft to test:

- **Vertical Conversion Service (VCS).**
- **Vertical ALert Service (VALS).**

The aircraft has been equipped with the ICARUS Electronic Flight Bag, placed on the cockpit simulator through a specific holder. The ICARUS EFB device was connected to the U-space prototype service.

Once the scenario started, the simulated GA aircraft performed a training flight mission, departing from “Rains Club” airfield and flying over the surrounding valley.

In the same time, the UAS takes-off on the top of a hill, about 10 kilometres from the airfield.

The UAS featured U-space to position tracking capabilities through the Pollicino Pro box and sent its telemetry information to ICARUS VCS and VALS services.

Figure 4-1: ***Cockpit simulator and Drone flying at the same for validation scenario S1***

As shown in the figures below, once reached the area of conflict, where the drone and the aircraft have been adjacent at the same time, the ICARUS EFB promptly warned the GA pilot (through the VALS service), indicating the distance and bearing of the drone, **including indication on the altitude of drone expressed in the same reference as used by the GA pilot (VCS).**

Figure 4-2: EFB for CAR service (VCS) exploitation for Manned aircrafts pilots.

The figure below shows the conversions of different altitudes obtained during this test (red rectangle on the bottom-right side)

Figure 4-3: Icarus Services exploitation (backend side)

As can be seen from the upper image, the simulator is able to receive the tracking data of both manned and unmanned aircraft.

In the case of **manned aircraft**, the input data is *h_obs_qne* (barometric altitude, transmitted by the on-board ADS-B) while in the case of **unmanned aircraft** the data transmitted will be *h_ellips* (geometric height with respect to the WGS-84 ellipsoid, transmitted by the GNSS receiver). Once the connection has been established, ICARUS, thanks to the *GNSS microservice*, is able *to track* the aircraft and provide the *Integrity values* (HPL, VPL). At the same time, the 3 microservices VCS-VALS and RGIS are activated which have the task of:

1) call the DTM and DSM model at the current point (RGIS)

2) convert the input height/altitude to:

I. *h_ort*: height with respect to the geoid (mean sea level)

II. *h_obs_qnh*: altitude with respect to the actual qnh of the reference airport

III. *h_agl*: height with respect to the terrain

IV. *h_asl*: height with respect to the surface

V. *h_ellips*: height with respect to the ellipsoid WGS-84 (only for manned users who provide h_obs_qne as input)

VI. *h_obs_qne*: altitude with respect to the actual qfe on the ground (only for unmanned users who provide h_ellips as input)

3) generate alerts if there could be a possible collision with terrain or obstacles (VALS)

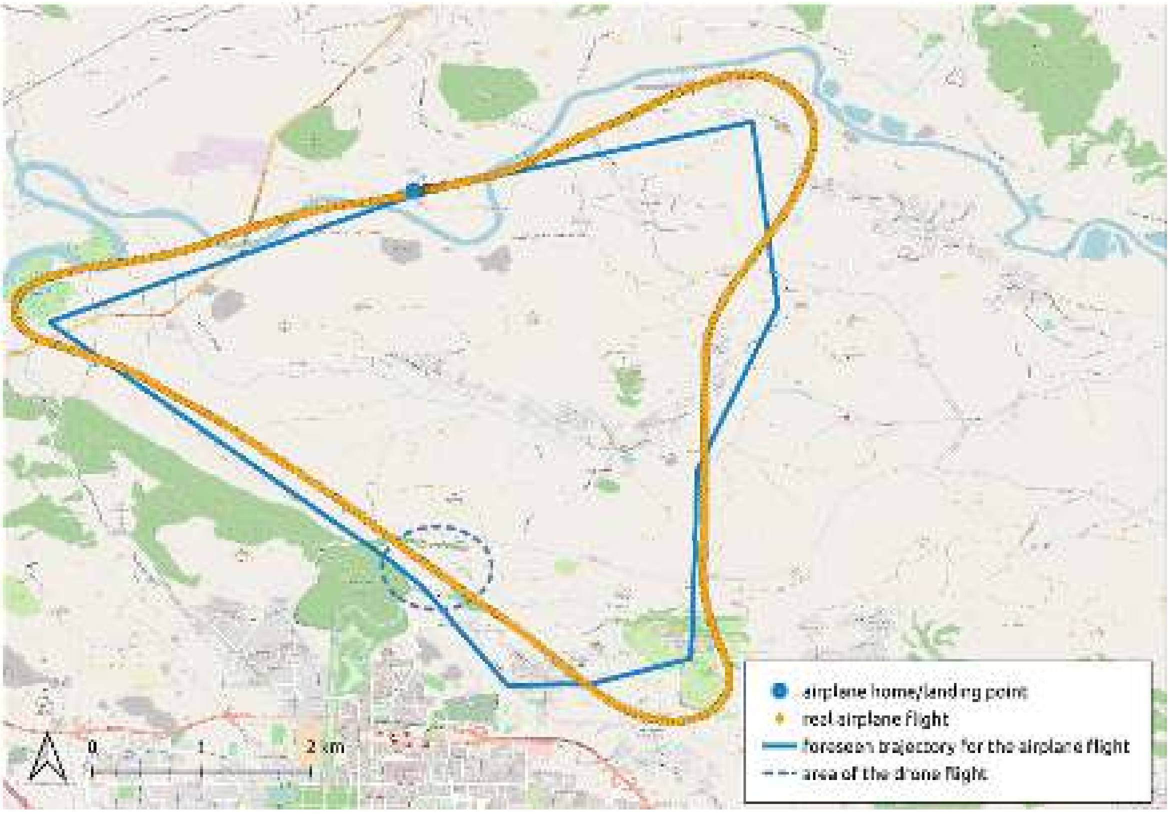


Figure 4-4: comparison between aircraft trajectory and drone flight

The figure above shows a synoptic picture of Scenario 1, comparing the planned route for the manned flight, the area of operations involved by the drone and finally the trajectory actually flown by the manned aircraft through the cockpit simulator.

In correspondence with the points represented relating to the flight of the cockpit simulator and the area flown by the drone, the ICARUS services have been activated and below is a table showing the results of the conversion for some representative points relative to the drone flights.

Scenario 1 - Data from flight above Caserta

Sample points have been chosen at 8 steps of h qne more or less equally spaced (15-16m). For the airplane case h_qne is measured (so it's in the input). For the drone case h_qne is calculated (so it's the output).

INPUT FOR THE CONVERSION SERVICE						
vehicle type	**lat**	**lon**	**h ell measured**	**p_w**	**h_w**	**p_qnh_airport**
Drone	41,1049	14,33902	391,3	975,35	329	1012
Drone	41,10385	14,33882	407,2	975,23	329	1012
Drone	41,1049	14,33901	421,8	975,2	329	1012
Drone	41,10404	14,33885	436,4	975,23	329	1012
Drone	41,10413	14,33887	450,1	975,19	329	1012
Drone	41,1049	14,33898	465,5	975,13	329	1012
Drone	41,1049	14,33898	481,7	975,11	329	1012
Drone	41,1049	14,33898	497,5	975,2	329	1012

DATA RETRIEVED FOR CALCULATION			
country_code	**h_dtm**	**h_dsm**	**n**
IT	329,671	329,162	47,684
IT	299,885	299,567	47,684
IT	329,628	329,117	47,684
IT	305,558	305,481	47,684
IT	308,161	307,56	47,684
IT	329,522	328,998	47,684
IT	329,522	328,998	47,684
IT	329,522	328,998	47,684

OUTPUT OF THE CONVERSION SERVICE				
h_ort	**h_obs_qnh**	**h_agl**	**h_asl**	**h qne calculated**
343,616	324,6607646	13,945	14,454	334,9949908
359,516	341,5974164	59,631	59,949	351,9276653
374,116	356,4607466	44,488	44,999	366,787505
388,716	370,8093156	83,158	83,235	381,1327045
402,416	384,857853	94,255	94,856	395,1779428
417,816	400,7782813	88,294	88,818	411,0946323
434,016	417,1559334	104,494	105,018	427,4684384
449,816	432,1911516	120,294	120,818	442,5001258

To view the goodness of the conversion service, the drone has been also equipped with an ADS-B and treated also as an aircraft at the same time.

The Tables below shows the results of the conversion service:

INPUT FOR THE CONVERSION SERVICE						
vehicle type	**lat**	**lon**	**h qne measured**	**p_w**	**h_w**	**p_qnh_airport**
Airplane	41,10489	14,33905	335	975,12	329	1012
Airplane	41,10488	14,33891	351	975,12	329	1012
Airplane	41,10488	14,33891	358	975,12	329	1012
Airplane	41,10488	14,33897	381	975,23	329	1012
Airplane	41,10488	14,33897	396	975,29	329	1012
Airplane	41,10489	14,33899	411	975,28	329	1012
Airplane	41,10488	14,33897	427	975,28	329	1012
Airplane	41,10489	14,33899	442	975,09	329	1012

DATA RETRIEVED FOR CALCULATION			
country_code	**h_dtm**	**h_dsm**	**n**
IT	329,538	329,401	47,684
IT	328,715	328,511	47,684
IT	328,715	328,511	47,684
IT	328,867	328,869	47,684
IT	328,867	328,869	47,684
IT	329,241	329,012	47,684
IT	328,867	328,869	47,684
IT	329,241	329,012	47,684

OUTPUT OF THE CONVERSION SERVICE				
h_ort	**h_obs_qnh**	**h_agl**	**h_asl**	**h_ell_calculated**
341,647183	324,665775	12,10918302	12,24618302	389,331183
357,6447656	340,6695332	28,92976563	29,13376563	405,3287656
364,643708	347,6711775	35,92870802	36,13270802	412,327708
388,5833184	370,67658	59,71631842	59,71431842	436,2673184
404,0949115	385,6801033	75,22791154	75,22591154	451,7789115
419,0064828	400,6836267	89,7654828	89,9944828	466,6904828
435,003566	416,687385	106,136566	106,134566	482,687566
448,3741467	431,6909084	119,1331467	119,3621467	496,0581467

The differences between the output of the conversion services, treating the drone equipped at the same time with an ADS-B and with the GNSS receiver are very low (less than 2m).

Comparing *h_ell calculated* when the drone treated as an aircraft and the *h_ell measured* when the drone has been treated as an unmanned aircraft, the differences are very low, as the same when we compare h_obs_qne calculated with h_obs_qne measured.

data	timestamp	vehicle type	lat	lon	h qne measured	h qne calculated	h ell measured	h ell calculated	accuracy
ADSB	2022-04-06 08:41:19.966541563	1	41,10489	14,33905	335			389,331183	1,968816982
GNSS	2022-04-06 08:23:51.929526349	0	41,1049	14,33902		334,9949908	391,3		
ADSB	2022-04-06 08:44:10.111241207	1	41,10488	14,33891	351			405,3287656	1,871234372
GNSS	2022-04-06 08:36:28.291600779	0	41,10385	14,33882		351,9276653	407,2		
ADSB	2022-04-06 08:44:42.144926855	1	41,10489	14,33893	366			420,3264993	1,473500675
GNSS	2022-04-06 08:26:03.854143208	0	41,1049	14,33901		366,787505	421,8		
ADSB	2022-04-06 08:45:33.207588887	1	41,10488	14,33897	381			436,2673184	0,132681585
GNSS	2022-04-06 08:36:15.921243892	0	41,10404	14,33885		381,1327045	436,4		
ADSB	2022-04-06 08:46:55.277471095	1	41,10488	14,33897	396			451,7789115	-1,678911539
GNSS	2022-04-06 08:36:09.922315189	0	41,10413	14,33887		395,1779428	450,1		
ADSB	2022-04-06 08:47:51.341036863	1	41,10489	14,33899	411			466,6904828	-1,190482802
GNSS	2022-04-06 08:29:53.998621469	0	41,1049	14,33898		411,0946323	465,5		
ADSB	2022-04-06 08:49:08.423366572	1	41,10488	14,33897	427			482,687566	-0,987566035
GNSS	2022-04-06 08:31:36.895322516	0	41,1049	14,33898		427,4684384	481,7		
ADSB	2022-04-06 08:49:57.493179518	1	41,10489	14,33899	442			496,0581467	1,441853344
GNSS	2022-04-06 08:32:18.893130353	0	41,1049	14,33898		442,5001258	497,5		

Figure 4-5: Accuracy of the conversion service

4.2 Scenario 2

This paragraph describes the activities performed in the second validation scenario (S2) that concerns concurrent UAS and ultralight aircraft operations.

This scenario implemented the VCS and VALS in real operations with a real ultralight aircraft and a real UAS flight, flying in a segregated area.

Figure 4-6: Concurrent Flight operations

The mission has been designed to provide the UAS pilot with alerts about the incoming traffic nearby, during the flight, by using the value-added services offered by ICARUS, particularly the alerting service (VALS).

As shown in the next figures, the EFB has been installed on the cockpit of Ultralight GA aircraft to collect barometric and GNSS data during the flight.

In addition, the ultralight aircraft has been equipped with Pollicino Pro© and Pollicino Box tracking devices for reporting the ultralight position to U-space and to test the performance of the high-end GNSS chipset on-board under the same conditions. Moreover, in this scenario has been tested the radio coverage in remote areas as a stress test for this kind of equipment, using the ground-based 4.5G NB-IOT network for communication as reported already in the test case TEST_OPS.GNSS.30.

Figure 4-7: Equipment installed on drone and Ultralight aircraft for tracking.

The UAS featured U-space position reporting and tracking capabilities through the Pollicino Box. The information generated by the trackers installed on-board the ultralight aircraft has been used to feed the ICARUS VALS service.

Figure 4-8: UAS pilot Traffic information and converted altitude.

The GA aircraft flew several times alongside the UAS to test the VCS and VALS. The flight tracking has been displayed on both Telespazio/E-geos and d-flight platforms.

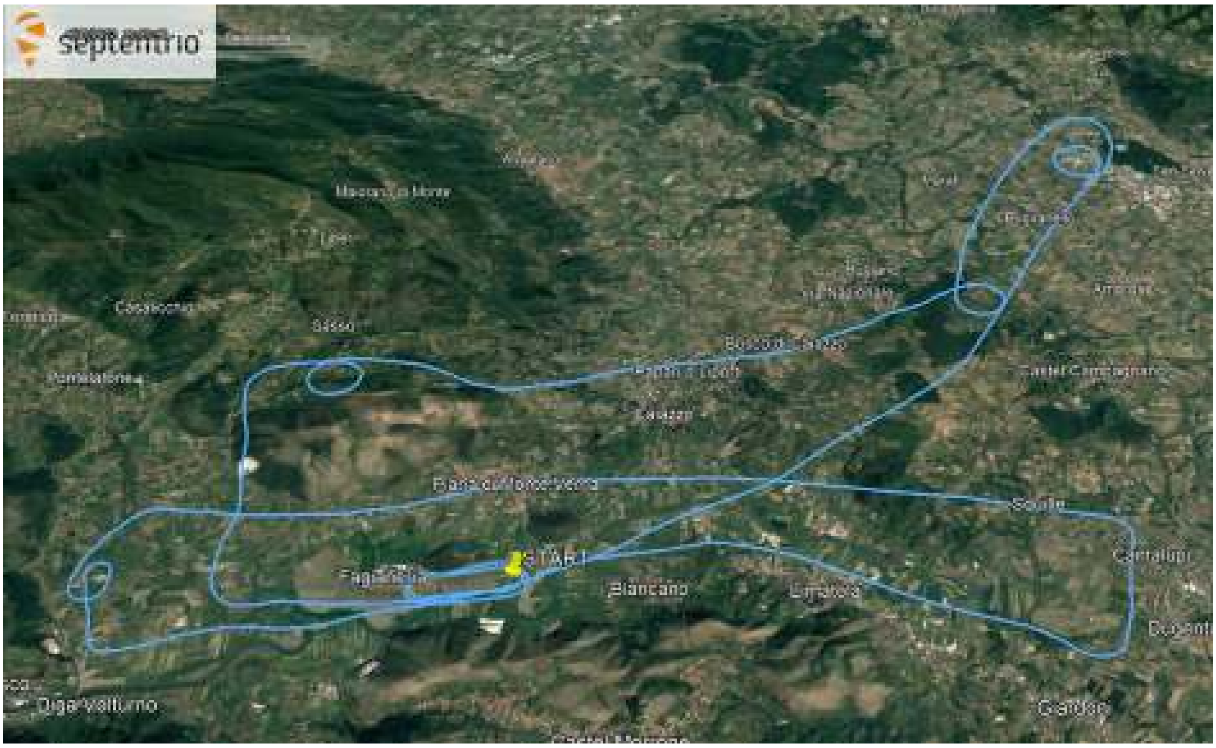


Figure 4-9: Flight data flown by ultralight aircraft.

The figure above shows a picture of Scenario 2, with the path followed by the real GA Aircraft

Scenario 2 - Data from real GA Aircraft flight above Caserta

	INPUT FOR THE CONVERSION SERVICE						
p/p velivolo	**vehicle_type**	**lat**	**lon**	**hqne**	**p_w**	**h_w**	**p_qnh_airport**
911,79	1	41,23174	14,46707	881,040257	1014,87	32	1018
934,12	1	41,21235	14,43168	680,5602635	1014,87	32	1018
897,51	1	41,18708	14,41002	1011,340813	1014,87	32	1018
934,53	1	41,17931	14,34923	676,915705	1014,87	32	1018

FURTHER INPUT
z coord (Gnss input)
937,4168416
735,3901737
1066,449069
731,5028171

Further input has been retrieved from on aircraft board GNSS receiver.

h_qne has been calculated from the pressure measured (**p/ $p_{velivolo}$**) from the vehicle using the following formula:

$$H_{qne} = \frac{T_0}{L}\left[\left(\frac{p_{velivolo}}{p_{QNE}}\right)^{-\frac{LR}{g}} - 1\right]$$

L	-0,0065	K/m
R	287,05287	J / (Kg K)
T0	288,15	K
g	9,80665	m/s^2
P_QNE	1013,25	hPa

DATA RETRIEVED FOR CALCULATION			
country_code	**h_dtm**	**h_dsm**	**n**
EU	80,76526	80,76526	11,5579
EU	56,71756	56,71756	11,4418
EU	217,1746	217,1746	11,4418
EU	185,3411	185,3411	11,4418

OUTPUT OF THE CONVERSION SERVICE				
h_ort	**h_obs_qnh**	**h_agl**	**h_asl**	**h_ell**
925,5994	919,6867	844,8341	844,8341	937,1573
725,325	719,385	668,6074	668,6074	736,7668
1055,766	1049,871	838,5917	838,5917	1067,208
721,6842	715,7437	536,3431	536,3431	733,126

Comparing *h_ell* calculated by the ICARUS VCS service applied to the aircraft and the *h_ell measured* from the GNSS receiver on board (further input), the differences are very low as reported in the table below:

accuracy (m)
-0,259535692
1,376637684
0,759065759
1,6231734

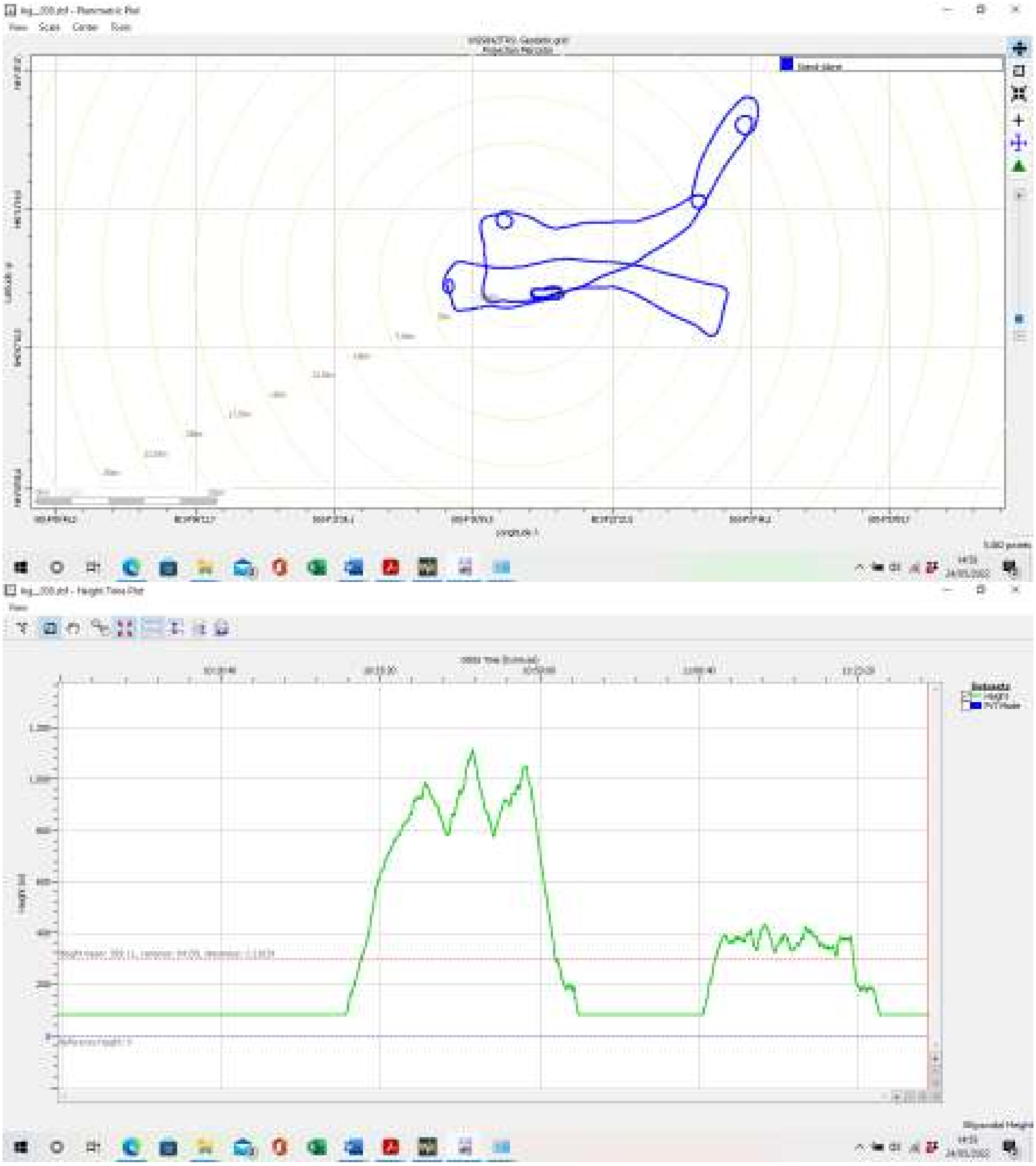


Figure 4-10: Trajectory of aircraft and flight height profiles for the two flights performed

4.3 Scenario 3

This paragraph describes the activities performed in the third validation scenario (S3) which is focused on Urban Air Mobility.

This scenario consisted of a simulated flight carrying passengers from the airport to the city centre in a mixed urban and non-urban environment, validating the following ICARUS micro-services:

- **Real time Geographical Information (RGIS)**
- **Vertical Alert Service (VALS)**

The simulation showed how the remote pilot of a taxi-drone can safely manage the aircraft thanks to accurate ground obstacle information provided by DSM/DTM service and a system that alerts to both obstacles and other manned and unmanned air traffic (VALS).

The mission also showed how an aircraft relates to the height and altitude datum when entering a Common Altitude Reference Area (CARA).

The taxi-drone took off from Torino Caselle Airport, carrying one passenger to the centre of Turin.
The altimeter of the taxi-drone is set to the QFE of Caselle Airport.
In the first part of the mission the taxi drone mostly flew over fields in the countryside. Once it has reached the river Stura, it followed the river for few kilometres until it gets closer to the urban area.
The taxi-drone entered a Zu type airspace, with more relevant ground obstacles and ground risks, and with the possibility of encountering other UAS flights on delivery missions.
The Scenario 3 identifies this area as a CARA (previously named GAMZ), therefore the taxi-drone in the area flew with a common altitude reference set to the WGS-84 datum and expressed in metres.
Finally, the taxi-drone approached its final destination - “Piazza della Repubblica” - and landed.

Figure 4-11: Simulated VTOL departing from Caselle Airport

Figure 4-12: Cockpit of simulated VTOL during the virtual flight

Figure 4-13 - S3, Taxi Drone flight path (Google Earth)

Scenario 3 - Data from flight above Torino

Figure 4-14 - S3, Taxi Drone planned and flown trajectory

The figure above shows a picture of Scenario 3, with the path followed by taxy drone compared to the planned one. Sample points have been chosen near the foreseen waypoints chosen and reported into the D.6.2 Simulation trials execution plan (Table 4 1: S3 - Details of the main waypoints foreseen in the flight plan).

Taxy drone has been treated for the exploitation of ICARUS Services as an aircraft so:

INPUT FOR THE CONVERSION SERVICE						
vehicle_type	**lat**	**lon**	**h_qne (calc)**	**p_w**	**h_w**	**p_qnh_airport**
1	45,188488	7,638572	488,8969888	981,06	287	1015,84
1	45,177456	7,614112	656,228497	981,06	287	1015,84
1	45,149895	7,640082	507,5886571	981,06	287	1015,84
1	45,127312	7,65103	645,856208	981,06	287	1015,84
1	45,120544	7,668937	679,9379302	981,06	287	1015,84
1	45,113922	7,683071	678,5155956	981,06	287	1015,84
1	45,097939	7,685119	702,4548567	981,06	287	1015,84
1	45,080826	7,672043	458,2253901	981,06	287	1015,84
1	45,076538	7,683558	239,1366779	981,06	287	1015,84

FURTHER INPUT
h_msl misured
507
669
524
663
697
697
721
482
253

Further input are the value transmitted by the drone taxy simulator, so the altitude with respect to the mean sea level actually measured.

h_qne has been calculated from the pressure measured (**p/** $\mathbf{p}_{\mathrm{velivolo}}$) using the same formula of Scenario 2.

DATA RETRIEVED FOR CALCULATION			
country_code	**h_dtm**	**h_dsm**	**n**
IT	287,574	287,728	51,971
IT	283,917	283,694	51,971
IT	272,112	274,015	51,478
IT	243,406	252,447	51,159
IT	233,609	244,727	50,987
IT	227,365	227,624	50,628
IT	237,429	237,659	50,628
IT	238,489	271,618	50,257
IT	235,525	235,305	50,257

OUTPUT OF THE CONVERSION SERVICE				
h_ort (calc)	**h_obs_qnh**	**h_agl**	**h_asl**	**h_ellipsoidal**
504,3498135	510,1865585	216,7758135	216,6218135	556,3208135
671,6223429	677,4368107	387,7053429	387,9283429	723,5933429
523,0348937	528,8691502	250,9228937	249,0198937	574,5128937
661,2537098	667,0695585	417,8477098	408,8067098	712,4127098
695,3234193	701,1347306	461,7144193	450,5964193	746,3104193
693,9015861	699,7130867	466,5365861	466,2775861	744,5295861
717,8324094	723,640723	480,4034094	480,1734094	768,4604094
473,6890257	479,529854	235,2000257	202,0710257	523,9460257
254,677535	260,5475309	19,15253497	19,37253497	304,934535

Comparing *h_msl misured* from the on board altimeter (further input) of the drone taxy, and the *h_ort (calc)* calculated by the ICARUS VCS service applied to the aircraft, the differences are very low as reported in the table below:

accuracy
2,650186453
-2,622342907
0,965106277
1,74629017
1,676580727
3,098413916
3,167590623
8,310974334
-1,677534973

4.4 Validation Test-Poland

During the entire project, dozens of unit validation tests were performed. Many of them took place in Poland. For validation purposes, the mobile and stationary setups described in chapter 2.1.2 were used primarily.

Validation tests were carried out by collecting streams of the telemetry data and subjecting them to a decoration process in accordance with the assumptions of the ICARUS project.

The source of the barometric altitude data were primarily provided by ADS-B transponders. The GNSS data source was primary provided by the Aerobits HOD device (https://www.aerobits.pl/product/the-hod-hook-on-device-for-uas/) and the telemetry data stream from various other sources as part of the GOF2 project.

5 Traceability Matrix

In this chapter a second iteration of the ICARUS requirements has been done, considering the outcomes of the verification and the validation phase. When relevant some considerations and findings were reported in the field "Remark" of the attached file excel.

Finally, the traceability matrix of test case vs test requirements is hereafter provided.

5.1 Test Cases vs requirements

Test Case ID (ref. D6.1)	Test Case Title	Req. ID	STATUS	Note
TEST_OPS.GNSS.10	UAS-UAS altitude reference (urban)	ICARUS-D31-0060 ICARUS-D31-0240 ICARUS-D31-0260 ICARUS-D31-0310 ICARUS-D31-0320 ICARUS-D31-0330 ICARUS-D31-0340 ICARUS-D31-0350	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.20	UAS-UAS altitude reference (open sky)	ICARUS-D31-0060	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.30	UAS-UAS altitude reference (continuity)	ICARUS-D31-0060 ICARUS-D31-0220	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.40	UAS-UAS altitude reference (availability)	ICARUS-D31-0060 ICARUS-D31-0230	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.DTM.10	UAS-Ground Obstacle common reference	ICARUS-D31-0070 ICARUS-D31-0090 ICARUS-D31-0100 ICARUS-D31-0210 ICARUS-D31-0380	passed	
TEST_OPS.BARO.10	static GNSS/BARO conversion	ICARUS-D31-0140 ICARUS-D31-0150 ICARUS-D31-0160 ICARUS-D31-0170	passed	

Table 5-1: Test Cases vs Requirements traceability Matrix

5.2 Requirements vs Test cases

ReqID	ReqTitle	ReqText	Test Case ID	Remark
ICARUS-D31-0070	UAS-Ground Obstacles vertical Reference at VLL	Ground Obstacles represented in a given DSM shall be reported and referenced by U-space Geospatial Information Service in the same datum used by UAS for Common Altitude Reference System (WGS-84) Remark Gedetic->Geometric transformations of Buldings and obstacles might be needed to ensure the same reference for all airspace users at VLL	TEST_OPS.DTM.10	
ICARUS-D31-0090	AGL Height information in BVLOS	AGL Height (Above Ground Level) information shall be always visible on UAS pilot's Ground Control Station during BVLOS operations in tactical phase Remark during planning, at least each waypoint shall report its AGL height	TEST_OPS.DTM.10	ICARUS service can be can be conceived also as a planning tool capable to convert the panning information of the mission to a common reference (i.e. AGL height). When designing the route, each actor can use their preferred system
ICARUS-D31-0100	Altitude information in BVLOS	Geometric Altitude (above WGS-84 ellipsoid) information shall be always visible on pilot's Ground Control Station during BVLOS operations for Common Altitude Reference with other UAS	TEST_OPS.DTM.10	WGS-84 datum in combination with the RGIS microservice (Providing real time information of distance to ground) and VALS microservice (providing real time infrmation of possibile impact with ground in the next 60 seconds) is the envisioned datum for CARS for drones in BVLOS conditions. It is reccomended to on UAS Pilot GCS to display Heights wrt to Home point for VLOS operations and Altitude (WGS-84) for BVLOS operations
ICARUS-D31-0150	Geometric-Barometric conversion service update	The Geometric-barometric coversion service must calculate the dynamic offset among WGS-84 and local QNH datum at least every 30'	TEST_OPS.BARO.10	During the validation exercises, the conversion service was update with 1 Hz update
ICARUS-D31-0170	Geometric-Barometric conversion service alert	The Geometric-barometric altitude (VCS) service must warn users in case of malfunctioning in less than 6 seconds	TEST_OPS.BARO.10	
ICARUS-D31-0280	ICARUS prototype service	ICARUS prototype service shall be available for verification and valdiation activities to USSPs involved in the project in the form of a microservice that can be queried through a specific Application Program Interface (API)	S1, S2, S3	API tested with 2 different potential USSPs in validation exercises S1, S2 and S3
ICARUS-D31-0290	ICARUS demonstrator	ICARUS demonstrator shall be capable of showing during the strategic and tactical phase of the flight the following functionalities: - vertical profile of the planned trajectory with respect to the WGS-84 datum and to the ground (terrain, ground obstacles, buildings); - warnings to the manned-aviation pilots and drones in proximity of "CARA"; - 3D model of buildings, ground obstacles and terrain profile in the defined area of simulation. - Display to airspace users, the conversion of reference datum (QNH/WGS-84) through the dedicated service with a simulated communication mechanism	S1, S2, S3	Functionalities showed in the valdiation exercises S1, S2 and S3. Though most of the them where more concentrated on the tactical phase.
ICARUS-D31-0310	Total System Error (Accuracy)	During BVLOS operations, for a straight trajectory (Waypoint 2 Waypoint), according to PBN ICAO definition, it shall possible for UAS to reach a navigation accuracy performance with TSE of about: - 10 meters for the horizontal accuracy for copters; - 3 to 9 meters for the vertical accuracy for copters; - 14 meters for the horizontal accuracy for planes; - 3 to 9 meters for the vertical accuracy for planes;	TEST_OPS.GNSS.10	The requirment was verified only in straight lines or vertical climbing conditions with success. A more comprehnsive analysis should be assessed for manouvers (though other studies already addressed this problem with very similar results
ICARUS-D31-0380	Detailed Surface Model Position Accuracy	Detailed Surface Model accuracy must be: - for urban areas, in the range of [0,50-1,00] m; - for rural areas in the range [5,00 – 10,00] m; - for suburban areas [0,50 – 2,00] m, in case of inspection operations; - for suburban areas [5,00 – 10,00] m, in case of transit;	TEST_OPS.DTM.10	

Table 5-2: Requirements vs Test Cases traceability Matrix

5.3 Update of ICARUS Requirements list

The Requirements list is updated accordingly to the methodology described in §1.3. The Requirements can be found in the attached excel file.

Conclusions

The verification and validation activities demonstrated the feasibility of ICARUS approach for the realization of the CAR service, deployed through a scalable architecture with in three microservices (VCS, VALS,RGIS).

The verification and validation performed on field confirmed in most of the cases the hypothesis made during the simulation activities in the first part of the project. The conclusions and recommendation of this phase can be summarized as follows:

- A proposal of Error Budget for vertical UAS-UAS vertical distance (1 sigma) has been done and validated. This result can be used as starting point for traffic schemas implementation for furture projects
- Operational environment and Navigation performance also in the vertical dimension: The outcomes of ICARUS suggest «corridors dedicated to UAS» inside U-space airspace (EC Regulation 2021/664) providing that a certain navigation performance is achieved, not only in the horizontal plane, but also in the vertical one
- A maximum Number of vertical corridors (layers) at VLL for the capacity assessment can now be assessed
- MFMC GNSS Receiver could be recommended for UAS BVLOS operations in combination with VALS service
- Navigation Monitoring Service Should include CORS (Continuous Operating GNSS Reference station for RTK correction to UASs (identification of a new service provider)
- Proposal for the introduction of CARA (Common Altitude Reference Areas) where VCS (Vertical Conversion Service is expected to operate
- Standardization, best practice and calibration of barometric sensors and certified source on ground (trusted source GIS / METEO)
- DTM/DSM undulation references
- Need to add more data from land pressure stations to reduce the unknown error between real QNH Reference and calculated QNH reference (possible network of ”certified” baro sensors on drones?!)
- Certification of service provider
- GNSS Integrity algorithms to be further investigated for real time application even with dissimilar technologies and cross check correlation
- Certification of GNSS receivers for UAS operations