FP: Final Presentation

NAVISP-EL3-011: In-Orbit Demonstration of PPP on-board NorSat-TD

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FGO-SS-NORTD-FP v1.0 | 20.06.25

Project Summary

Objective:	In Orbit Demonstration of PPP onboard NorSat-TD
Contractor:	StatSat AS
Sub-Contractor:	Fugro Norway AS
Start:	May 2020
End:	June 2025

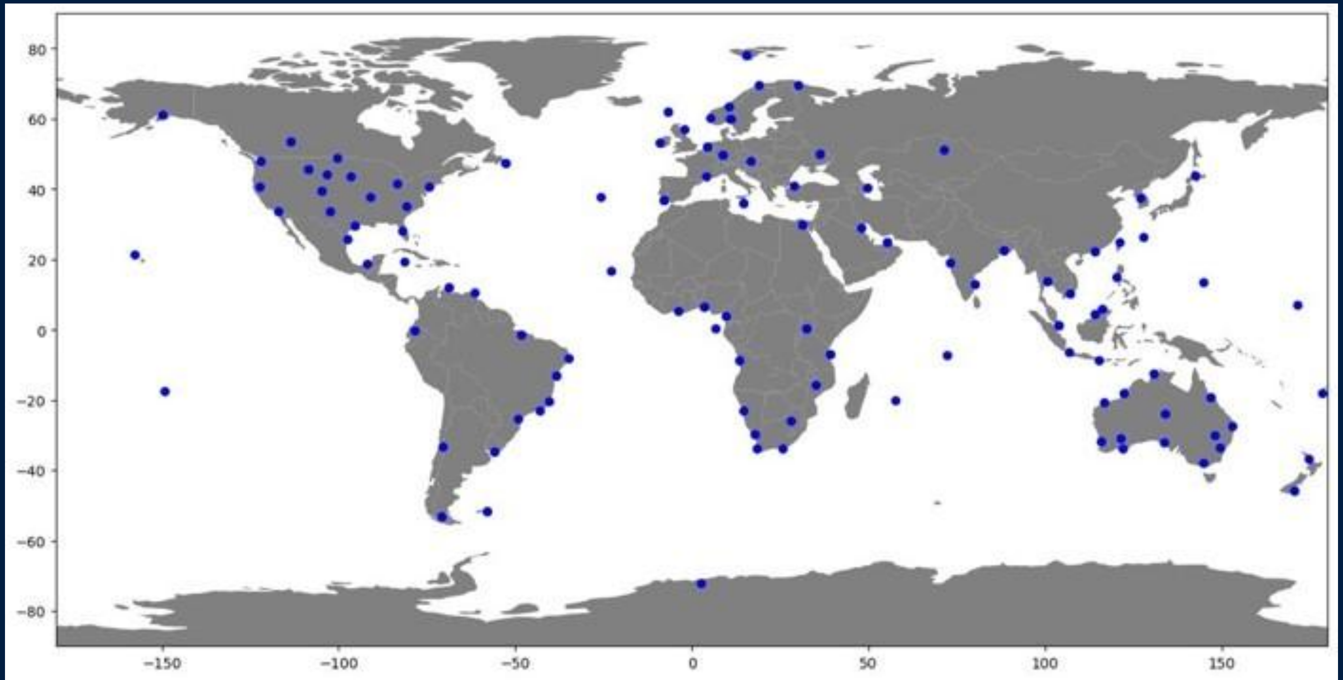
Contents

FUGRO SPACESTAR®

Motivation & Objectives

- Bringing Precise Point Positioning (PPP) from sea to space (<10cm)
- No additional ground infrastructure for the user
- Low size, weight, and power (SWaP) footprint

Generating Precise Point Positioning Corrections



- Leveraging Fugro's existing global network of over 100 reference receivers
- Raw observation of GPS, GLONASS, Galileo, BeiDou orbit and clock errors
- Corrections generated and distributed over L-band

Distributing Corrections to LEO

Precise Point Positioning (PPP) technology

GPS/GNSS orbit and clock corrections

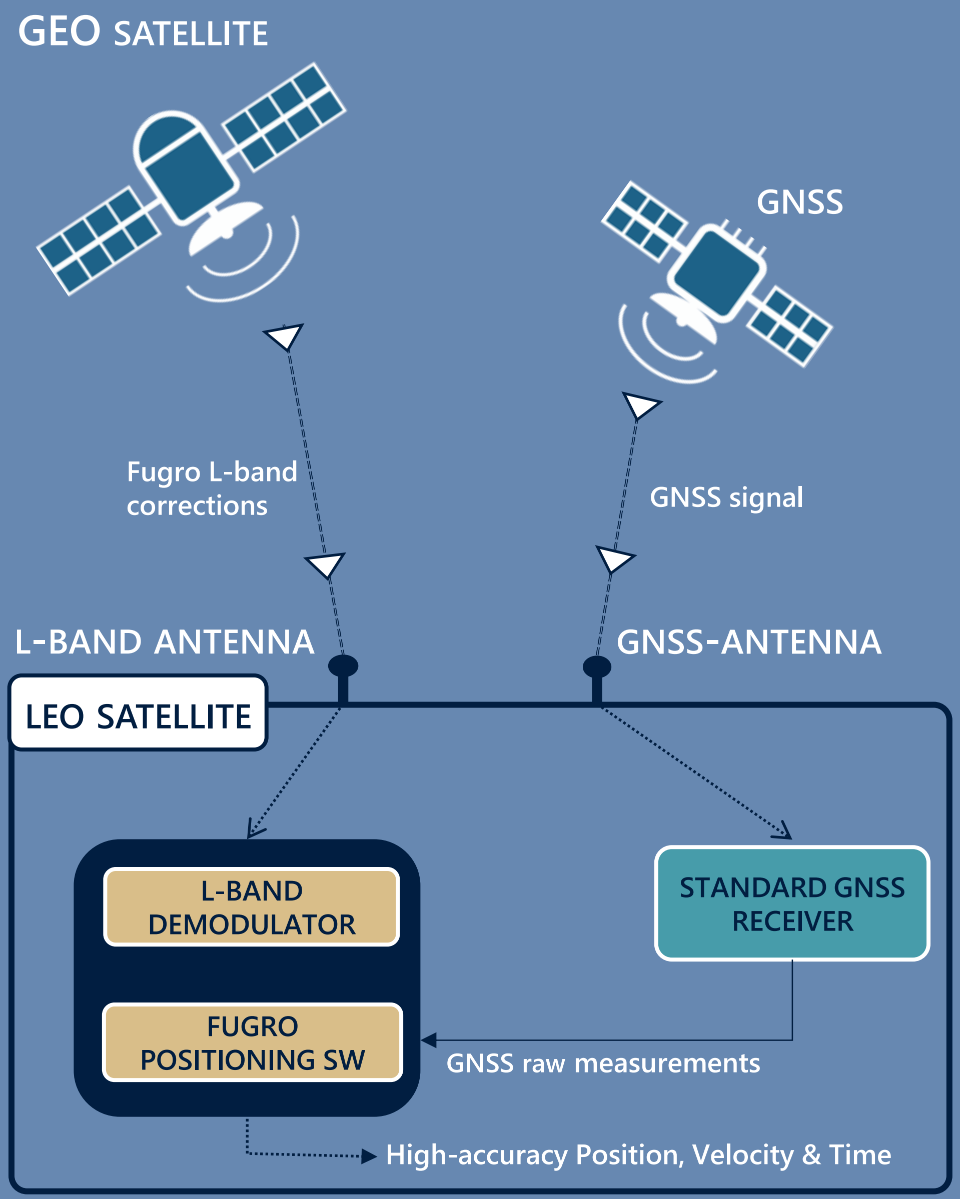
NorSat-TD On-board architecture

(image credit: UTIAS-SFL)

- SpaceStar software was integrated onto a SDR and flown as a payload on NorSat-TD satellite
- SDR is based on the Zync 7000-series, system-on-a-chip which includes both an FPGA and a powerful Arm processor
- A COTS GNSS receiver was used, configured to track:
  - GPS & GLONASS L1 + L2
  - Galileo E1 + E5
- COTS antennas used to receive the GNSS and L-band signal

NorSat-TD On-board Architecture

- L-band tracking and demodulator is implemented in firmware at FPGA level
- Processor runs PPP position engine in software
- Setup is receiver agnostic

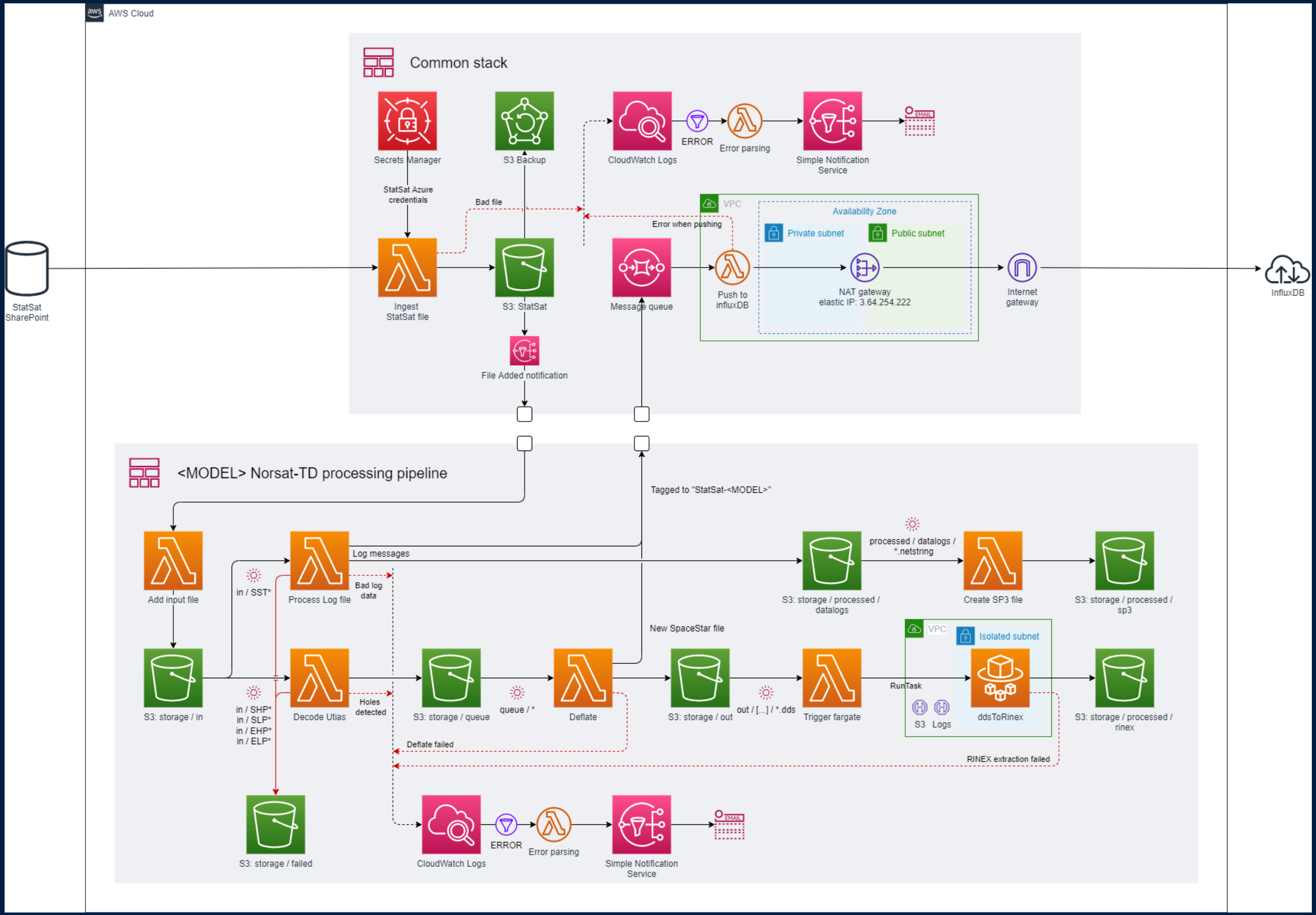


SpaceStar Operations

- Satellite operated by StatSat. Missions defined and scheduled via templates made available to payload providers.
- SpaceStar missions typically ran on Saturday.
- Missions plan created in YAML format, processed by Python scripts and converted into DyST missions

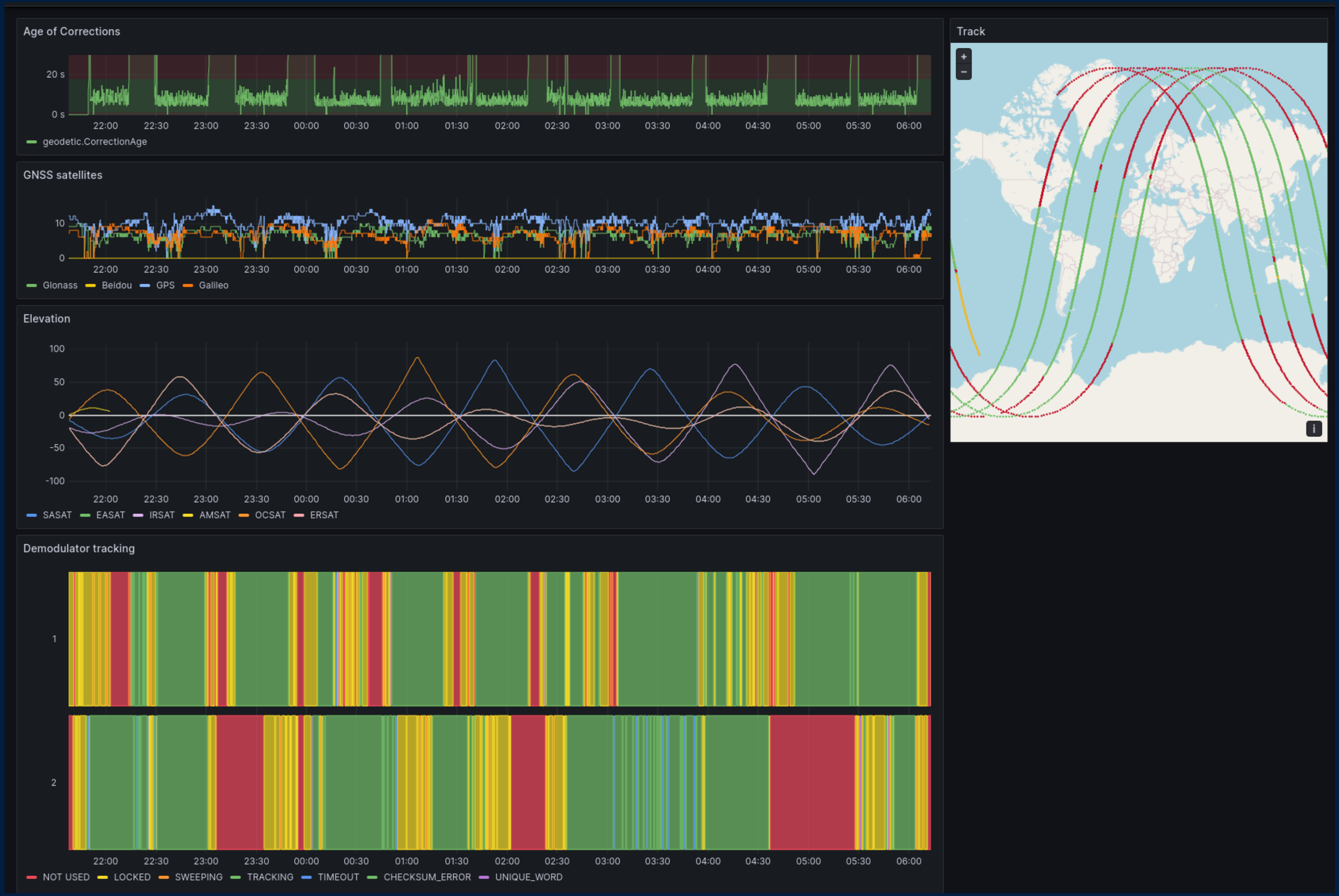

```yaml
name: Full engine update to v1.2.2

start: 2023-05-20 19:00
end: 2023-05-21 0:20

padding: 15m

plan:
- copy_from_pobc: { source: STT-FM-FW-V2, destination: norsat_n_engine_189377_3.swu, duration: 20m }
- update_engine: { filename: norsat_n_engine_189377_3.swu }
- restart_engine_no_dds: {}
- allow_adcs_as_tm: { start: +1h }
- start_adcs_tracking: {}
- list_dir: { dir: '/data/staging' }
```

Telemetry processing



Telemetry Visualisation

Received Data:
- Whole Orbit Data
- Attitude
- DDS
- Journal
- Debug
- NMEA
- IQ

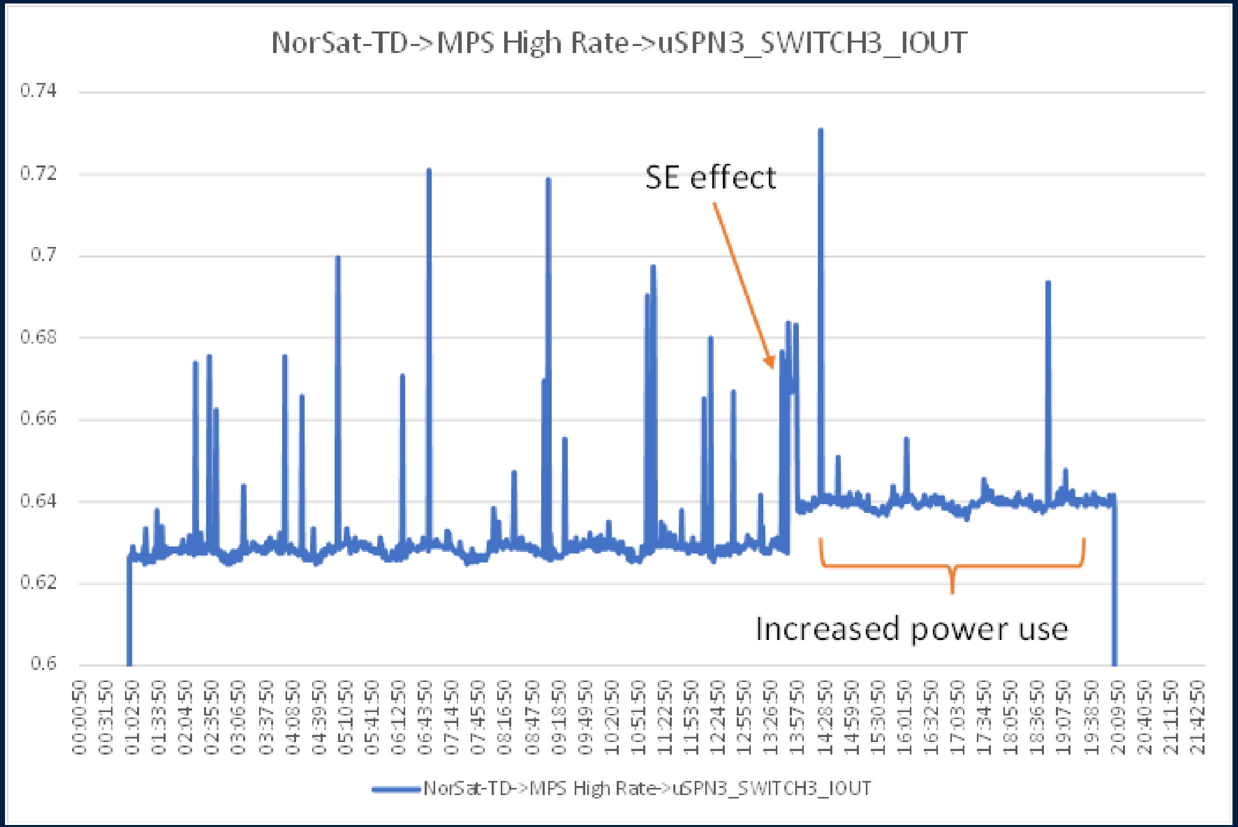


Telemetry Visualisation

eMMC Failure

- Saturday 23 Sept 2023
- SpaceStar experienced overcurrent condition
- eMMC filesystem became inaccessible/corrupt
- SpaceStar modified to work in RAM-only mode.

1. Self-extracting archive stored on platform and uploaded to SpaceStar on every boot
2. Archive creates all necessary RAM filesystems, copies all binaries, and configures the FPGA
3. Once full eMMC running system replicated in RAM, SpaceStar application is started



eMMC Failure Limitations

- Telemetry storage limited to 300MB (was 25GB on EMMC)
- Storage lost on powerdown

Resulting in

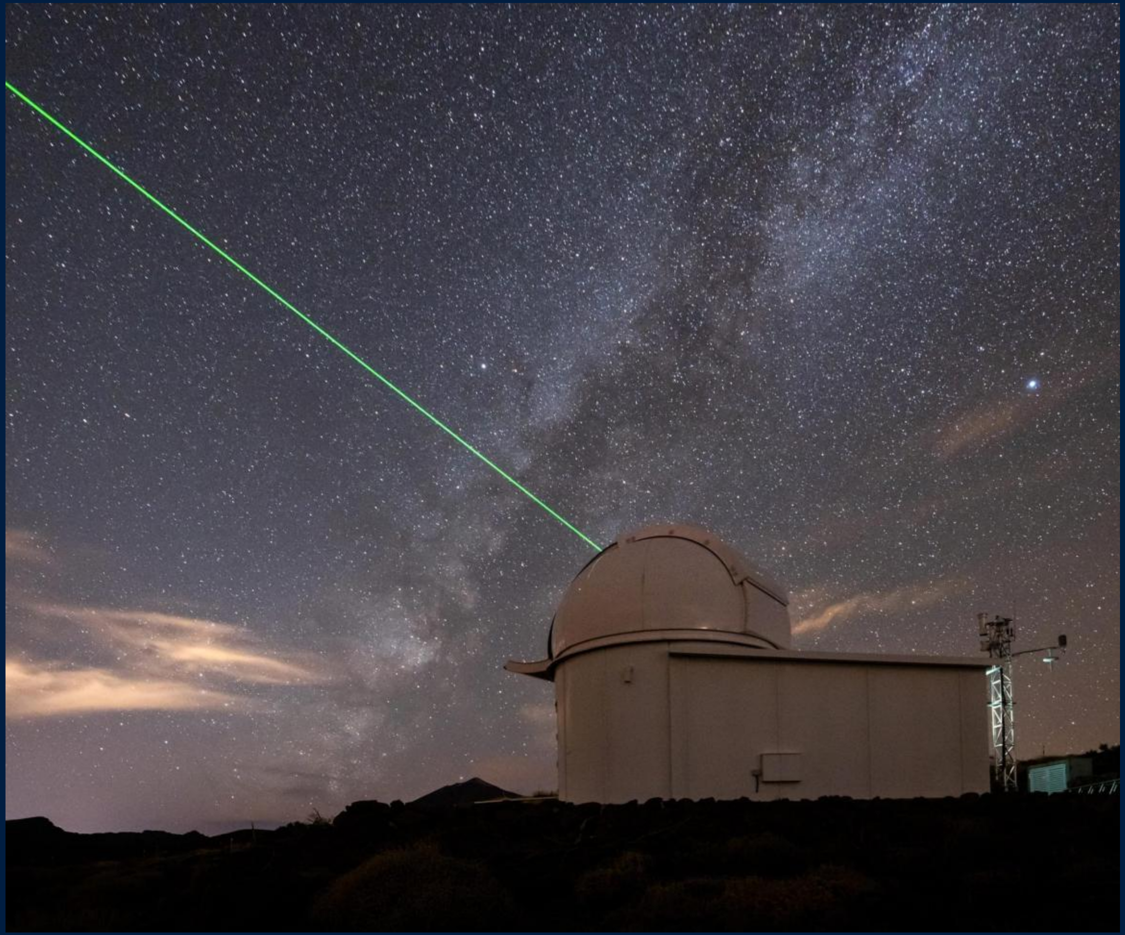
- Very limited IQ samples collected
- Limitation on the size of new binaries to be deployed alongside the main executable

SLR

- NorSat-TD outfitted with retroreflector
- SLR attempts from MeO Grasse station

- SLR attempts unsuccessful due to
  - Delayed SLR campaign due to orbit decay
  - Bad weather
  - Organisation challenges
  - Uncertain satellite position predictions

- Jamming over Europe would complicate any validation with SLR



Mission End

- Failed on-board propulsion system resulted in early orbital decay
- Noticeable more difficulty getting the ADCS stable in lower altitudes
- Satellite de-orbited in May 2025

Typical Initial Result From Orbit

- Bad GNSS receiver configuration resulted in poor tracking performance, significantly affecting the PPP solution from SpaceStar
- Improved by reconfiguring GNSS receiver, as well as SpaceStar's PPP parameters.

L-band tracking improvements

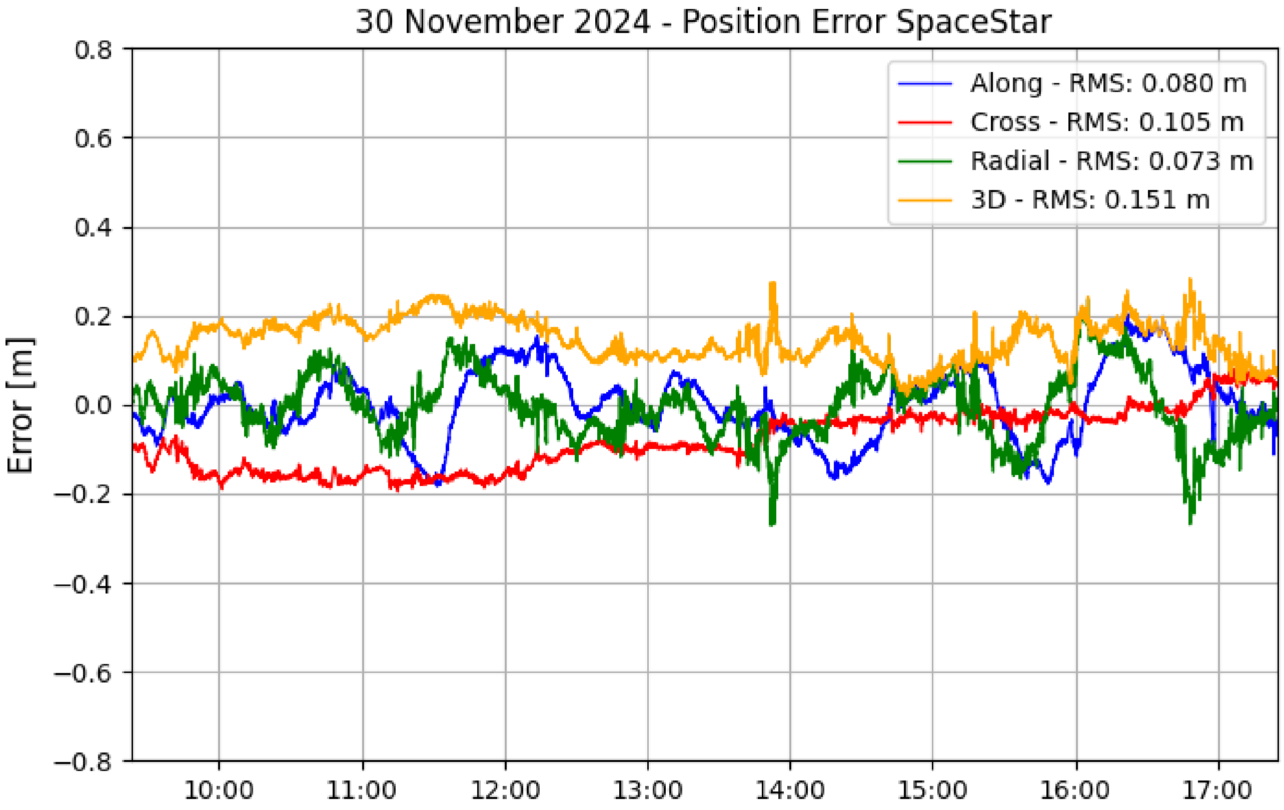
- Correction age as metric for L-band tracking performance
- Continuous improvements throughout the mission lifetime
- Expected outages over poles, depending on attitude

Intermediate results

Final results

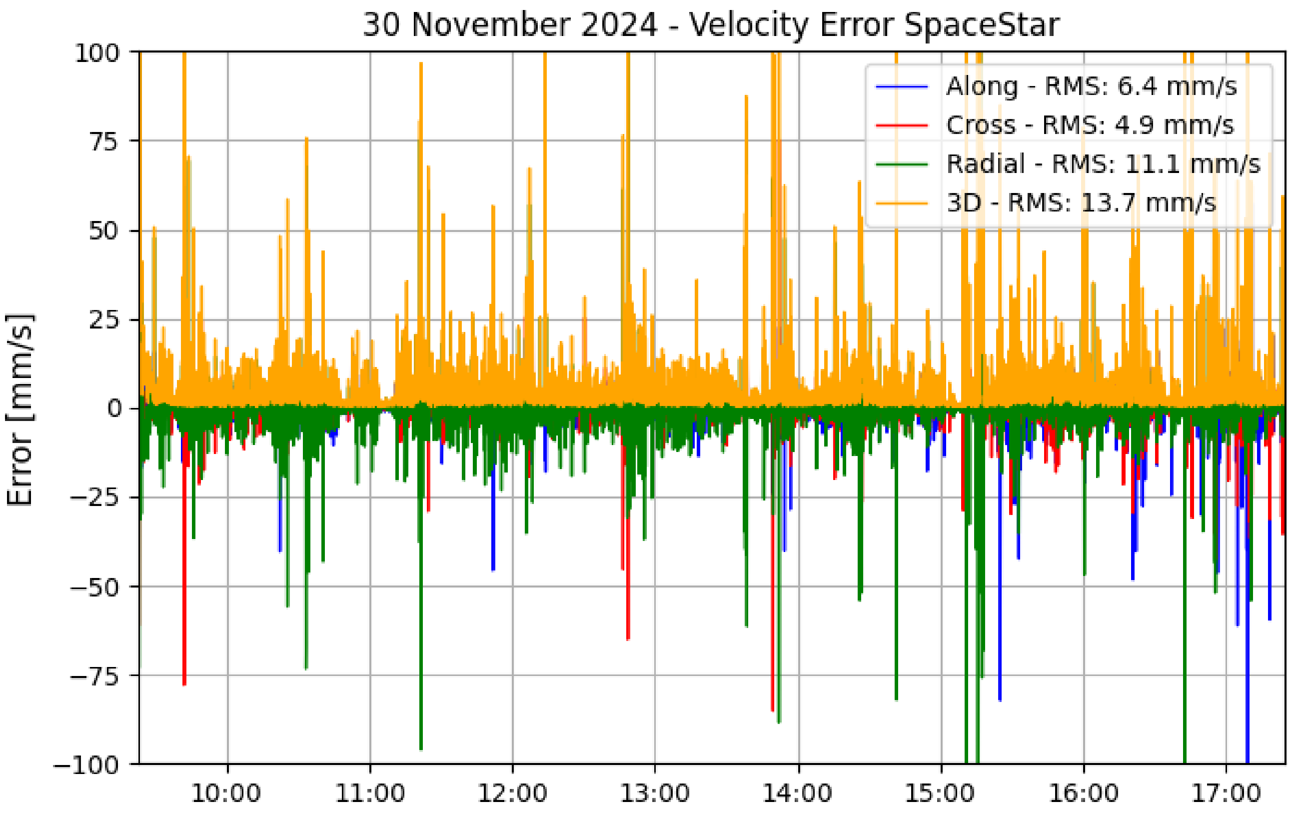
Final Performance: Position Accuracy

- PPP achieved in LEO
- Real-time onboard position was compared to a reference orbit computed on the ground
- Position error remains steady around the 10cm level for several orbits



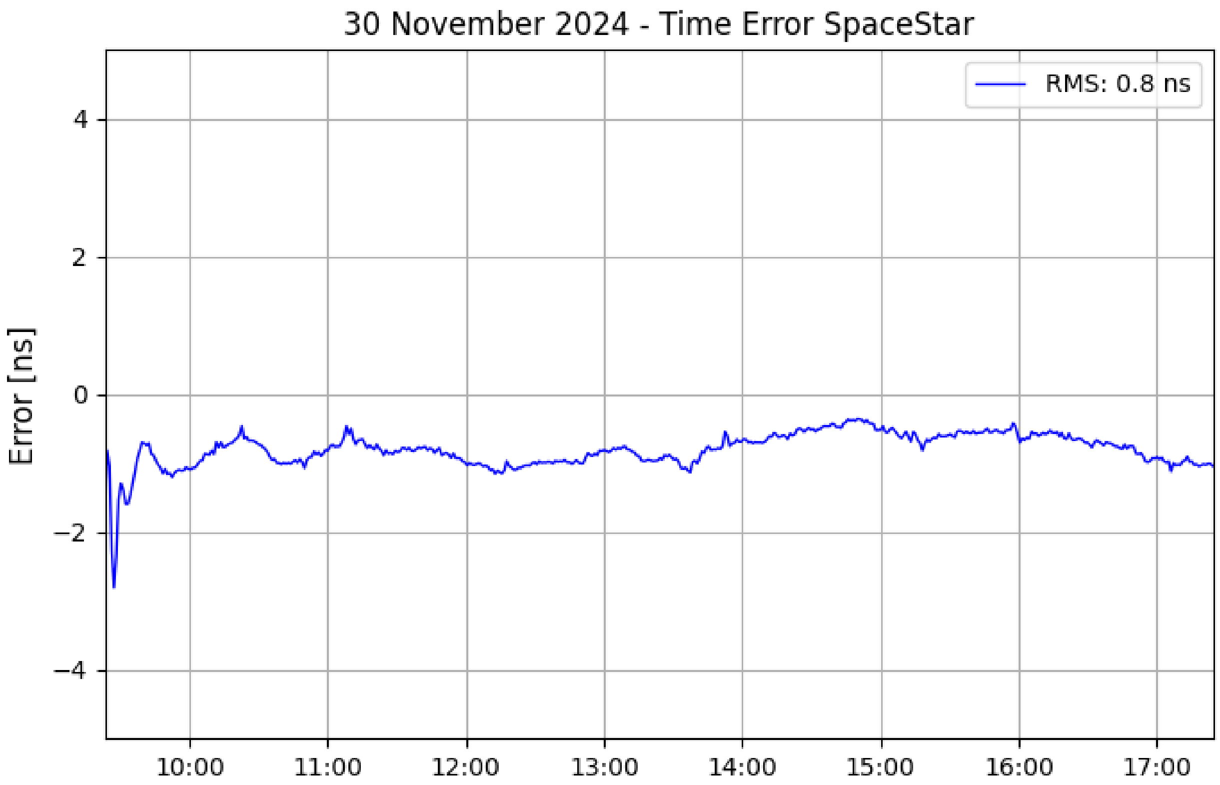
Final Performance: Velocity Accuracy

- PPP achieved in LEO
- Real-time onboard position was compared to a reference orbit computed on the ground
- Velocity accuracy in the 5-11 mm/s range



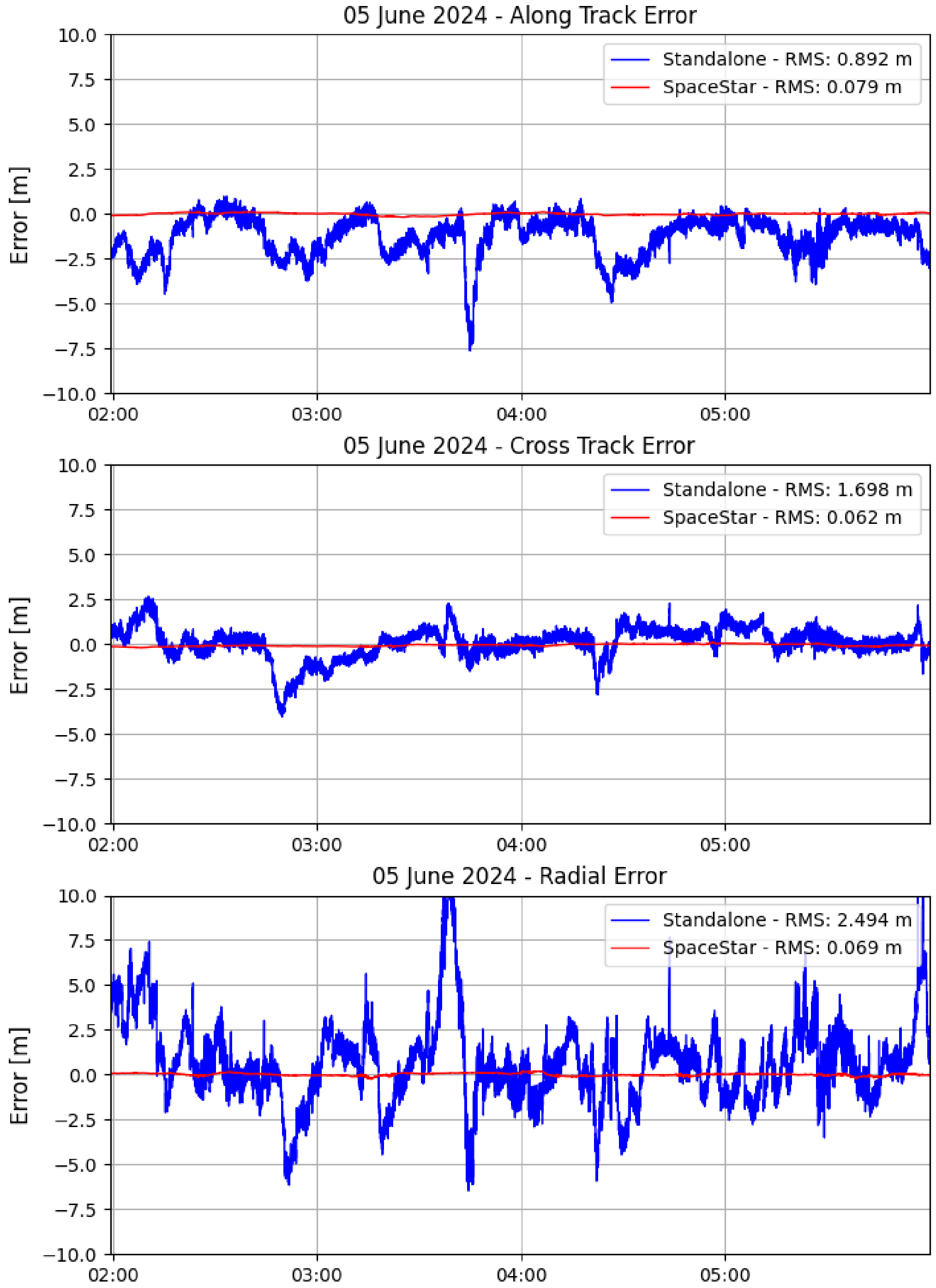
Final Performance: Time Accuracy

- PPP achieved in LEO
- Real-time onboard position was compared to a reference orbit computed on the ground
- Time error <1 ns RMS



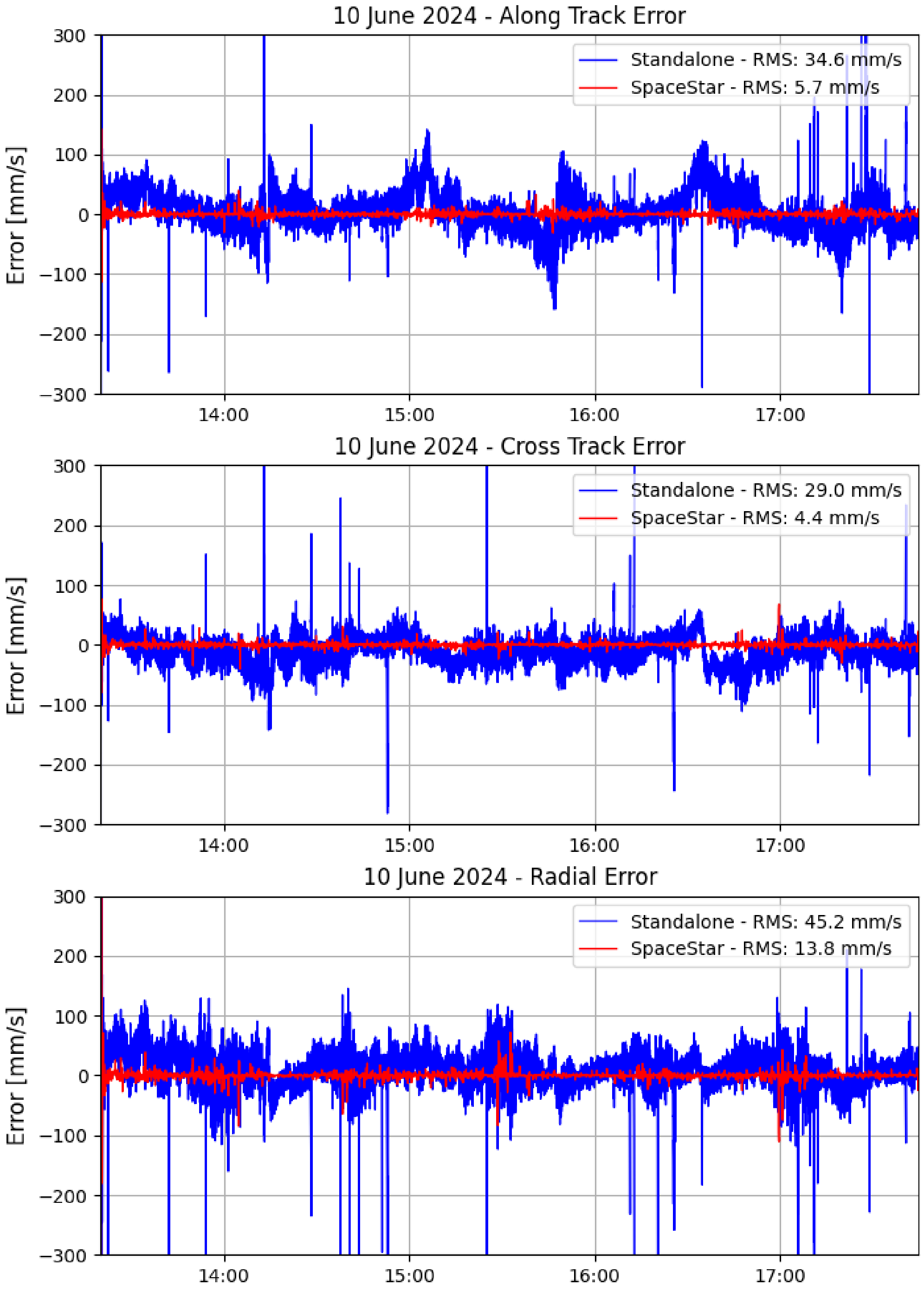
Comparison with standalone GNSS: Position

- Red is with SpaceStar, blue without
- Results show about order of magnitude improvement compared to standalone receiver output



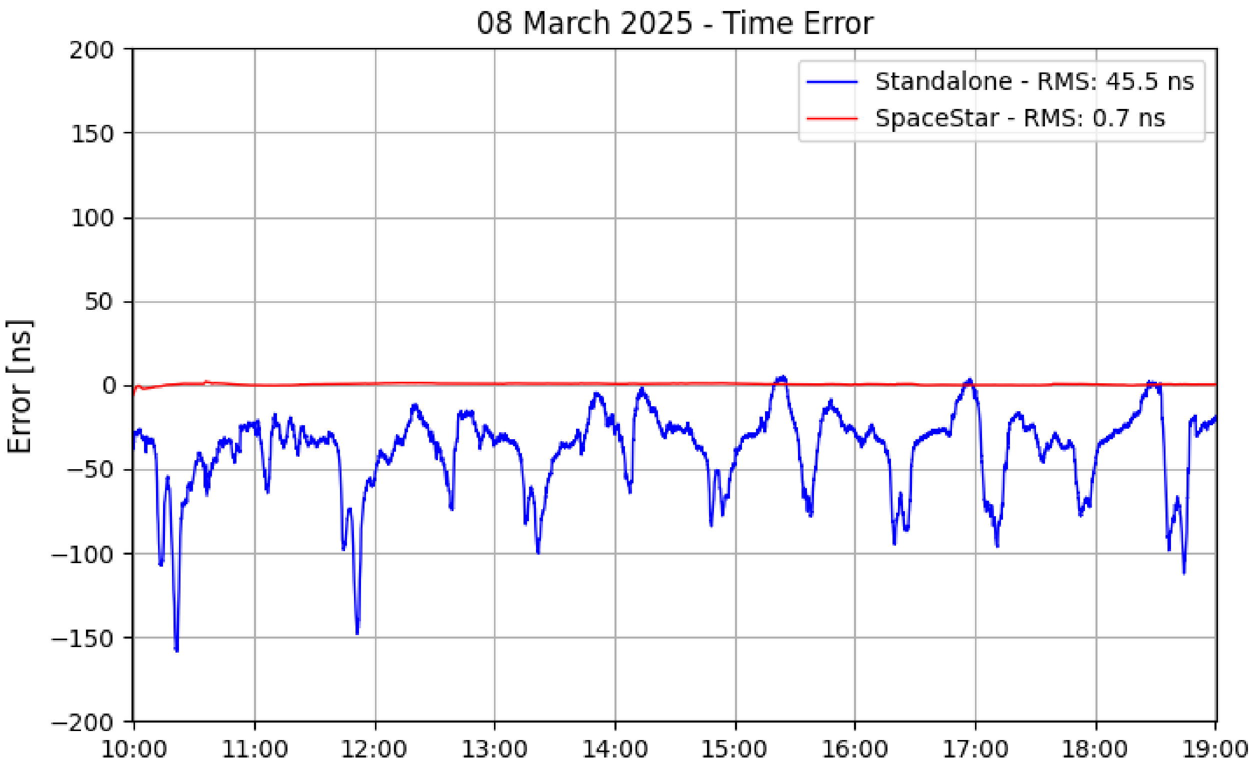
Comparison with standalone GNSS: Velocity

- Red is with SpaceStar, blue without
- Results show several factors improvement compared to standalone receiver output



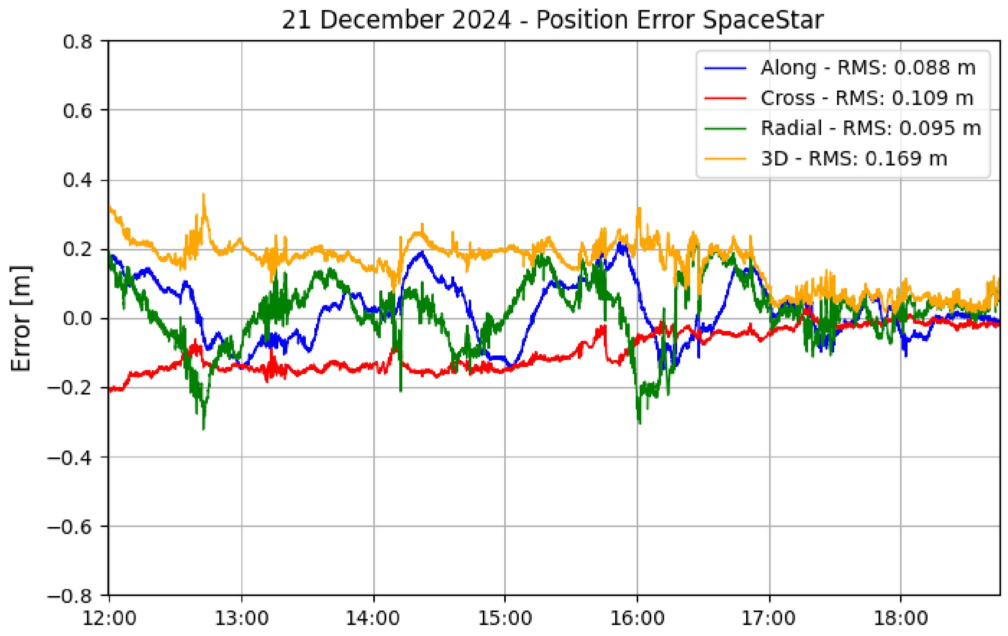
Comparison with standalone GNSS: Time

- Red is with SpaceStar, blue without
- Results show increased consistency and over an order of magnitude improvement compared to standalone receiver output

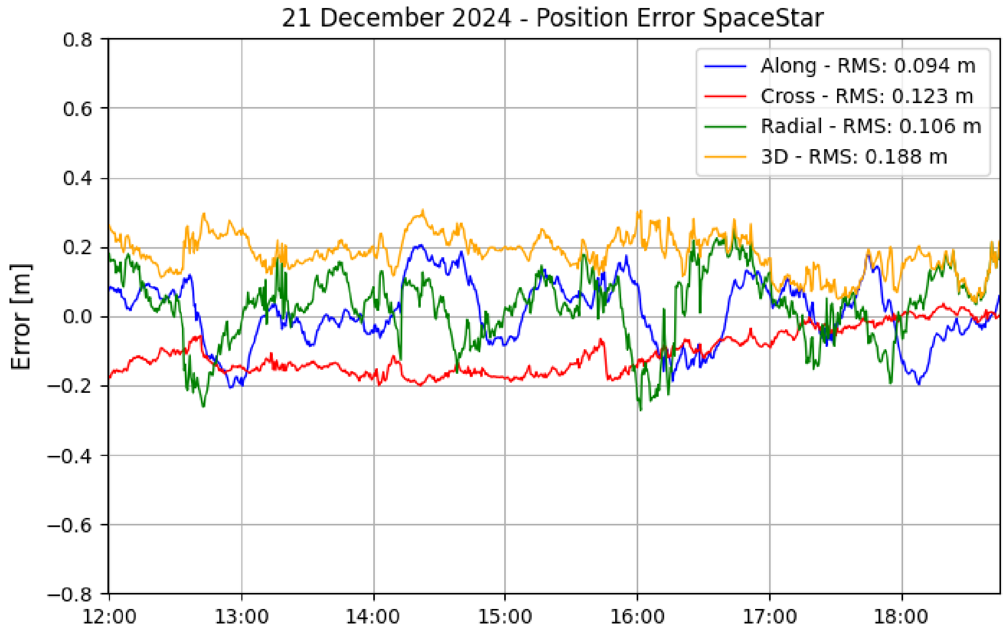


External Validation

- External reference orbits computed by ESA
- Difference between reference orbits is a few centimeters.



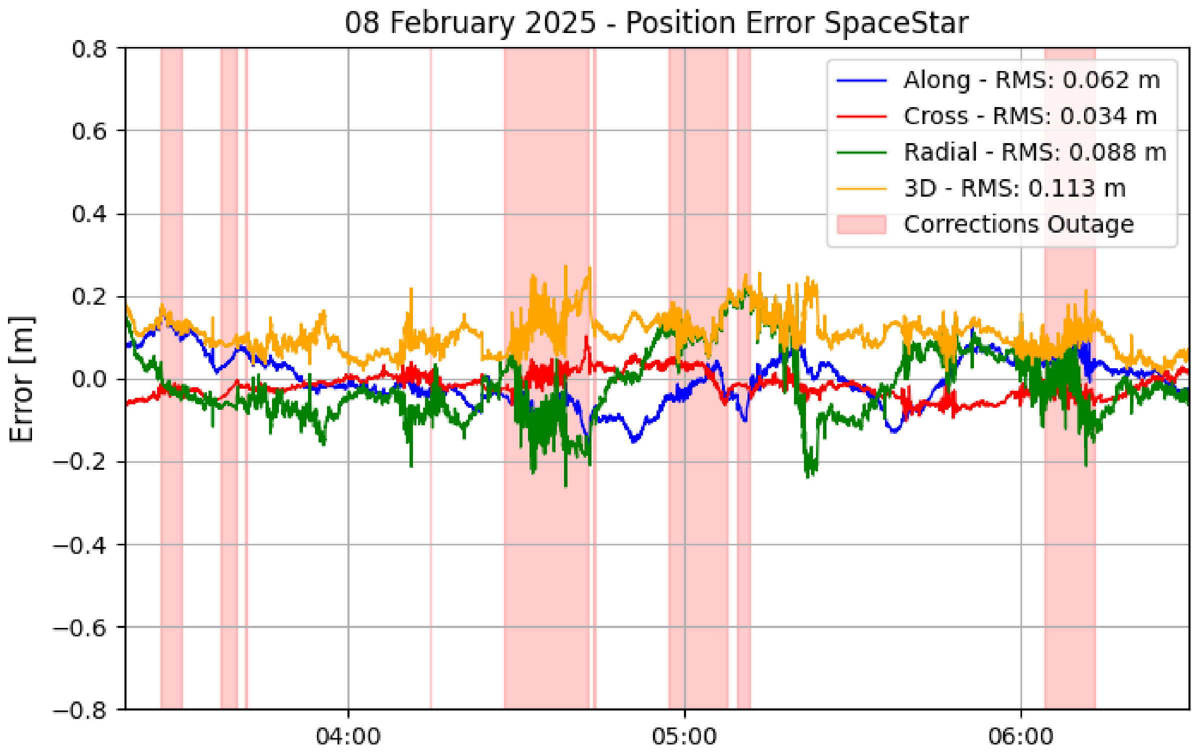
Internal



External

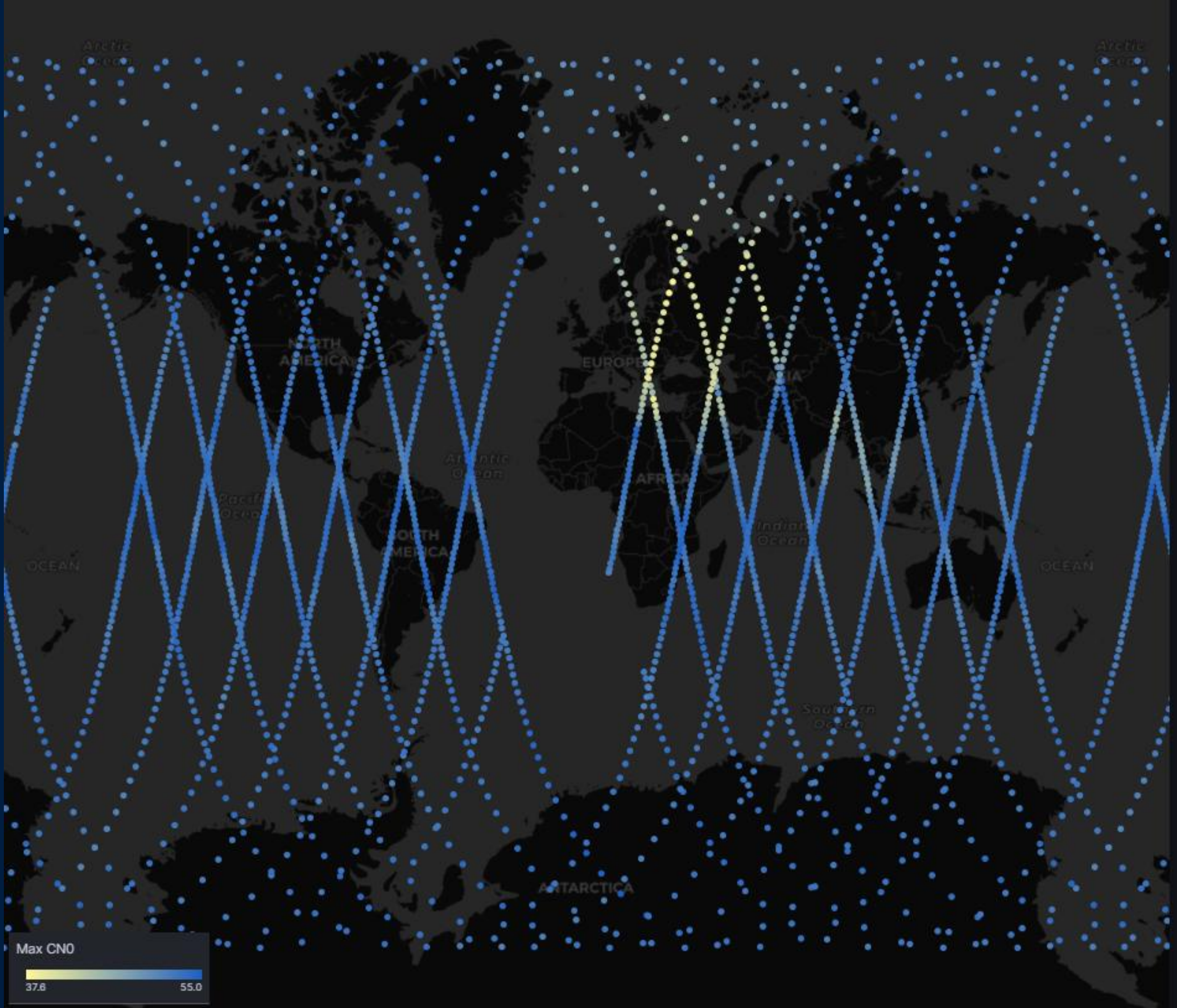
L-band Outages

- Inevitable L-band outages in LEO
- SpaceStar is able to coast on older corrections without significant performance degradation



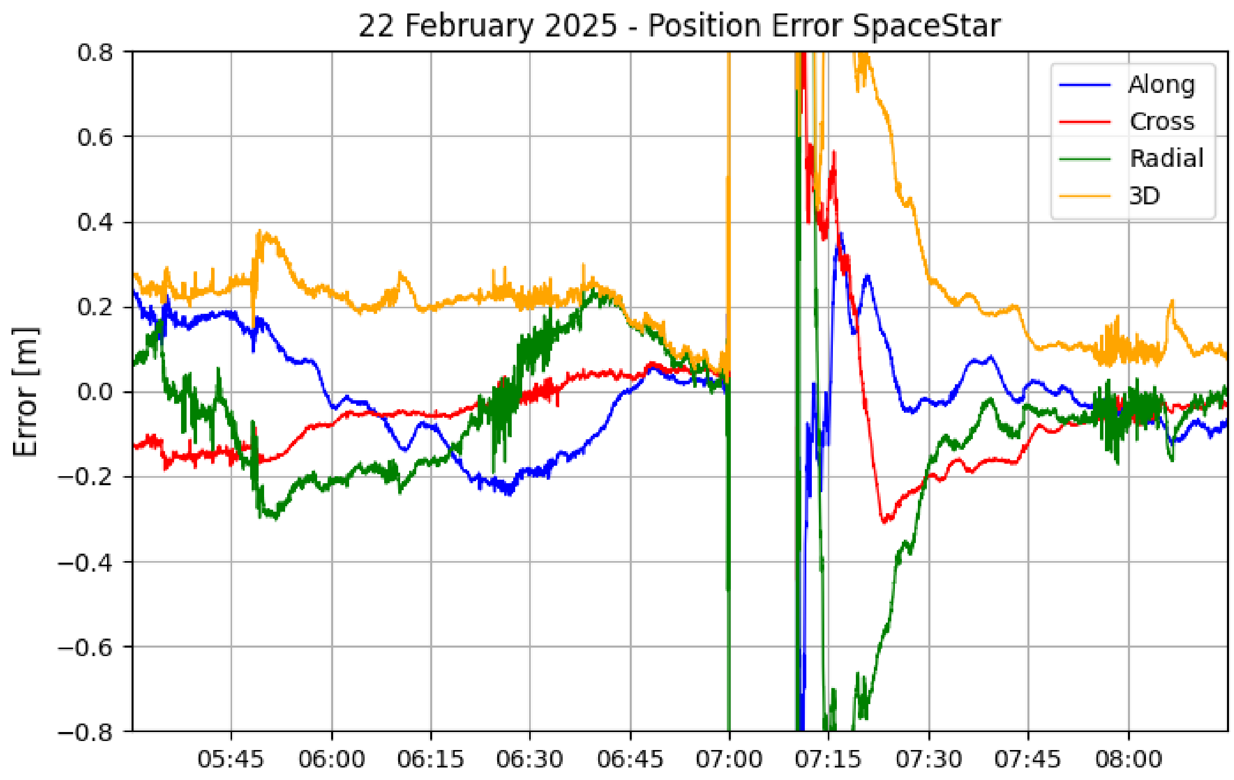
GNSS Outages

- Jamming areas cause tracking degradation



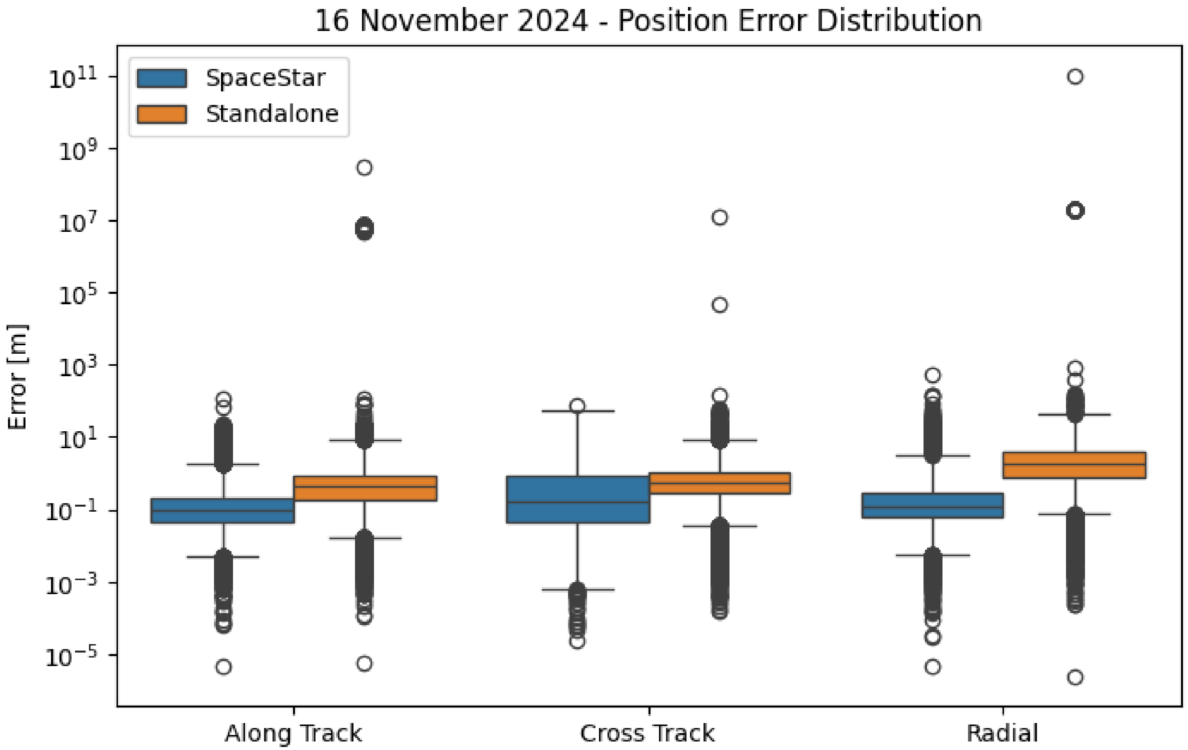
GNSS Outages

- Jamming areas cause tracking degradation
- SpaceStar shows fast reconvergence after outage



Solution integrity

- Standalone GNSS shows position outliers of thousands of kilometers.
- While SpaceStar rejects these faulty observations



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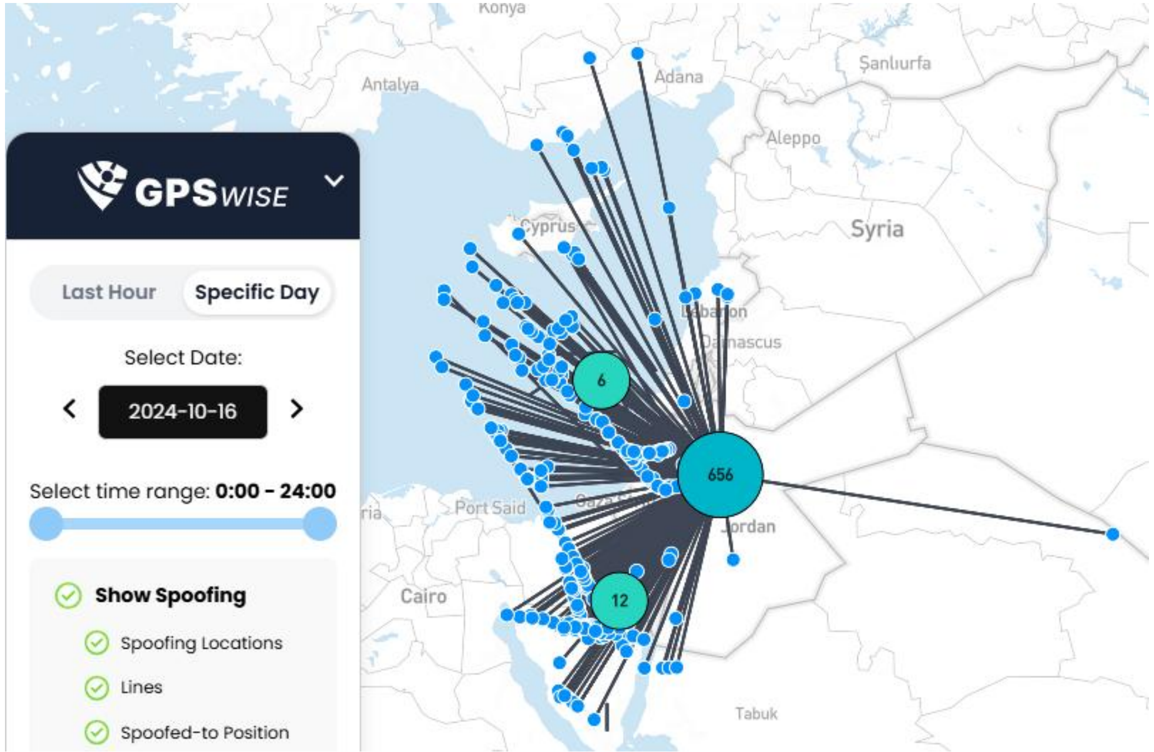
Solution integrity

- Spoofing activity on 16 Oct 2024 (https://spoofing.skai-data-services.com/)
- Satellite spoofed in LEO



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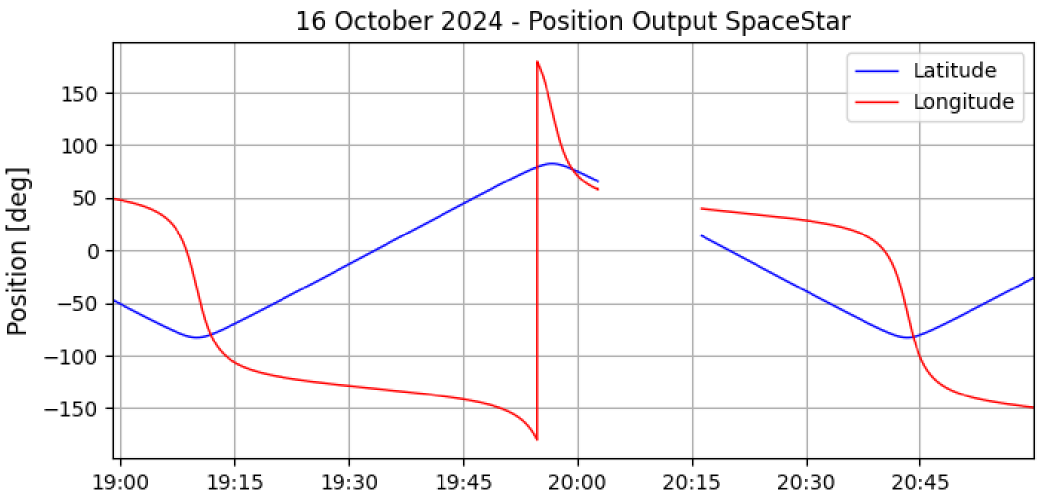

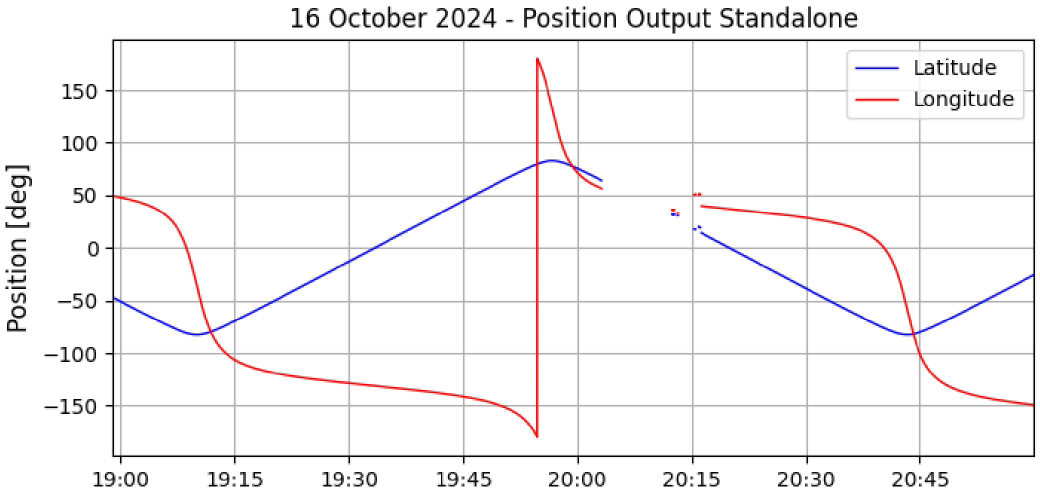

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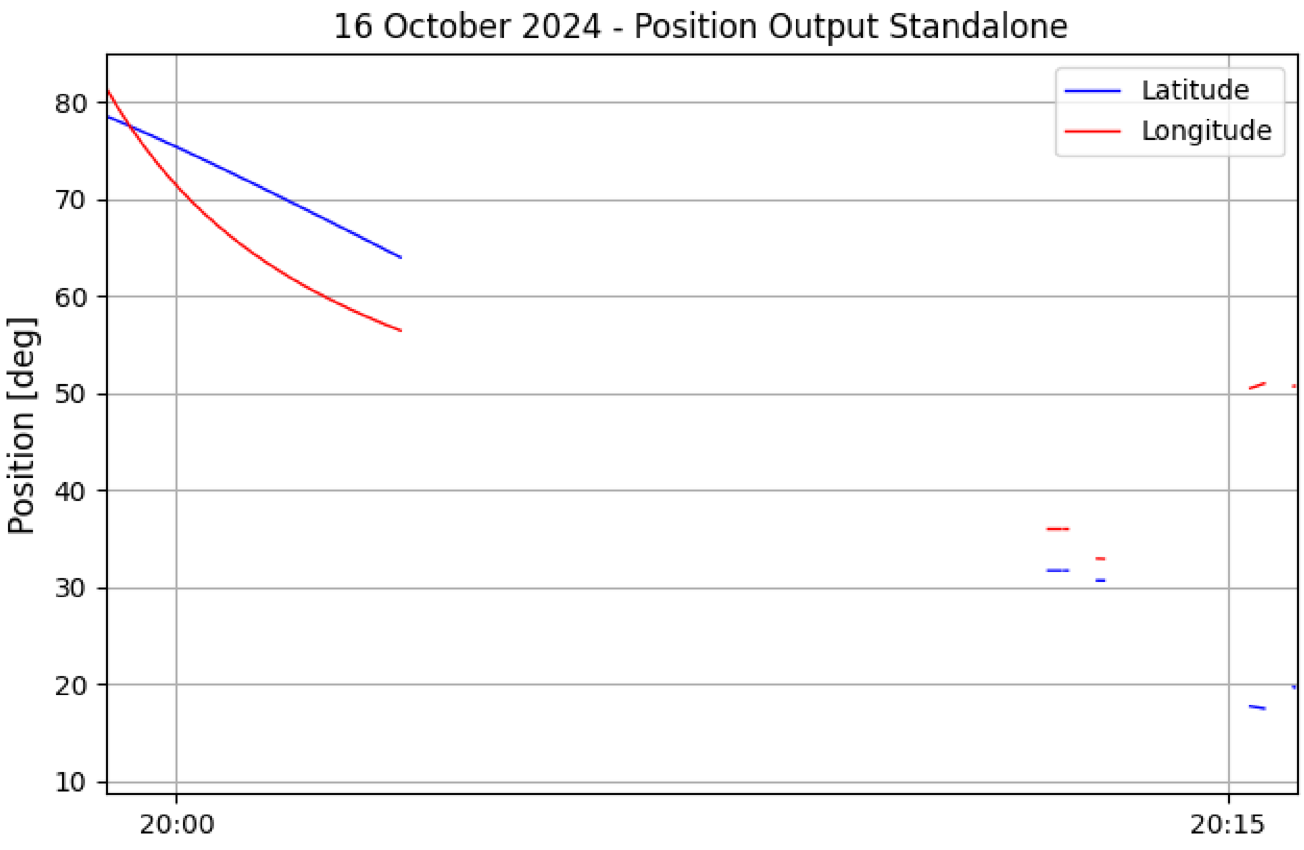
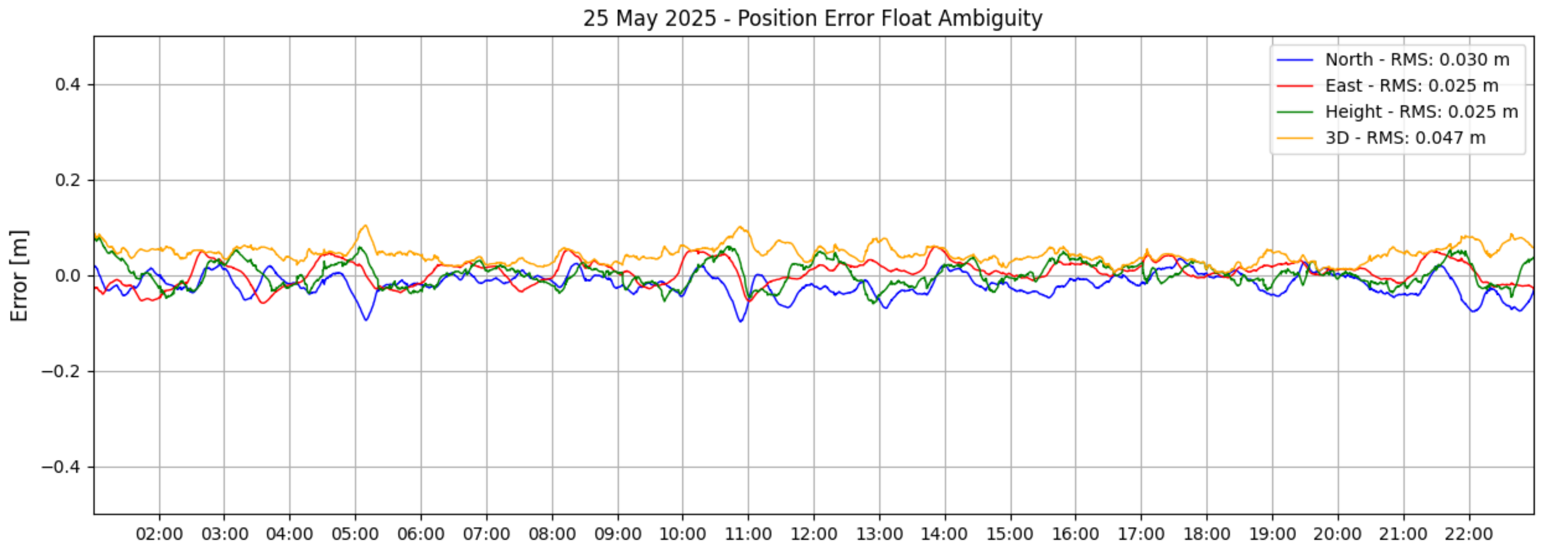
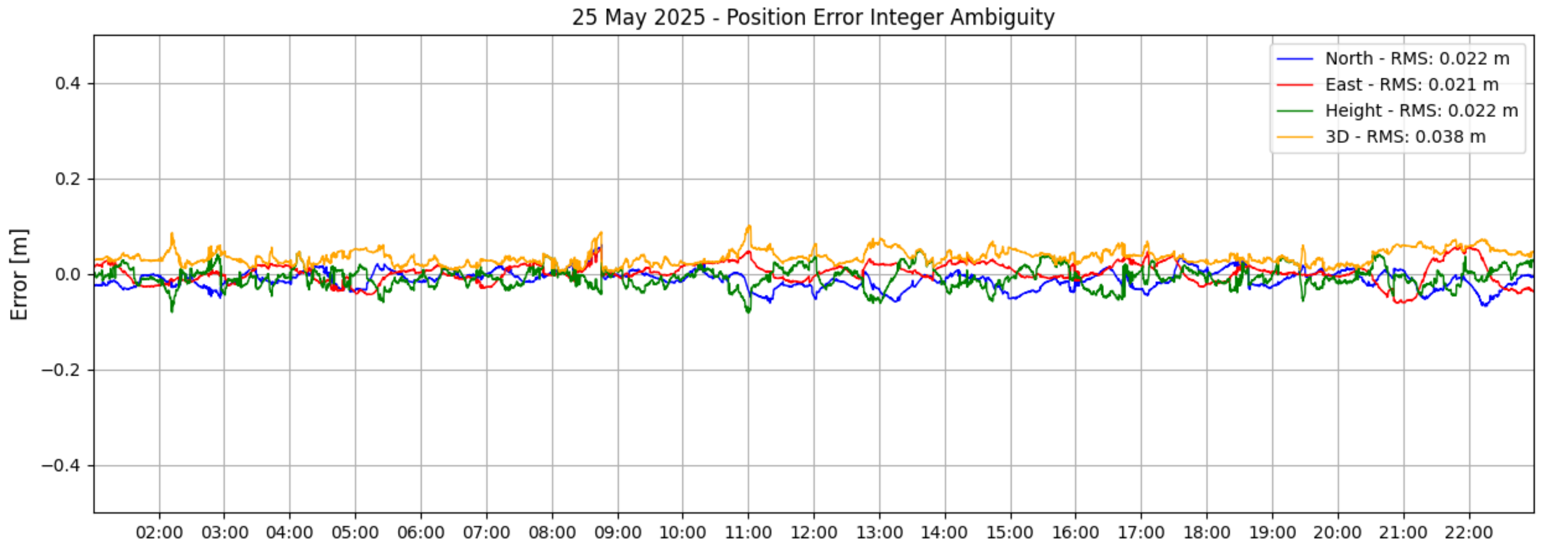


IAR Feasibility Study

- Based on Sentinel 6A GNSS data
- GPS + Galileo Dual Frequency
- Using Fugro Corrections
- ~24% improvement with fixed ambiguities





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Conclusions and looking forward

- PPP can be achieved in LEO with position accuracy better than 10cm and time accuracy on ns-level
- Achieved using COTS hardware and no additional infrastructure
- Enhanced position integrity compared to stand-alone GNSS

What next:

- Cooperation with commercial hardware partners: Javad, SpacePNT, GomSpace
- Potential to build further on PVT integrity

FUGRO SPACESTAR®
REAL-TIME ACCURATE POSITIONING
SYSTEM ENABLED

Fugro

Unlocking **Insights**
from **Geo-data**