Atlans R series
Railway Localization Applications
Performance Assessment-PART1

S. Glevarec, L. Poletti, P. d'Harcourt

Summary

Introduction

The European Railway Traffic Management System Group (ERTMS Group) edited in 2023 a global cost benefit analysis[1] which emphasizes the Capital Expenditure & Operational Expenditure (CAPEX/OPEX) benefits which could be brought by the next generation of Localization On-Board Unit (LOC-OBU).

This implies a drastically different LOC-OB architecture than the ones deployed today based on odometry, radars, physical balises and track circuits used as the fix blocks management (so called track occupancy management).

The established geo-positioning technologies of Global Navigation Satellites Systems, Inertial Navigation System, with its inertial components (Inertial Measurement Unit) coupled with Digital Mapping of the railway network are the focus of deep investigation as the localization game changers in this next generation LOC-OB scenario by many industrial players and research consortia worldwide.

On another hand, the train localization for non-critical applications – such as traffic management, driver advisory systems, passenger information on-board and at station, metrology on-board, etc…- needs to be renewed for better efficiency, robustness, performance, and availability compared to the ones in use today. This system, so called a LOC-OB for non-critical applications, must provide an “all-in-one system” more accurate and finally, a more reliable position, speed, and attitudes “everywhere and all the time” in all conditions (weather, ionospheric-tropospheric conditions…), whatever the locomotive types (urban, regional, high-speed…) or the physical and railway infrastructures (forests, mountains, tunnels, buildings, stations in urban area, etc…).

Exail is a worldwide reference in inertial components (Fiber Optic Gyroscopes & Micro Electro-Mecanic Accelerometers manufacturer) and in inertial navigation systems and has developed and deployed its innovative and robust on-board solutions dedicated for the railway train localization market.

Exail offers to their customer the best position, speed and attitude performance for any railway applications in real-time delivering continuous and reliable localization performance whatever the localization zone (tunnel, canopy, dense urban zone, depot zone, suburban & high-speed train…).

Exail is also deeply engaged in the next generation LOC-OB architecture for critical applications through the LOC4RAIL project as the manager and the inertial solutions developer. The results of the LOC4RAIL project studies are available on website page: www.exail.com/rail.

The present document summarizes the train positioning performance obtained with the **Exail Atlans R7** product installed on-board for more than two years. It is the solution for the non-critical applications. This product can be supplied off the shelf today and is ready to be widely deployed.

The results presented in this technical note (PART1) come from the analysis of data collected over the period 2021-2023 during more than 100,000 km of rail journeys on the French rail network. The **Exail Atlans R7** product has been deployed on board the Paris suburban trains (RER), Regional intercity trains (TER) and high-speed trains (TGV).

[1] RCA.Doc.071 Business case for the Track Occupancy Concept_V2.0.1_Public

Results synthesis

This first part of massive data analysis collected during the past two years on-board of trains across the French rail network demonstrate the relevant role of Atlans product for non-critical localization applications.

Whatever the climatic conditions (snow, wind, rain...), whatever the train types (High-speed train, regional train, suburban train), whatever the human infrastructures (tunnels, bridges, stations…) and the natural constraint (mountains, rivers…), the performance remains in the same scope of performance.

These results synthesis in the table below is computed for two years on-board and on more than 84000km rides and 2000hours and cover the use cases as follow:

- UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case
- UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case
- UC3- HIGH-SPEED & NATIONAL use case

Trains & Lines	**Along-track (m) 2σ (95%)**			**Across-track (m) 2σ (95%)**			**Forward speed (m/s) 2σ (95%)**		
Performance requirements for Along-track Speed forward Attitudes	UC1	UC2	UC3	UC1	UC2	UC3	UC1	UC2	UC3
	2.2	1.3	2.3	1.7	1.3	1.7	0.019	0.017	0.028
	Heading (°) 2σ (95%)			**Roll (°) 2σ (95%)**			**Pitch (°) 2σ (95%)**		
For more than 95% of data transmitted (2σ)	UC1	UC2	UC3	UC1	UC2	UC3	UC1	UC2	UC3
± 10 m ± 2km/h (± 0.55m/s) ± 0.5 °	0.044	0.066	0.053	0.019	0.012	0.012	0.013	0.035	0.077

Figure 1. Performance synthesis over 84000km and 2000hours rides on French rail network

This analysis focuses on navigation performance where train is in motion most of the time.

One of the next analyses will focus on STANDSTILL performance during train stops and when the train remains a long time at station: this is another relevant scenario for non-critical and critical applications. It will be reported in PART2 assessment note available soon.

Another analysis will focus on performance including inertial virtual balise method (Exail patent). This method has been integrated for critical applications in LOC4RAIL architecture (refer to Exail website) but can also be used for non-critical applications; This analysis will be reported in PART3 and will be available soon.

Set up and reference

The set-up was made up with:

- Atlans R7 product installed on board the trains,
- Railway Data Analysis Platform[2] [RDA Platform] Software including Exail DelpHINS Software for Post-processing data and reference data management.

Atlans R7 rack

The rack Atlans R7[3] used for these applications is a 3U railway standards rack (EN50155) with:

- an inertial navigation system Atlans A7 natively including a GNSS receiver board,
- a railway DCDC power supply (from 24VDC up to 110VDC),
- an embedded Computer-4G link and hard disks.

This rack is easily installed on board a train and is connected to on-board power supply, a GNSS antenna and a wheel sensor (optional). With 4G antenna, the rack automatically transfers data from the internal datalogger to a customer server via embedded software for later analysis with Exail Delph INS software tools at customer lab.

Railway Data Analysis Platform (RDA Platform)

The live-continuous real time data and the post-processing data can be uploaded easily to a customer cloud data server for later analysis with Delph INS software set and/or supported by Exail's team using its dedicated Railway Data Analysis Platform for big data analysis more adapted for numerous rides.

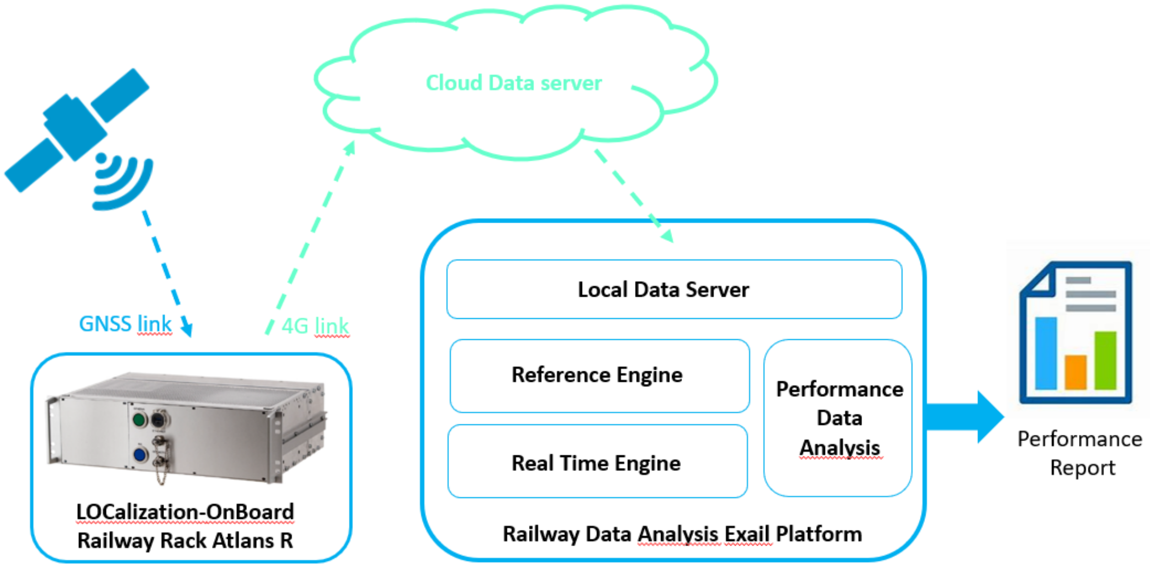


Figure 2. Railway Data Analysis Platform and global Set with Atlans-R on board

---

[2] Only Delph INS software and RDA reports are supported as products & services for customer.
[3] Technical documentation 00018324 - Atlans R7 technical description

The Railway Data Analysis Platform is able to:

- Upload data from the customer cloud data server to dedicated Exail analysis server,
- Treat and post-process the data for:
    - Ground truth generation using the reference engine API,
    - Live and real time position [LA, LO, height, along-track, across-track], speed [northing, easting, along-track] & attitudes [heading, roll, pitch] replayed,
    - Generic information and graphs for a global performance overview (rides duration, distance travelled, cumulative errors and standard deviation, map performance projection, navigation system and GNSS performance)

Direct analysis and configuration could also be done with the Exail advanced post-processing Delph INS software[4] as depicted below.

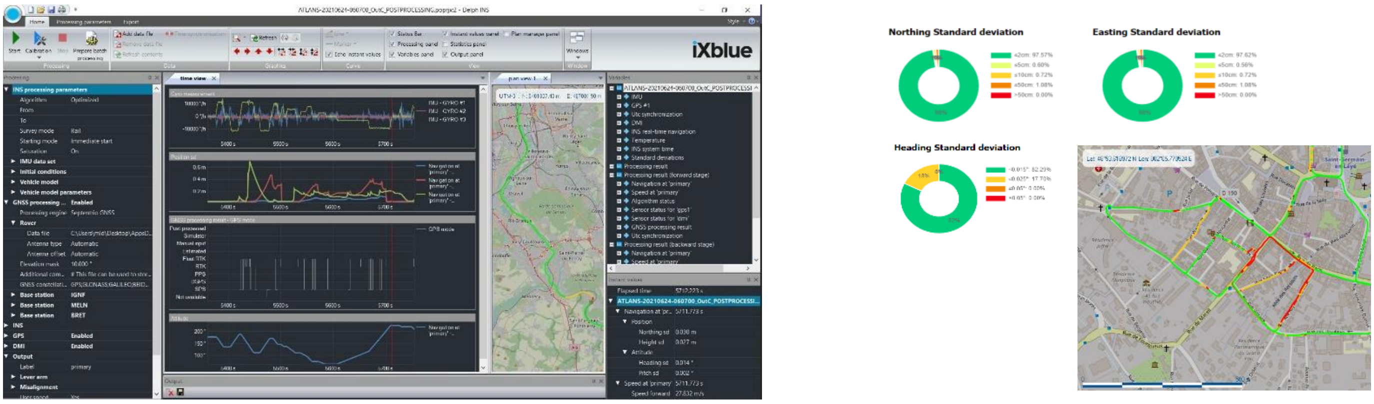


Figure 3. MMI for configuration, replay and data analysis.

Track records

Extensive records have been collected during the past two years on French network on board trains (High-speed trains, Paris suburban trains and regional trains). Exail as leader of LOC4RAIL project supported by ADEME agency (French Ecology Ministry) and SNCF innovation & research partner allowed Atlans R7 installation on board and data upload for extensive mass data analysis.

Figure 4. Atlans R7 installed on board – installation and France Map with all rides period 2021-2023 overview.

[4] Delph INS Software technical description

Train localization use cases

The results are presented in the chapters below and cover large spectra of the train localization use cases as follow:

- DEEP URBAN & REGIONAL HIGH DENSITY use cases (UC1)
- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use cases (UC2)
- HIGH-SPEED & NATIONAL use cases (UC3)

DEEP URBAN & REGIONAL HIGH DENSITY use case emphasizes the resilient performance of the inertial Atlans R7 solution in long tunnels or when GNSS is not reliable (under canopy and bridges, covers at station, etc…); majority of disturbed GNSS reception area, many short stops and very dense urban area.

LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case for standard regional performance with a TER train speed at medium density traffic and medium/large towns (Bordeaux, Limoges, Saintes, etc…) including few short stops at station and mostly open-sky conditions.

HIGH-SPEED & NATIONAL use case for high-speed performance (up to 320km/h) at medium density traffic, national network, medium/dense towns (Paris, Strasbourg, Nice…) including a few short station stops and majority open-sky area.

The main performance requirements in “track coordinates” as position of train (along-track position), attitudes and speed of the train (forward speed) for each use cases are reported in the table below[5].

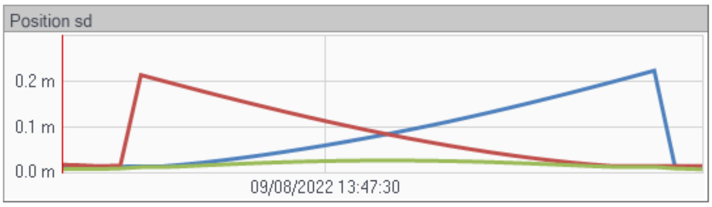
Non-critical applications performance	**For more than 95% of data transmitted (2σ)**
Along-track position	± 10 m
Speed forward	± 2km/h (± 0.55m/s)
Attitudes	± 0.5 °

[5] Requirements from Loc4Rail project - L2.2.2 – System specification – consolidated version – 2021-10-03 SNCF documentation

Reference trajectories

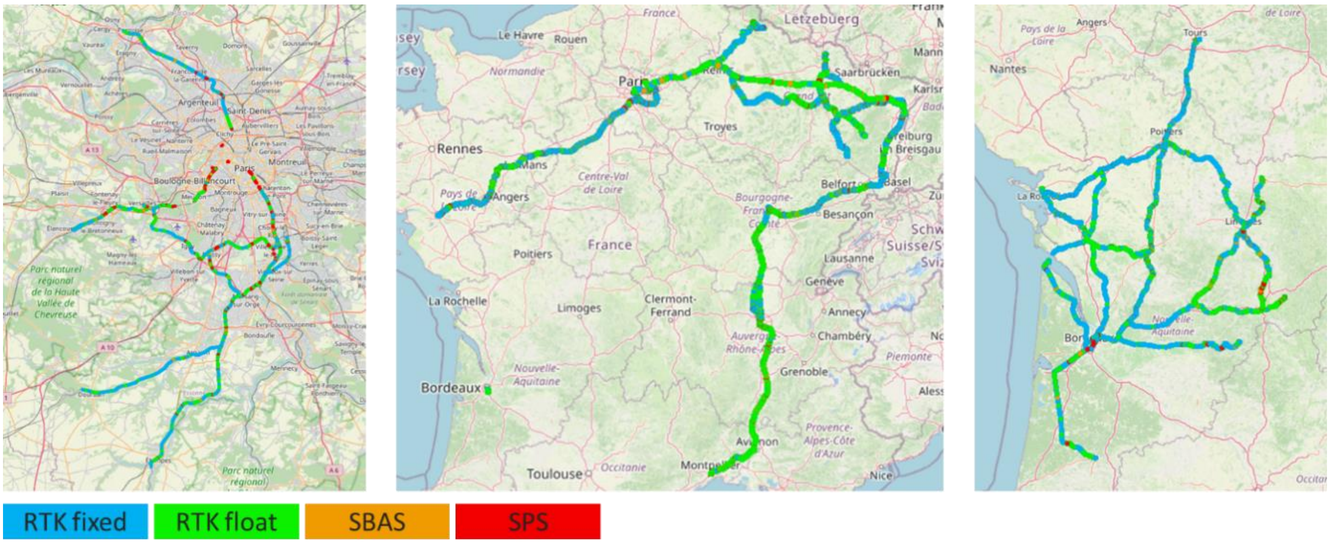
All the use cases performance presented in this note are the results from the difference between the replayed real-time trajectory, so-called forward trajectory (which is equivalent to real time), and its reference trajectory as ground truth, so-called the optimized trajectory computed massively with post-processing software (PP-RTK Exail Delph INS tools and railway data analysis).

The optimized trajectories are generated from all the raw data collected (GNSS raw data and IMU raw data) with RTK database from IGN (French National Geographic Institute) and with the optimization process: merging result (in



green) between the forward replay trajectory (chronological run in blue) and the backward replay trajectory (anti-chronological run in red) with the same data.

This process is computed on all rides (more than 100.000 kms) through a large geographical area with a various availability of GNSS modes (Natural, SBAS, RTK float, RTK fix) as shown in the geographical view below.



The table below gives the GNSS mode percentage value computed during these same rides*.

% value of all rides		None	Natural	SBAS	RTK Fix	RTK Float
UC1-Deep Urban & Regional High-Density Lines	Mean	14%	7%	5%	50%	24%
424hrs/8086km rides	Max	33%	14%	38%	91%	52%
	Min	0%	2%	1%	21%	3%
UC2-Light Urban & Medium Low-Density Lines	Mean	1%	4%	4%	67%	24%
953hours/36300km rides	Max	3%	20%	41%	98%	55%
	Min	0%	1%	0%	29%	1%
UC3-High-speed & National Lines	Mean	1%	4%	4%	51%	40%
532hours/39831km rides	Max	6%	22%	18%	84%	67%
	Min	0%	1%	0%	22%	13%

Figure 5. GNSS modes availability observed during rides analysed.

**Max and Min in the table are obtained on one trajectory of the set of trajectories for each GNSS mode and Mean value in the table stand for all trajectories analysed*

Despites the large variety of GNSS signal quality and modes during these rides - as shown in the graphic views and table above – the track references generated from Atlans R7 raw data remain relevant for massive data analysis and performance estimation.

As shown in the table hereafter, a good ratio between reference and the non-critical requirements still maintained:

- The 2D-Horizontal reference standard deviation values (2D Horizontal) are maintained under half a meter,
- The speed forward reference standard deviation values are maintained under 0,006m/s,
- The attitudes (heading, roll, pitch) reference standard deviation values are maintained under 0,02°.

For Note: improvement of the reference performance especially for UC1-deep urban lines in position is easily possible with a higher grade of FOG INS (better performance under tunnels than FOG Atlans A7 FOG).

	2D Horizontal (m)			Forward speed (m/s)		
Trains & Lines	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
UC1-Deep urban lines Paris RER trains	0.48	1.4	1.7	0.006	0.015	0.019
UC2-Regional lines TER Regional trains	0.25	0.5	0.7	0.005	0.009	0.015
UC3-High-speed lines TGV High-speed trains	0.45	0.83	1.1	0.006	0.01	0.018
	Heading (°)			**Roll (°) / Pitch (°)**		
Trains & Lines	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
UC1-Deep urban lines Paris RER trains	0.02	0.03	0.035	0.006	0.009	0.01
UC2-Regional lines TER Regional trains	0.01	0.009	0.03	0.005	0.008	0.009
UC3-High-speed lines TGV High-speed trains	0.02	0.03	0.03	0.005	0.009	0.01

Figure 6. Reference trajectories Standard Deviation performance (mean value)

Figure 7. Example of UC1-PARIS SUBURBAN RIDE reference track in blue (Google earth View)

Results

UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case

PARIS SUBURBAN AREA RER LINE C rides on more than 424 hours rides.

UC1- Suburban Paris - RER line C data characteristics	
Distance travelled	8086 KM – 424 hours of rides
Typ. speed forward	Typ. 80km/h incl. many stops at stations
From To Cities through Paris Intra- muros	DOURDAN - ELANCOURT – ETAMPES – PONTOISE - VERSAILLES
GNSS not available or unreliable %	Typ. 18% w/o GNSS (tunnel and dense suburban area)
Rides characteristics	Large zone under tunnel and under cover stations, presence of the Seine River and dense urban environment, many short stops/start at stations (metropolitan conditions)

GNSS Coverage analysis

For the real time non-critical localization, the GNSS modes are aggregated from the four constellations available (GPS, GALILEO, BEIDOU and GLONASS) thanks to the receiver board configuration of the Atlans R7 rack and are selected as only free augmentation services. Then, SBAS EGNOS which covers the UC1 area as well is the unique free augmentation service used in real time for this analysis. It could be relevant in the future to update it with the new free HAS Galileo service (when available) or with no-free other services (RTK, PPP…).

In the UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case, the global and average score along all the rides (inside and outside dense suburban and Paris urban area) is 71% of EGNOS SBAS, 11% of NATURAL and 18% unavailable.

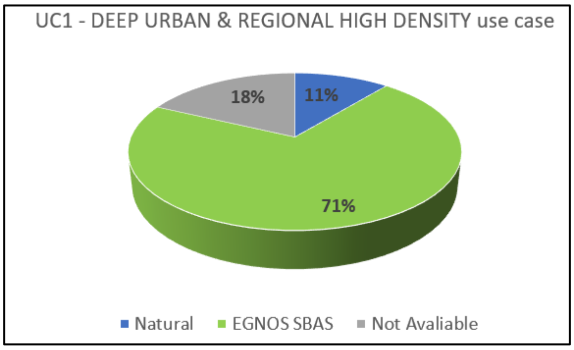


Figure 8. Score of GNSS modes for global UC1 rides and geographical view

In the UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case, this score becomes significantly worse (less than 30% coverage in the unique and not accurate NATURAL GNSS mode) when focussed in Paris and in its nearest vicinity areas as shown in the picture below.

Figure 9. GNSS Dark Zone inside Paris

Therefore, the added value in performance and in availability is totally covered with inertial Atlans product as the graphical Google earth view shown below.

Figure 10. No More Zone inside Paris with Atlans

Percentile Error Performances

The data in this table are the ones collected from the cumulative error graph depicted in the chapter below 'Cumulative Error Performances'.

The UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case 'Percentile Error Performances' table is the result of 8086km and 424hours of rides which are equivalent to more than 1,5. 10^9 data samples collected (@1Hz rate).

As shown in the table hereafter, the results are fully compliant with the non-critical performance requirements and remain totally compliant even after standard deviation reference errors:

- The Along-track error of 2,2m(95%) is better than 4 times the requirements (10m@95% with 2σ-ref <2m),
- The Speed forward error of 0,02m/s (95%) is better than 20 times the requirements (0,55m/s@95% with 2σ-ref <0,015m/s),
- The Attitudes (Heading, Roll, Pitch) error of 0,044° max (95%) is better than 10 times the requirements (0,5°@95% with 2σ-ref <0,03°).

Trains & Lines	**Along-track (m)**			**Across-track (m)**			**Forward speed (m/s)**		
UC1-Deep Urban Lines Paris RER trains	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.75	2.2	4.9	0.61	1.7	4.1	0.004	0.019	0.045
	Heading (°)			**Roll (°)**			**Pitch (°)**		
	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.012	0.044	0.12	0.005	0.019	0.05	0.006	0.013	0.051

Figure 11. Percentile Error Performances UC1 scenario

The Across-track error remains under 1,75m (95%) [under the middle between two tracks – 3,5m distance separation between tracks] meaning that track-selectivity is natively delivered by Atlans of more than 95% of the data collected all over the RER line C rides and network.

Exail innovative map matching including virtual inertial attitudes balises is not implemented in this mass data analysis and could demonstrate that 100% could easily be covered with this method (upgrade assessment is planed).

Cumulative Error Performances

The UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case 'Cumulative Error Performances' curves are the result of 8086km and 424hours of rides which are equivalent to more than 1,5. 10^9 data samples collected (@1Hz rate) and for all parameters; along-track and across-track errors, speed froward error, heading, roll and pitch errors.

Vertical axis stands for standard-deviation percentile value, horizontal axis stands for error expressed respectively in meters (along and across track error); meters per second (speed forward) and degrees (attitudes).

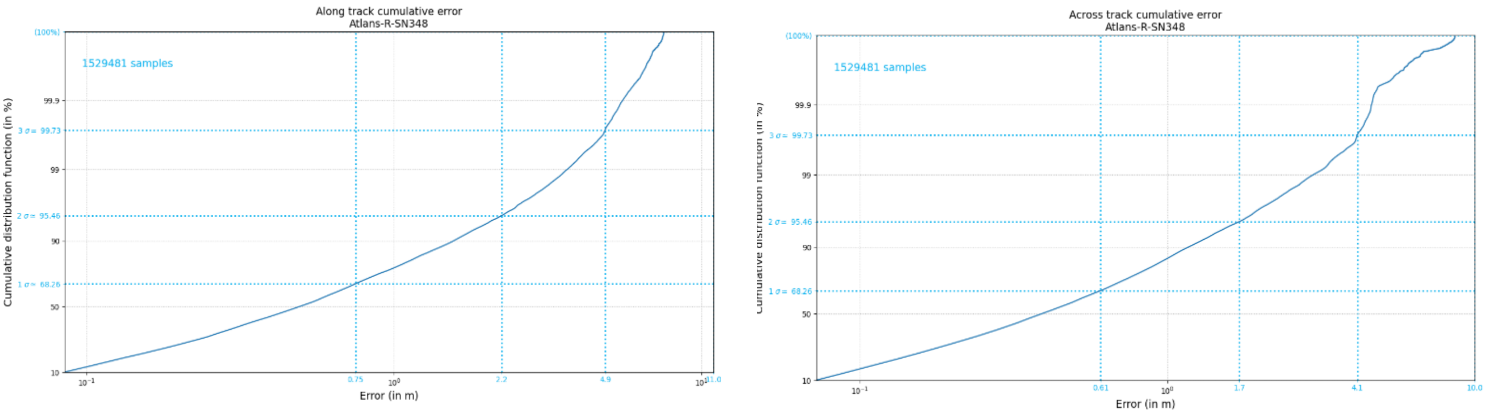


Figure 12. Along-track and Across-track cumulative errors graphs

For additional remarks, it is interesting to note that the maximum value of along-track error remains lower than 11m all along the rides computed.

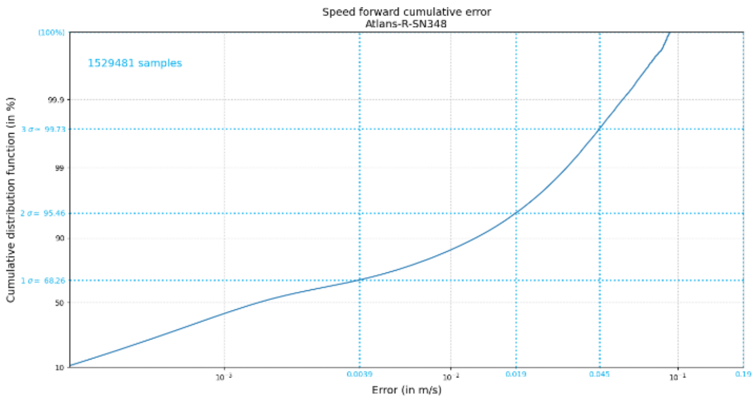
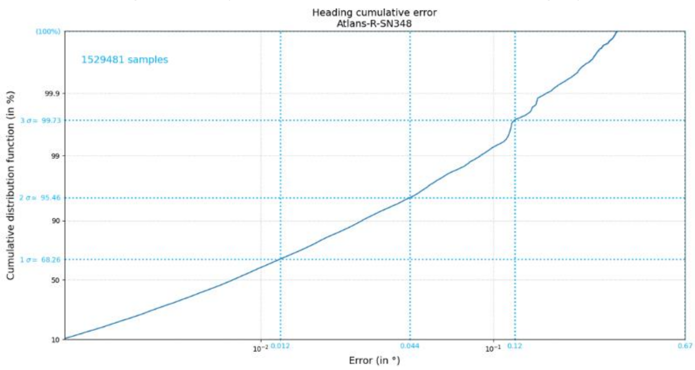


Figure 13. Speed Forward cumulative errors graph



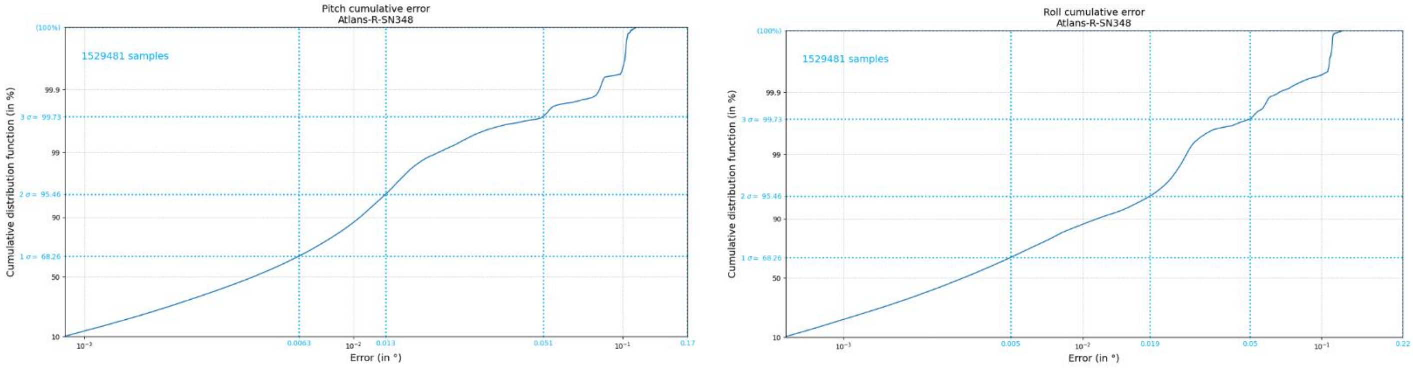


Figure 14. Atitudes cumulative errors graph

Geographic along-track error view

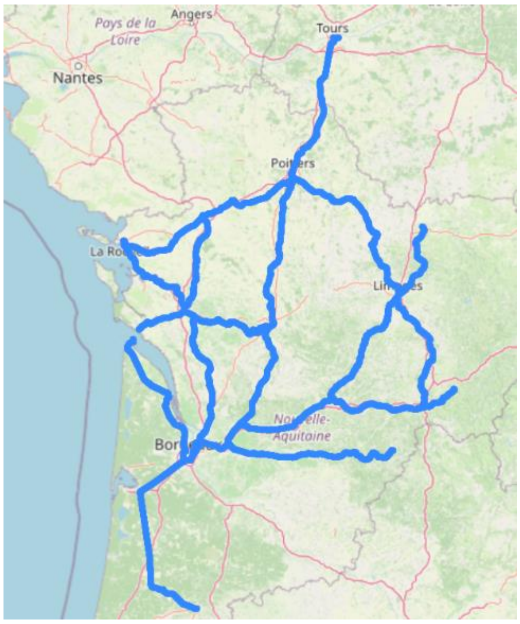
Figure 15. Along-track error geographical view

The geographical view shown in this chapter is the along-track error.

The UC1- DEEP URBAN & REGIONAL HIGH DENSITY use case analysis demonstrates the utmost advantage of Atlans for this non-critical localisation applications scenario; its total availability during all the rides, total continuity of the data delivered and its 100% compliance to performance requirements in Position, Speed and Attitudes.

UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case

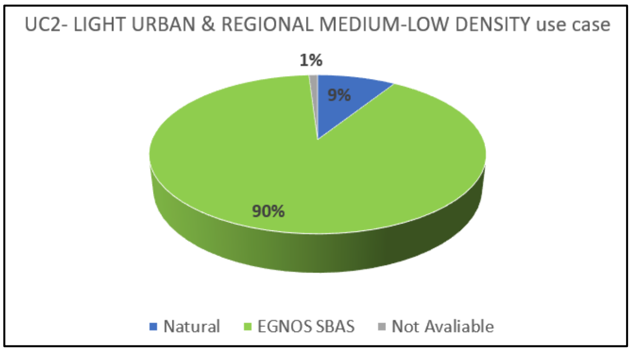
UC2- REGIONAL& MEDIUM-LOW DENSITY	
Distance travelled	36300 KM – 953 hours of rides
Typ. Speed forward	Typ. 140km/h incl. many stops at stations
From To Cities	BORDEAUX-LIMOGES-SAINTES-MONT-DE-MARSAN- PERIGUEUX
GNSS not available nor unreliable %	Typ. 90% SBAS GNSS
Rides characteristics	Open sky conditions, medium rides at medium-speed, stops at regional stations.



GNSS Coverage Analysis

For the real time non-critical localization, the GNSS modes are aggregated in the same way as explained in 'GNSS Coverage Analysis' in UC1 scenario.

In the UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case, the global and average score along all the rides (inside and outside dense suburban and Paris urban area) is 90% of EGNOS SBAS, 9% of NATURAL and 1% unavailable. This environment fits very well as an Open-Sky scenario.



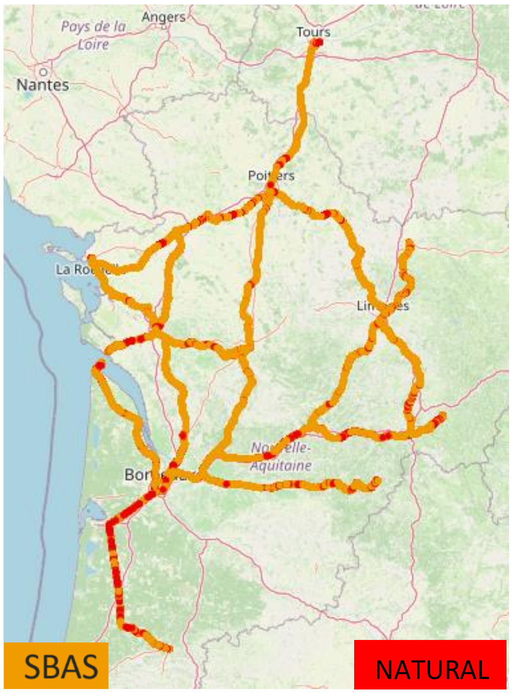


Figure 16. Score of GNSS modes for global UC2 rides and geographical view

Nevertheless, some specific areas are not well covered and impacts the global performance especially at station when partial or complete roofs are present. The spatial reflexions of GNSS signals affect the global GNSS performance.

This is particularly demonstrated in the figure showing the result of position performance at Bordeaux station where train location is partially covered by the roof.

The black points are measured up to 150m 2D-horizontal RMS.

In this scenario, the Atlans performance will erase these defaults and will provide a compliant localisation wherever the train is located in the station area.

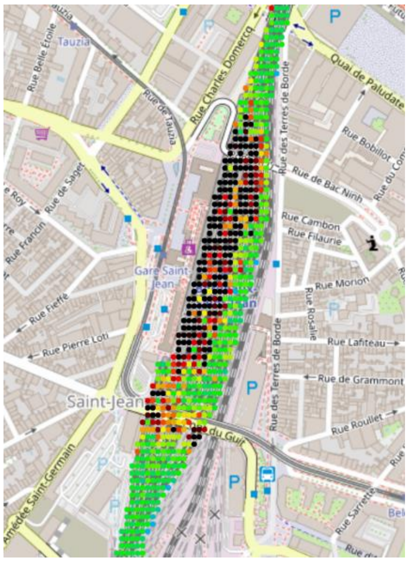


Figure 17. GNSS error at station

Percentile error performances

The data in this table are the ones collected from the cumulative error graph depicted in the chapter below 'Cumulative Error Performances'.

The UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case 'Percentile error performances' table is the result of 36300km and 953hours of rides which are equivalent to more than 3,4. 10^9 data samples collected (@1Hz rate).

As shown in the table hereafter, the results are fully compliant with the non-critical performance requirements and remain totally compliant even after standard deviation reference errors:

- The Along-track error of 1,3m(95%) is better than 6 times the requirements (10m@95% with 2σ-ref <2m),
- The Speed forward error of 0,017m/s (95%) is better than 20 times the requirements (0,55m/s@95% with 2σ-ref <0,015m/s),
- The Attitudes (Heading, Roll, Pitch) error of 0,066° max (95%) is better than 5 times the requirements (0,5°@95% with 2σ-ref <0,03°).

Trains & Lines	Along-track (m)			Across-track (m)			Forward speed (m/s)		
UC2- Light Urban & Regional Medium-Low Density	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.54	1.3	4.1	0.52	1.3	4.0	0.004	0.017	0.041
	Heading (°)			**Roll (°)**			**Pitch (°)**		
	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.012	0.066	0.2	0.005	0.012	0.049	0.008	0.035	0.061

Figure 18. Percentile Error Performances UC2 scenario

The Across-track error remains under 1,75m (95%) [under the middle between two tracks – 3,5m distance separation between tracks] meaning that track-selectivity is natively more than 95% of the data collected all over the TER Nouvelle Aquitaine rides and network.

Exail innovative map matching including virtual inertial attitudes balises is not implemented in this mass data analysis and could demonstrate that 100% could easily be covered with this method (upgrade assessment planed).

Cumulative error performances

The UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case 'Cumulative error performances' curves are the result of 36300km and 953hours of rides which are equivalent to more than 3,4. 10^9 data samples collected (@1Hz rate) and for all parameters; along-track and across-track errors, speed forward error, heading, roll and pitch errors.

Vertical axis stands for standard-deviation value, horizontal axis stands for error expressed respectively in meters (along and across track error); meters per second (speed forward) and degrees(attitudes).

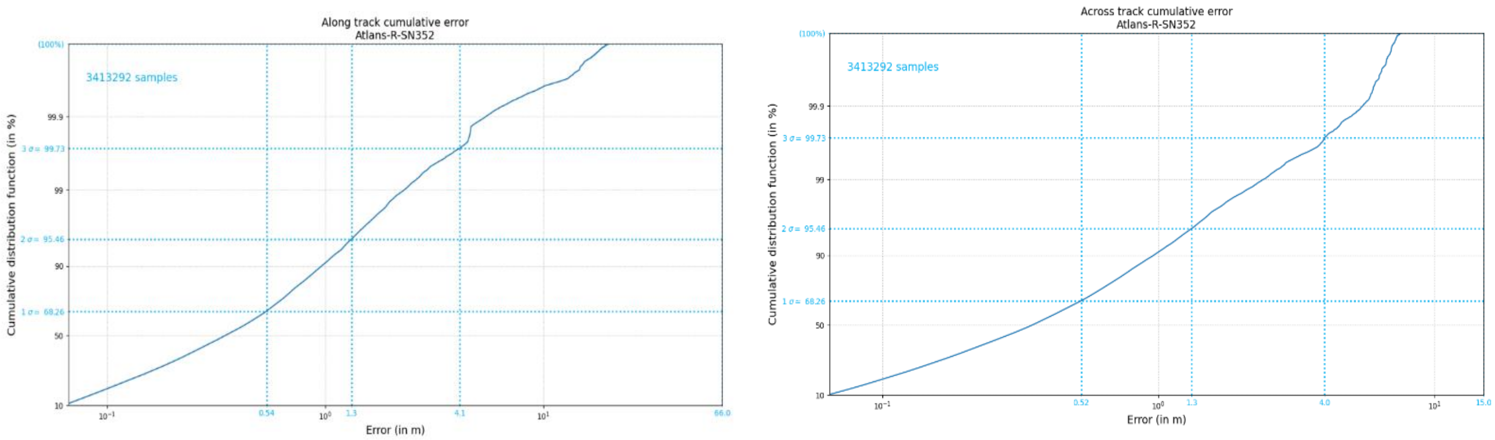


Figure 19. Along-track and Across-track cumulative errors graphs

For additional remarks, it is interested to note that the majority of along-track error remains lower than 10m all along the rides computed (>99,95%).

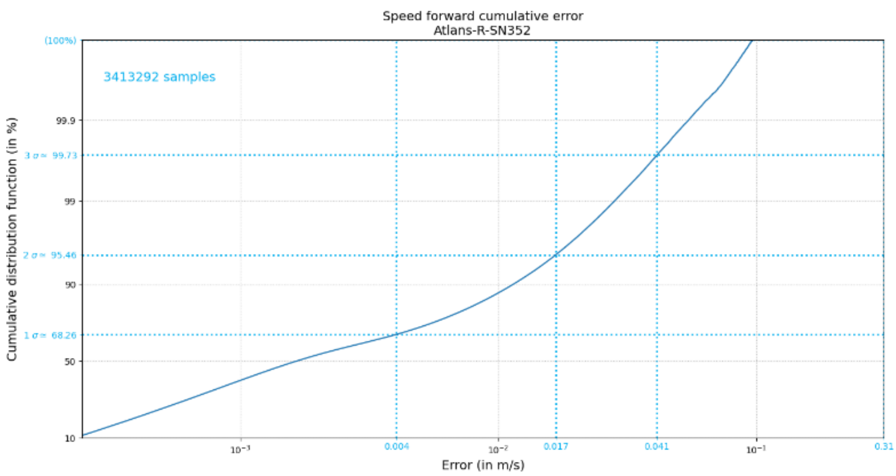


Figure 20. Speed Forward cumulative errors graph

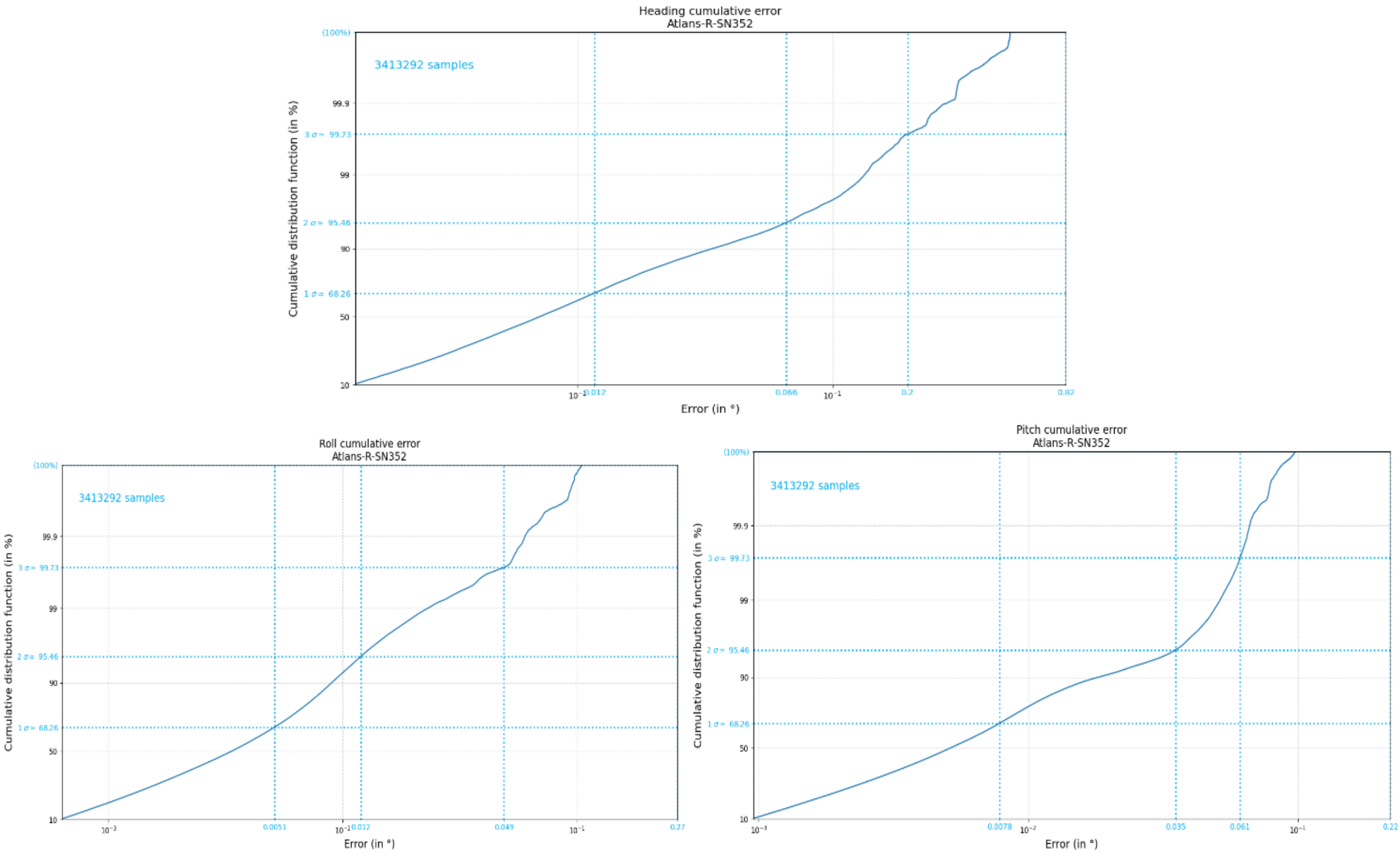


Figure 21. Atitudes cumulative errors graph

Geographic along-track error view

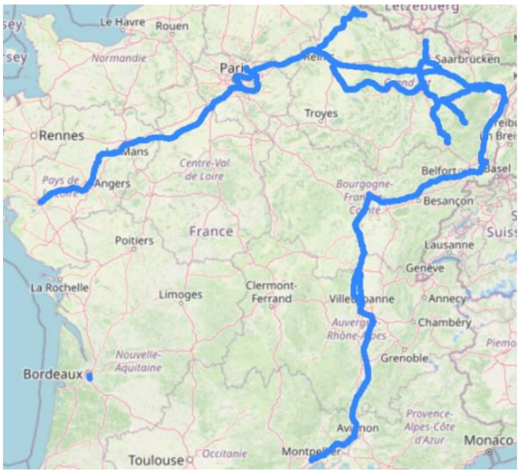
The geographical view shown in this chapter is the along-track error.

The UC2- LIGHT URBAN & REGIONAL MEDIUM-LOW DENSITY use case analysis demonstrates the utmost advantage of Atlans for this non-critical localisation applications scenario; its total availability during all the rides, total continuity of the data delivered and its 100% compliance with performance requirements in Position, Speed and Attitudes.

Figure 22. Along-track error geographical view

UC3- HIGH-SPEED & NATIONAL use case

UC3- National & High-Speed Lines	
Distance travelled	39831 KM – 532 hours of rides
Typ. Speed forward	Typ. 300km/h incl. stops at stations
From To Cities	RENNES-NANTES-NICE-MARSEILLE-METZ- STARSBOURG-MONTPELLIER
GNSS not available nor unreliable %	Typ. 85% SBAS GNSS
Rides characteristics	Long rides at high-speed, long stops at national stations, straighter lines than metropolitan use cases.



GNSS coverage analysis

For the real time non-critical localization, the GNSS modes are aggregated in the same way as explained in 'GNSS Coverage Analysis' in UC1 scenario.

In the UC3- HIGH-SPEED & NATIONAL use case, the global and average score along all the rides (inside and outside dense suburban and Paris urban area) is 85% of EGNOS SBAS, 14% of NATURAL and 1% unavailable. This environment fits very well as an Open-Sky scenario.

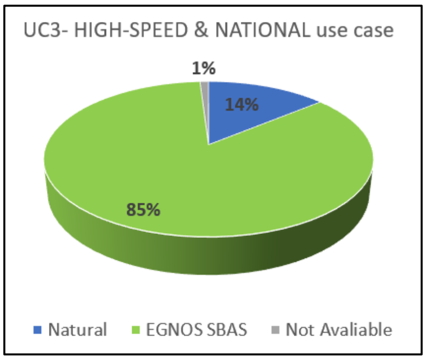


Figure 23. Score of GNSS modes for global UC3 rides and geographical view

Nevertheless, the same sensitivity observed in the UC2 scenario will affect the global performance. Indeed, some specific areas are not well covered and impacts the global performance especially at station when partial or complete roofs are present. The multipath and spatial reflexions GNSS signal will affect the global GNSS integrity and then performance.

This is particularly observed in TGV station where the station is very often fully covered and at the vicinity of mountains (many case in Côte d'Azur); the GNSS integrity performance (ratio between GNSS standard deviation and its real position) at station where train location is then affected strongly. In these cases, GNSS technology loses its reliability.

In this scenario, the Atlans R7 performance will overcome these faults and will provide a continuous compliant localisation wherever the train is located in station area.

Percentile error performances

The data in this table are the ones collected from the cumulative error graph depicted in the chapter below 'Cumulative error performances'.

The UC3- HIGH-SPEED & NATIONAL use case 'Percentile error performances' table is the result of 39831km and 532hours of rides which are equivalent to more than 1,9. 10^9 data samples collected (@1Hz rate).

As shown in the table hereafter, the results are fully compliant with the non-critical requirements and remain totally compliant even after adding the reference standard deviation errors:

- The Along-track error of 2,3m(95%) is better than 3 times the requirements (10m@95% with 2σ-ref <2m),
- The Speed forward error of 0,028m/s (95%) is better than 10 times the requirements (0,55m/s@95% with 2σ-ref <0,015m/s),
- The Attitudes (Heading, Roll, Pitch) error of 0,077° max (95%) is better than 5 times the requirements (0,5°@95% with 2σ-ref <0,03°).

Trains & Lines	**Along-track (m)**			**Across-track (m)**			**Forward speed (m/s)**		
UC3- High-Speed & National	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.86	2.3	9.0	0.69	1.7	3.5	0.008	0.028	0.077
	Heading (°)			**Roll (°)**			**Pitch (°)**		
	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)	σ (68%)	2σ (95%)	3σ (99.7%)
	0.015	0.053	0.11	0.005	0.012	0.049	0.034	0.077	0.11

Figure 24. Percentile Error Performances UC3 scenario

The Across-track error remains under 1,75m (95%) [under the middle between two tracks – 3,5m distance separation between tracks] meaning that track-selectivity is natively delivered by Atlans of more than 95% of the data collected all over the High-Speed lines rides and network.

Exail innovative map matching including virtual inertial attitudes balises is not implemented in this mass data analysis and could demonstrate that 100% could easily be covered with this method (upgrade assessment planed).

Cumulative error performances

The UC3- HIGH-SPEED & NATIONAL use case ‘Cumulative error performances’ curves are the result of 39831km and 532hours of rides which are equivalent to more than 1,9. 10^9 data samples collected (@1Hz rate) and for all parameters; along-track and across-track errors, speed froward error, heading, roll and pitch errors.

Vertical axis stands for standard-deviation value, horizontal axis stands for error expressed respectively in meters (along and across track error); meters per second (speed forward) and degrees(attitudes).

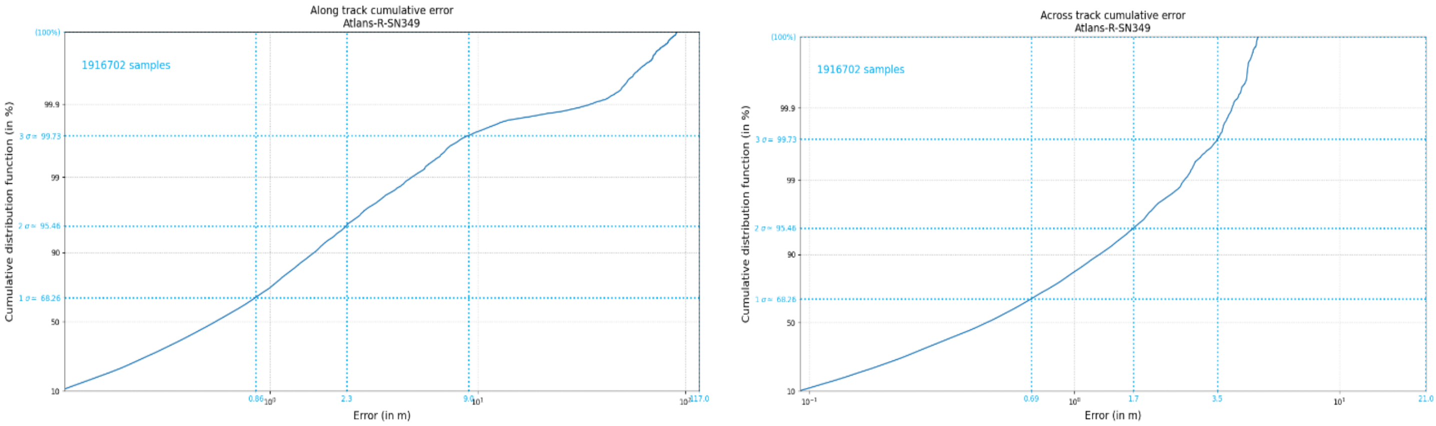


Figure 25. Along-track and Across-track cumulative errors graphs

For additional remarks, it is interested to note that the majority of along-track error remains lower than 10m all along the rides computed (>99,7%).

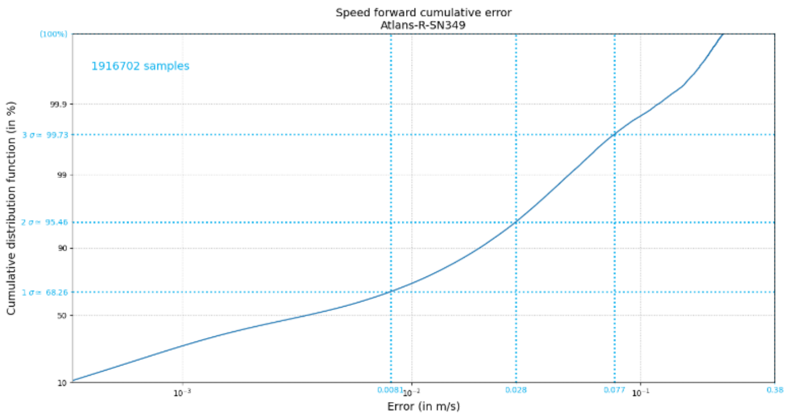


Figure 26. Speed Forward cumulative errors graph

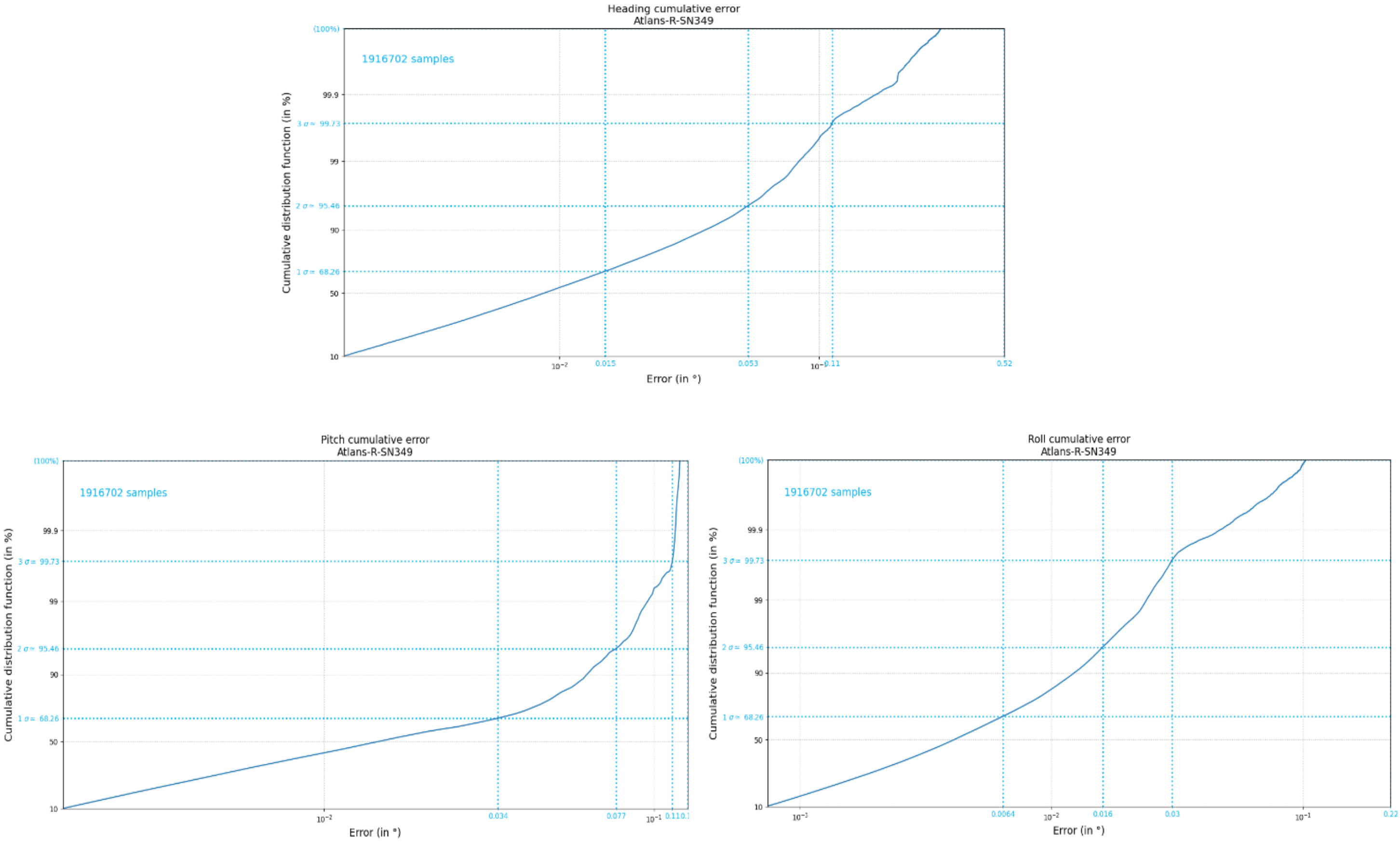


Figure 27. Atitudes cumulative errors graph

Geographic along-track error view

The geographical view shown in this chapter is the along-track error.

The UC3- HIGH-SPEED & NATIONAL use case analysis demonstrates the utmost advantage of Atlans for this non-critical localisation applications scenario; its total availability during all the rides, total continuity of the data delivered and its 100% compliance with performance requirements in Position, Speed and Attitudes.

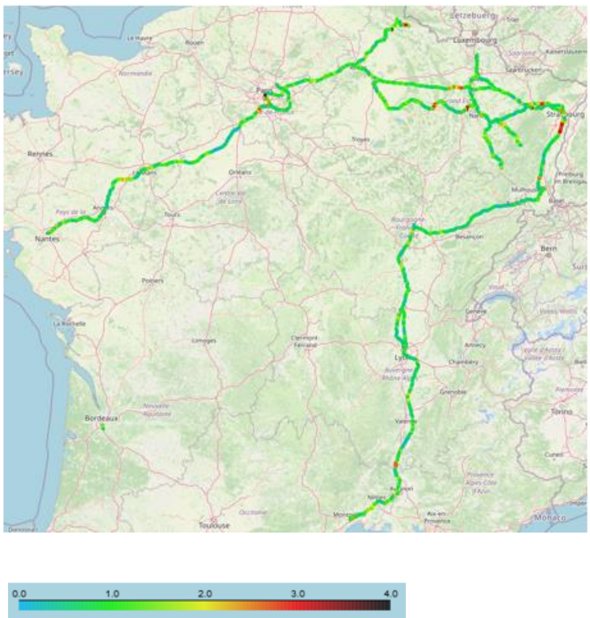


Figure 28. Along-track error geographical view