PNT Moon Surface Station: Performance Analysis and First Demonstrations

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DEMOS-1 Project

- NAVISP-EL1-062: Lunar Surface PNT Beacon Demonstrator
  - **NovaMoon predevelopment activity**

- The Moon Station is a PNT Moon surface beacon and reference station having the goal to locally enhance the navigation services provided by LCNS satellites. It provides two main services:
  - Computation and distribution of **local differential corrections** for the LCNS satellite signals
  - Generation of a **ranging signal**

- Main objectives of the activity:
  - Preliminary design of a complete flight model Moon Station
  - **Development of a Moon Station Elegant Breadboard (EBB) demonstrator** (TRL 4), which includes the most critical functionalities of the Moon Station. This allows to assess the critical technologies in due-time, reducing the implementation risk of future models.

- Activity finalized in December 2025, demonstrator deployed in the ESTEC navlab

QASCOM
AEROSPACE & DEFENCE

Moon Station Demonstrator

Developed Technology

Developed Technology

- QA707 – Radio Frequency Constellation Simulator
- Multi-frequency and multi-constellation
- GNSS (L1/E1, L5/E5, G1), LCNS (S), and custom transmitters / bands
- Jamming, spoofing, and integrity threats
- LCNS AFS-I – BPSK(1), data
- LCNS AFS-Q – BPSK(5), pilot
- AFS navigation message (first ICD)
- Support to DEM
- TRL 9

Developed Technology

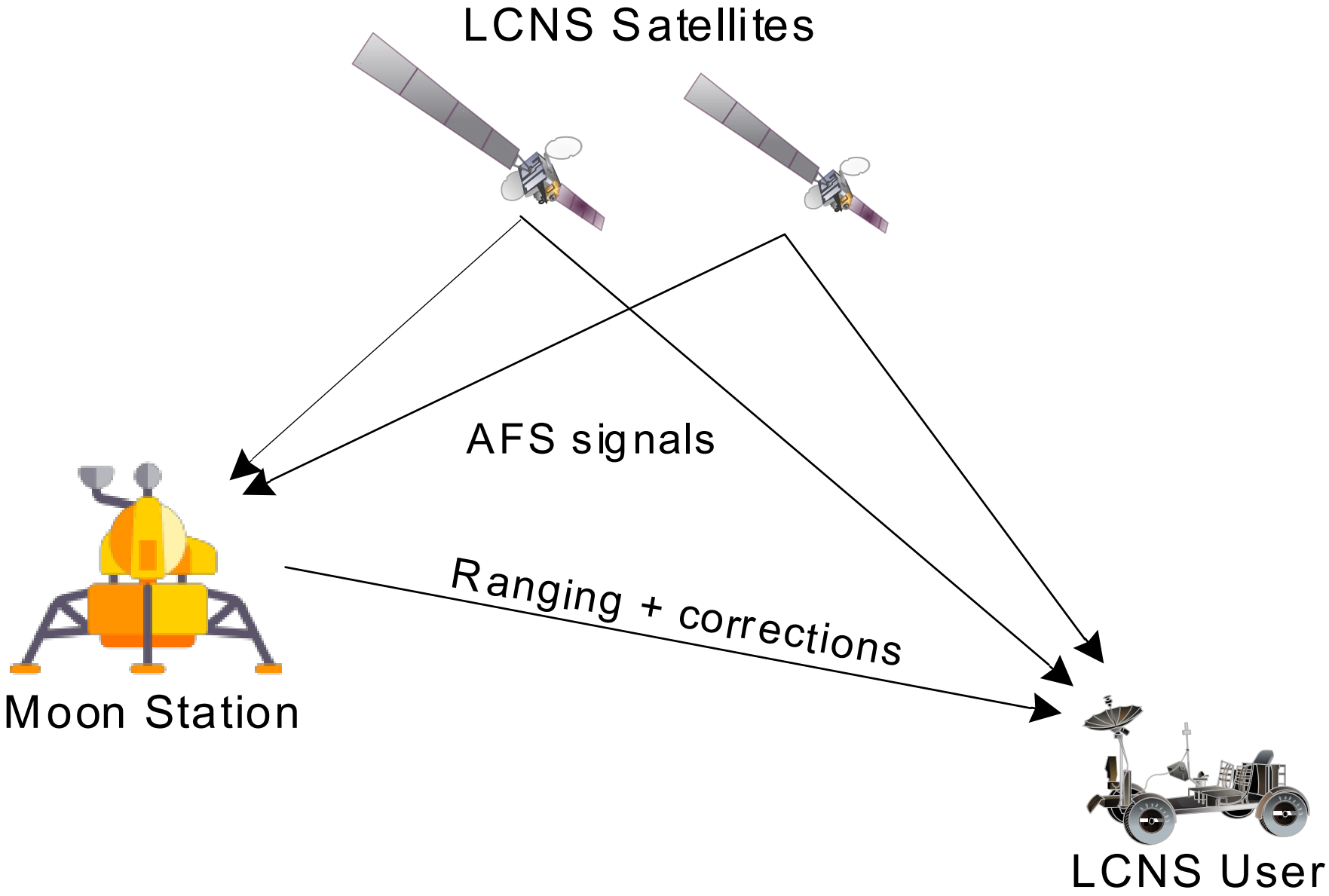
- LCNS receiver prototype (S-band)
- LCNS AFS-I – BPSK(1), data
- Demodulation of time information of AFS navigation message (first ICD)
- PPS aligned to system time
- External navigation engine: LS, EKF, differential corrections, DEM
- TRL 6

- As part of Moonlight:
  - LCNS AFS-Q – BPSK(5), pilot
  - Full demodulation capability
  - Improvement on PPS accuracy
  - TRL 9

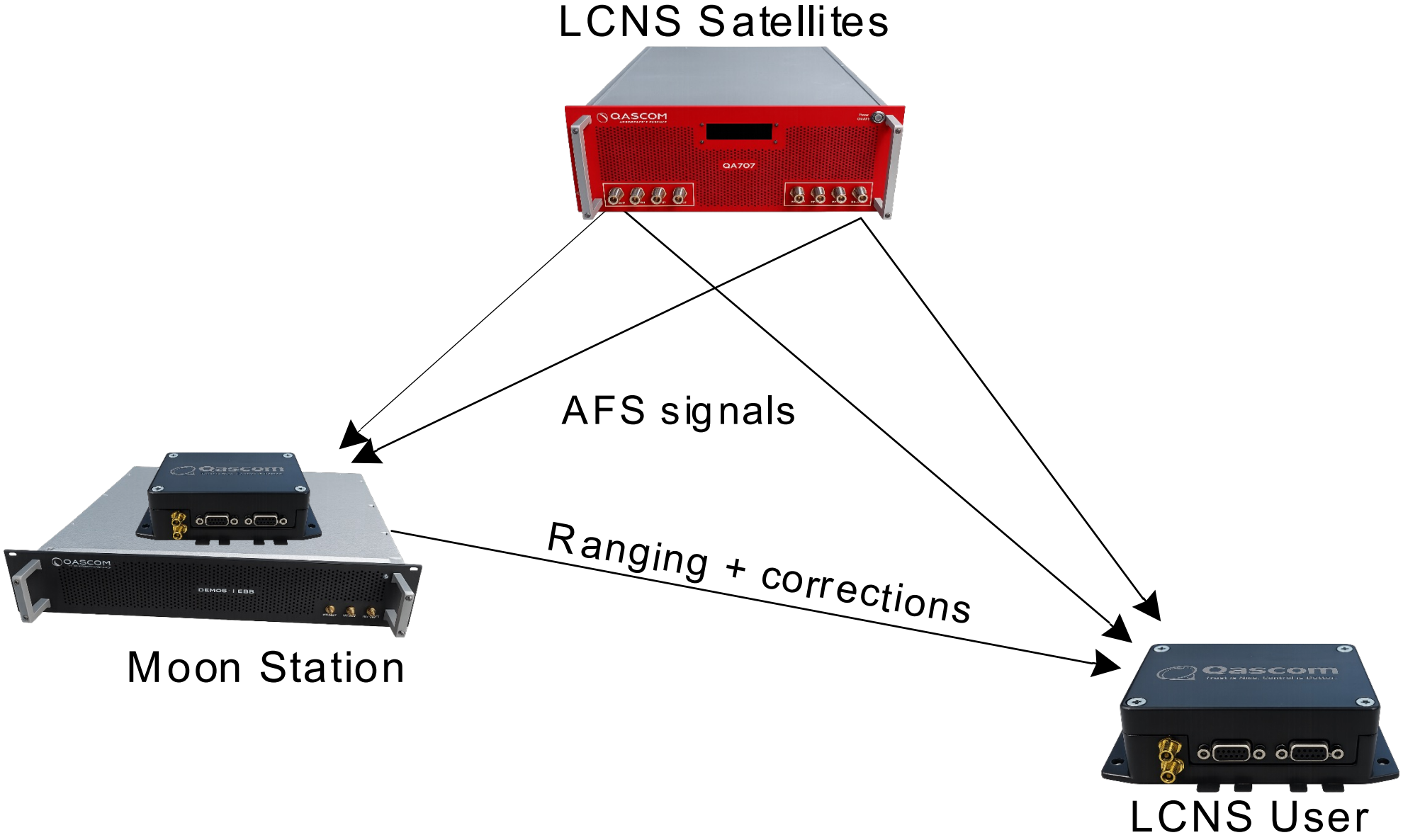
Developed Technology

- Beacon transmitter
- Configurable signal and band
- Accept external time reference (clock and PPS)
- Transmission aligned to provided PPS
- LCNS AFS-I – BPSK(1), data
- LCNS AFS-Q – BPSK(5), pilot
- Accept LCNS observables
- Position and time estimation
- Generation and distribution (ethernet) of differential corrections
- TRL 5

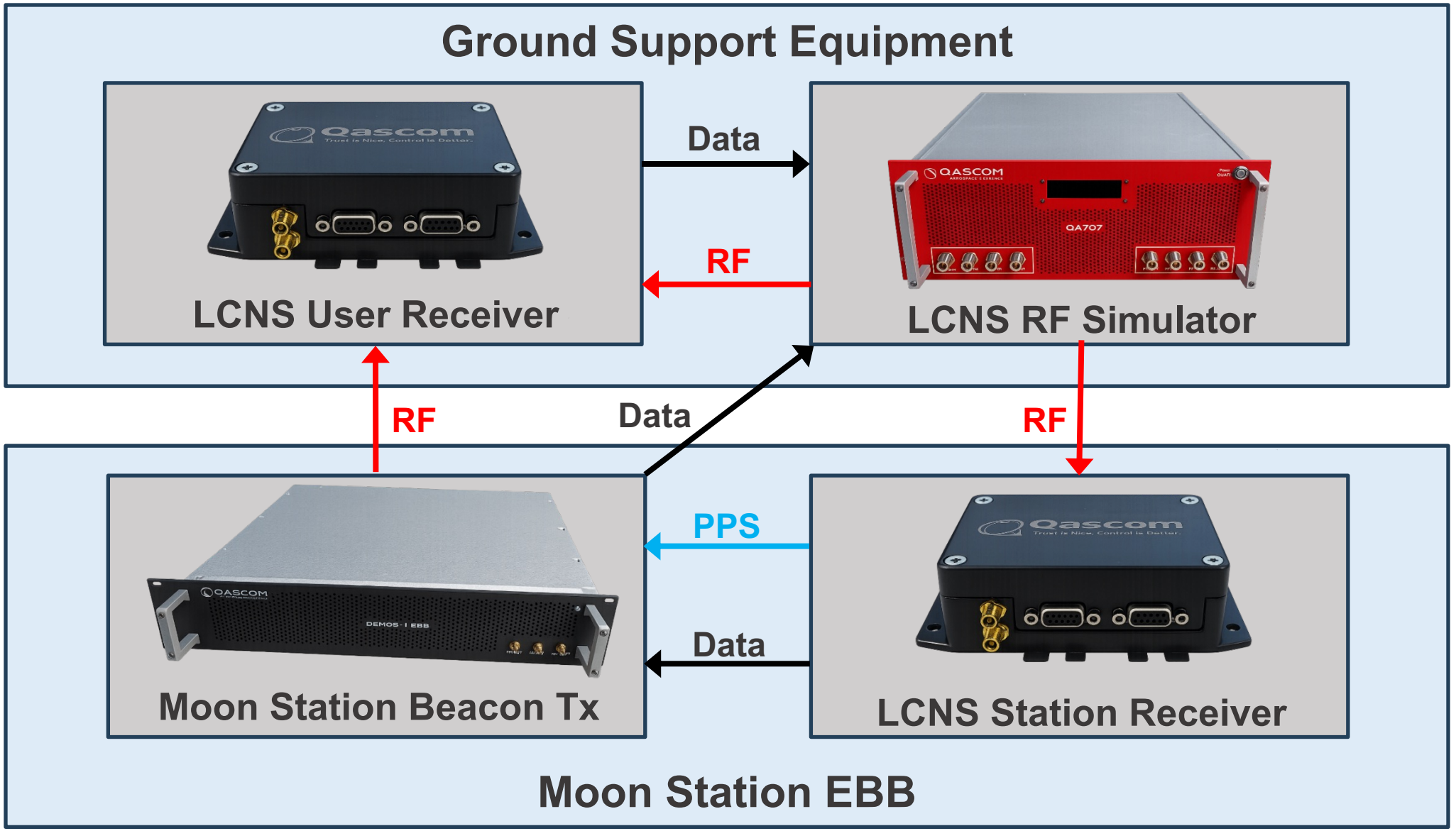
Demonstrator Representation



Demonstrator Representation



Demonstrator Architecture

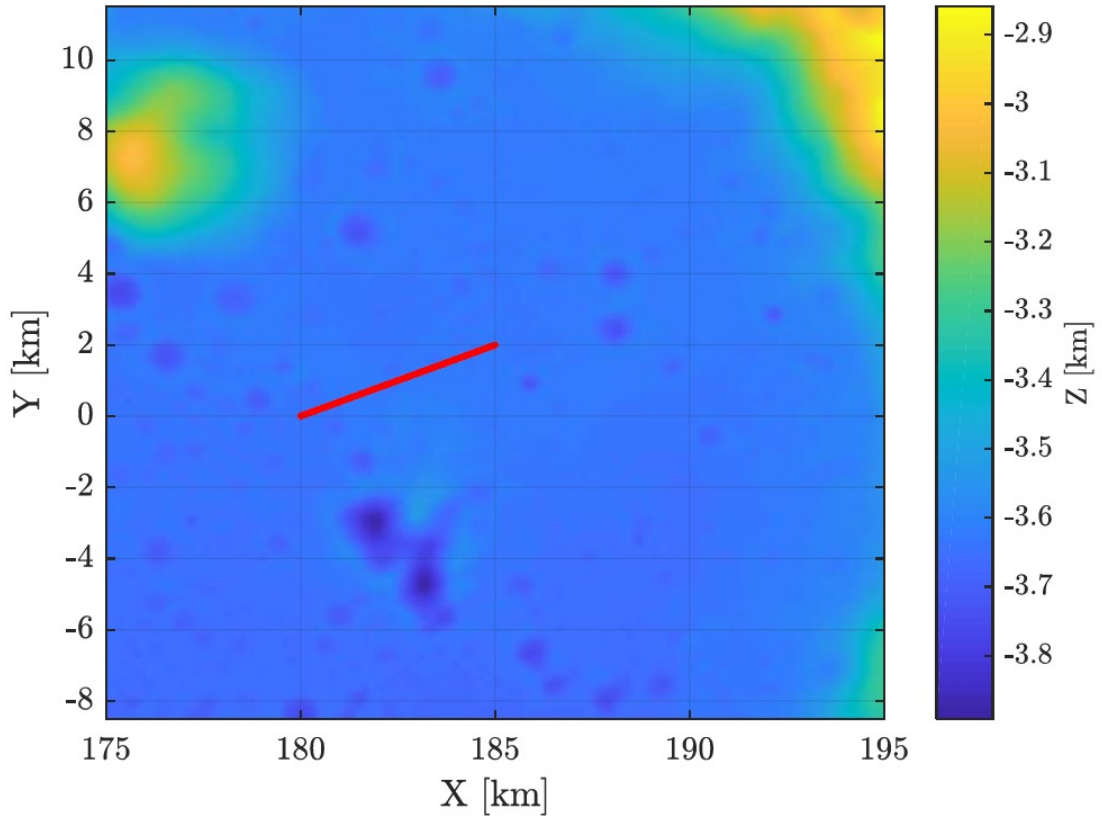


Demonstrator Picture

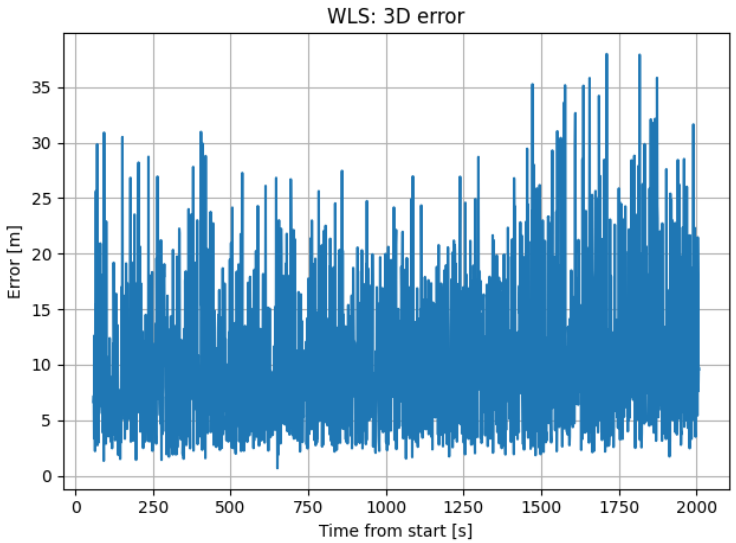
Preliminary Experimentation Results

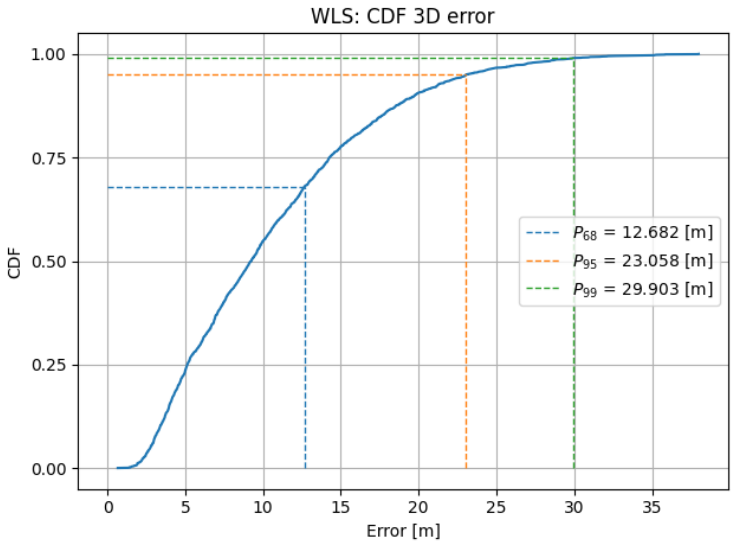
Dynamic Scenario

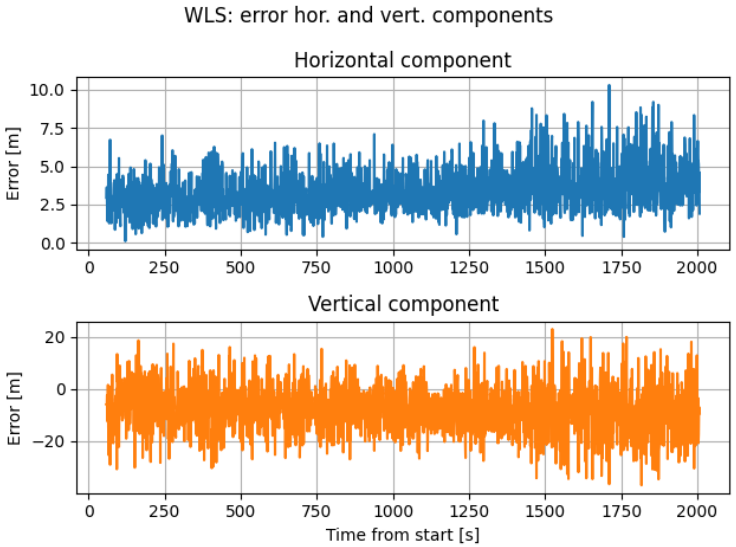
- Moving user over the Moon surface
- 4 LCNS satellites broadcasting AFS-I data component
- Satellite trajectories affected by orbit determination errors
- Observables coming from:
  - AFS only
  - AFS + DEM
  - AFS + differential corrections
  - AFS + DEM + differential corrections
- Positioning techniques: WLS

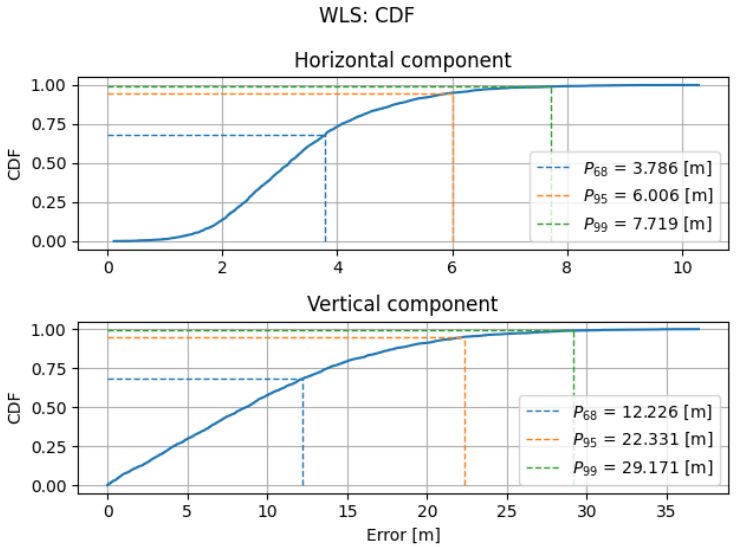


Dynamic Scenario – AFS-I only

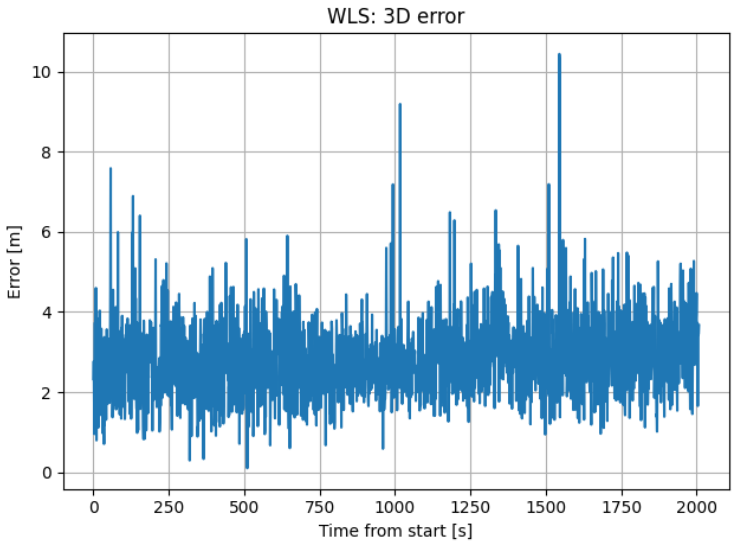


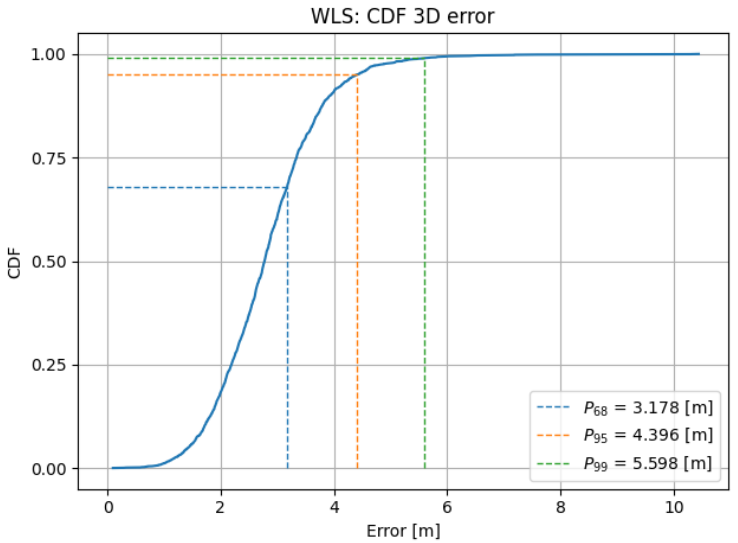


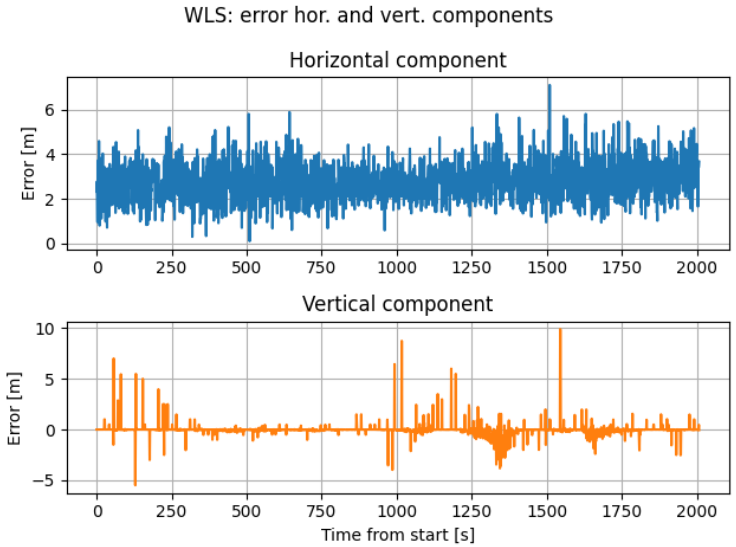


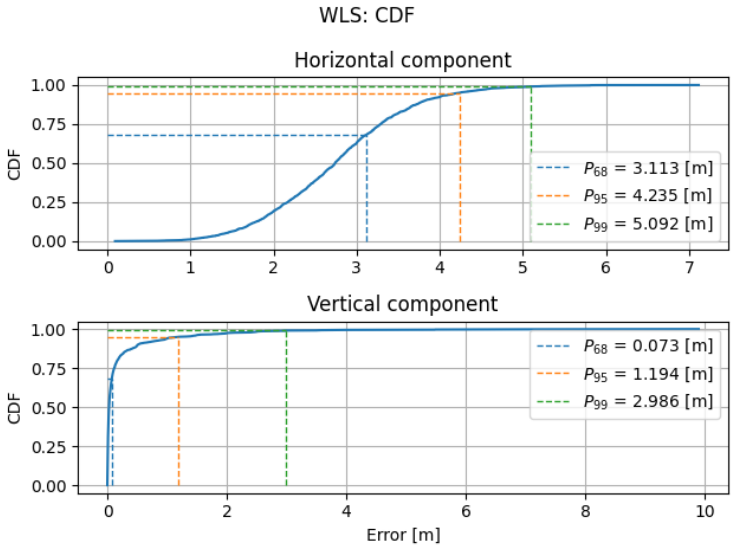


Dynamic Scenario – AFS-I + DEM

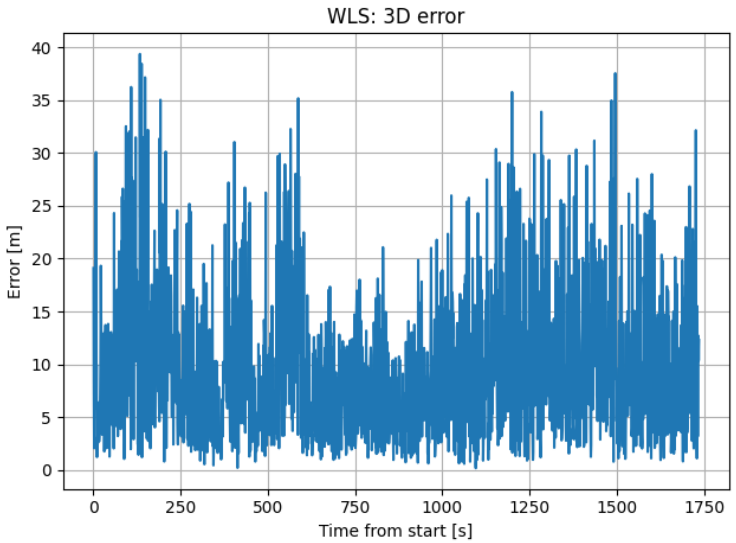


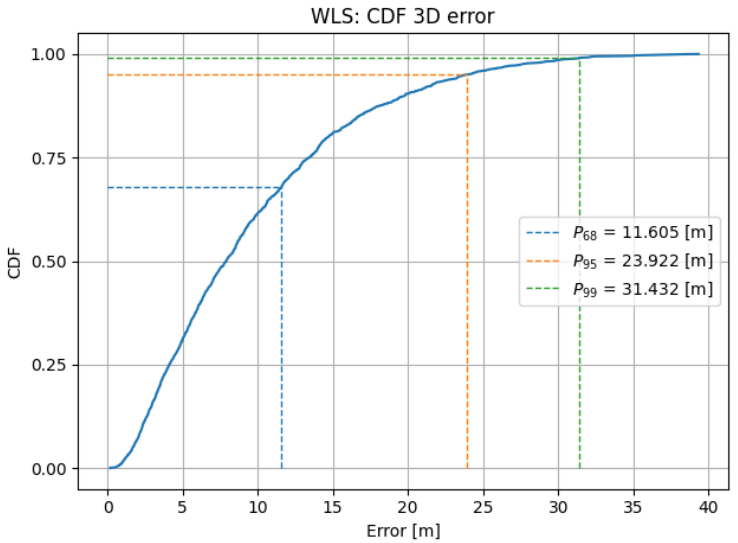


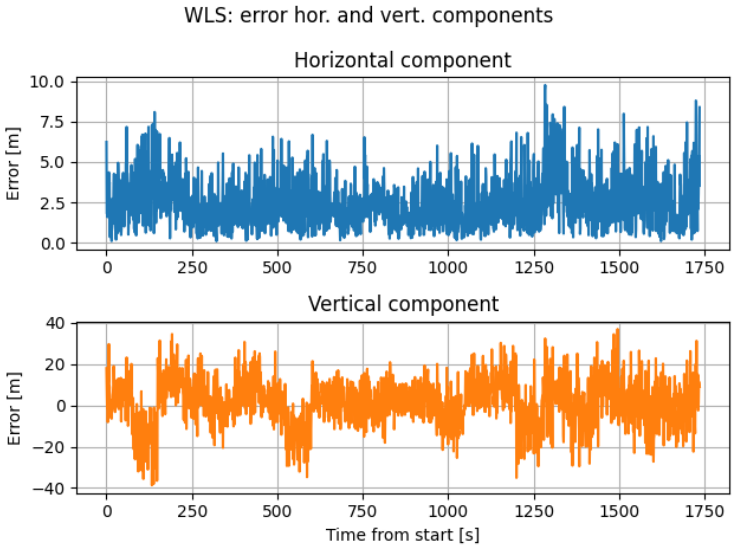


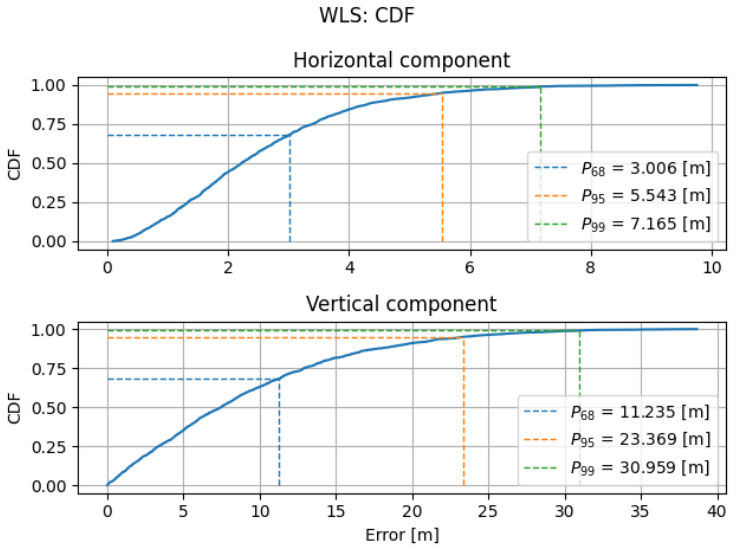


Dynamic Scenario – AFS-I + differential corrections

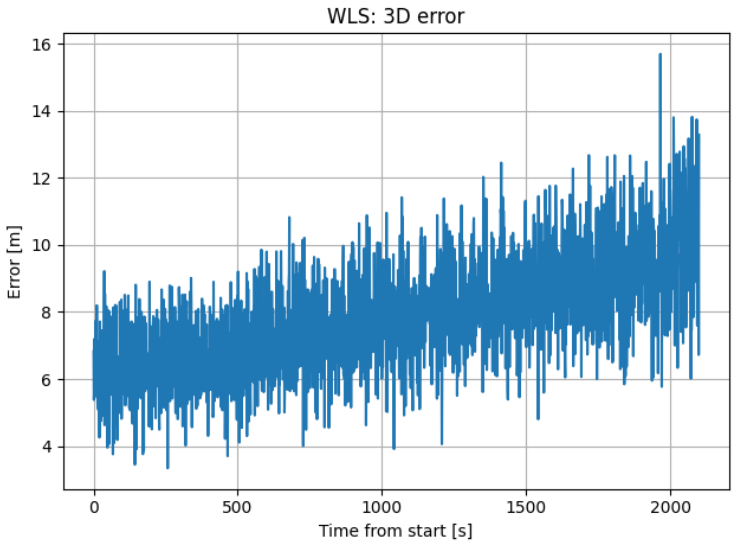


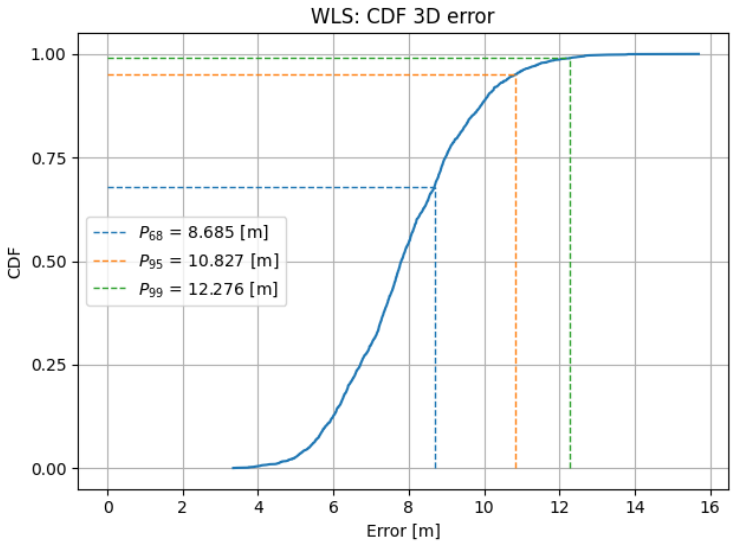


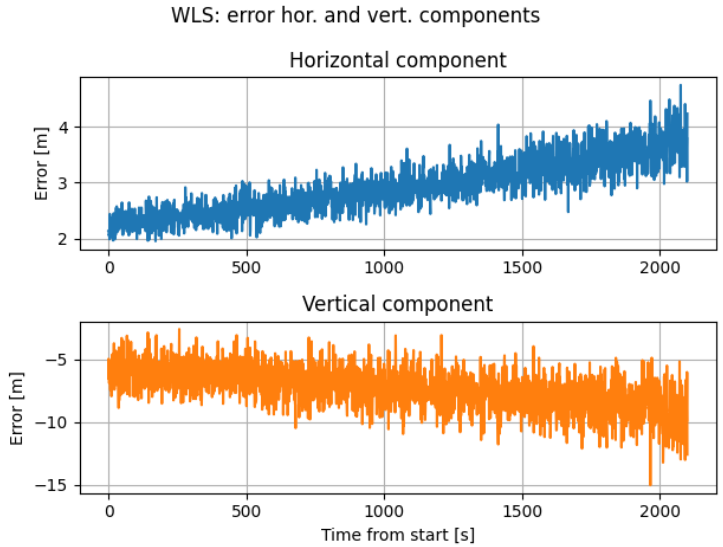


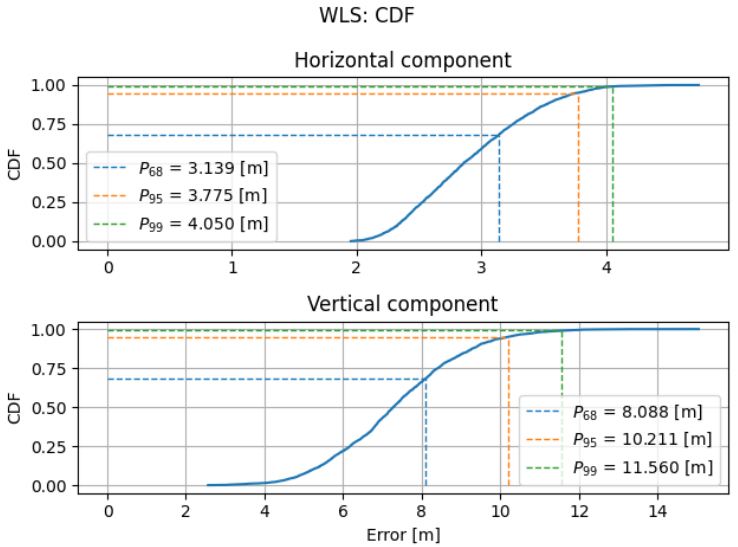


Dynamic Scenario – AFS-Q only

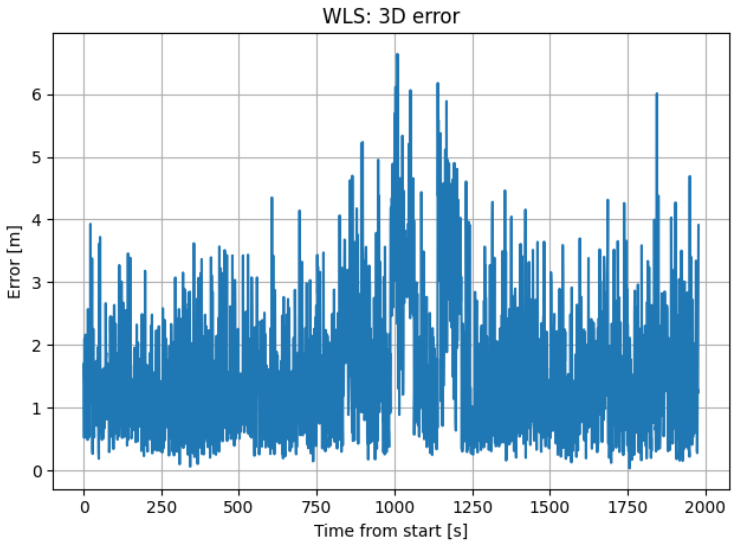


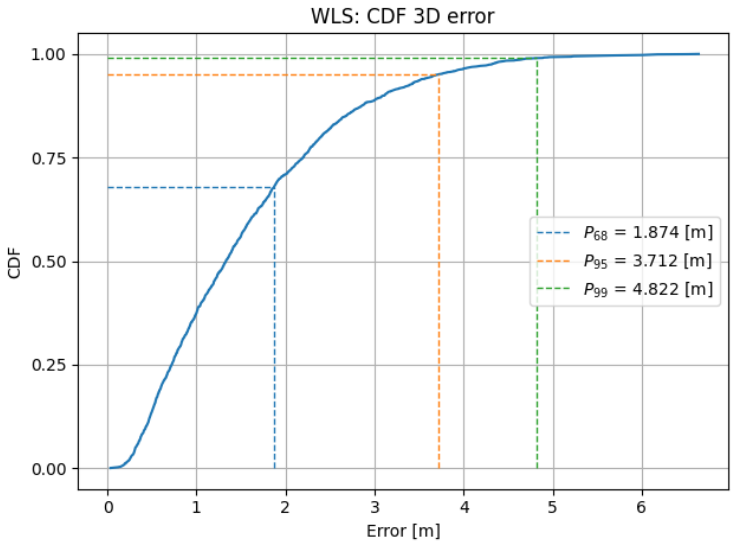


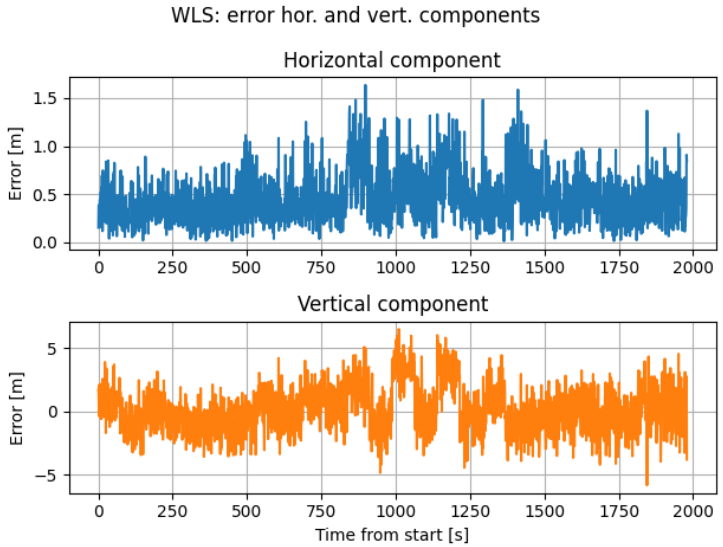


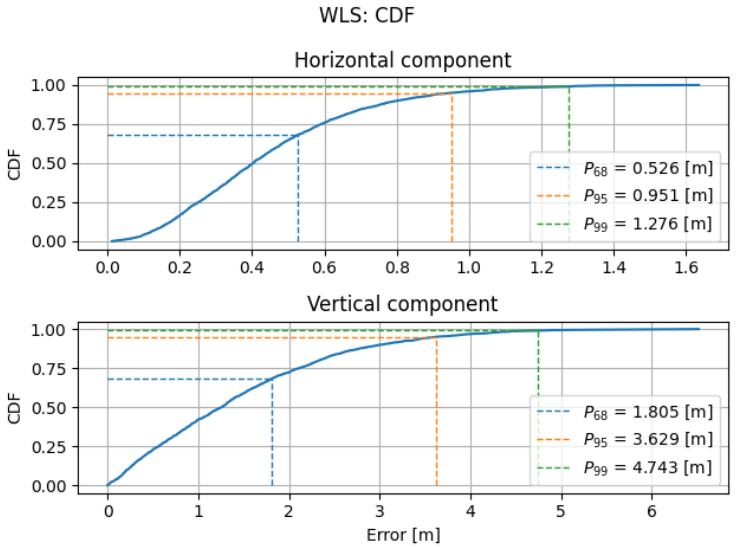


Dynamic Scenario – AFS-Q + differential corrections









Summary tables – 2-sigma accuracies

AFS-I	Horizontal	Vertical	3D
AFS-I only	6.006	22.331	23.058
AFS-I+DEM	4.235	1.194	4.396
AFS-I + diff. corr.	5.543	23.369	23.922
AFS-I + DEM + diff. corr.	3.872	2.003	4.185

AFS-Q	Horizontal	Vertical	3D
AFS-Q only	3.775	10.211	10.827
AFS-Q+DEM	2.917	1.011	3.025
AFS-Q + diff. corr.	0.951	3.629	3.712
AFS-Q +DEM +diff. corr.	0.748	1.102	1.121

- DEM strongly improves vertical direction
- Differential corrections strongly improves horizontal direction when using AFS-Q

Conclusions

Conclusions

- Development of an end-to-end testbed, including:
  - Moon station prototype (beacon + LCNS receiver) – TRL 5
  - LCNS constellation simulator (QA707) – TRL 9
  - LCNS receiver prototype (QN400) – TRL 6
- Performed experimentation campaign shows that:
  - Moon station beacon provides limited advantages if DEM and differential corrections are used
  - DEM provides significant benefits in the vertical direction
  - Differential corrections provides significant benefits in the horizontal direction, if the pilot signal is used
  - Corrections are effective for long intervals (several minutes) and large areas (few hundreds of km)
- Foreseen improvements on LCNS receiver:
  - Support to pilot signal component
  - Full demodulation capability
  - Improvement on PPS accuracy
  - TRL 9

Thank you!

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