DEMOS-1
Final Presentation

January 15th, 2026
Webinar

Contract n.:
4000139484/22/NL/PS
NAVISP-EL1-062
“Lunar Surface PNT Beacon Demonstrator”

Consortium

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Agenda

- Introduction to the Project
- Preliminary Full Moon Station Design
- Moon Station Testbed Development
- Main Results from Experimentation
- Conclusions

Introduction to the Project

Objectives

- 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 ranging signals
- 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 the future models.

Preliminary Full Moon Station Design

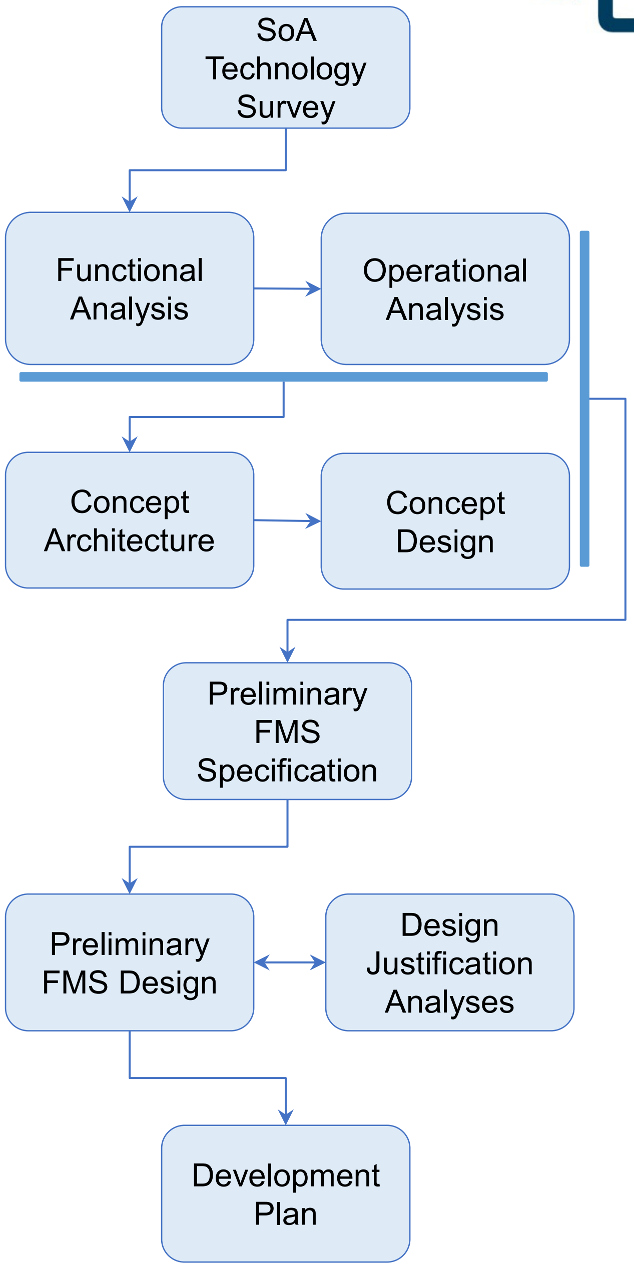
FMS Activity overview

The *Lunar PNT Beacon and Reference Station* (Full Moon Station, FMS), consists in a Fixed Lunar Surface system, cooperating with the future MoonLight and LunaNet lunar navigation orbiters, and providing:

- Enhanced navigation service performance to users in the area of the Lunar South Pole (surface and orbiters), by means of differential corrections computation and broadcasting and a local navigation beacon transmission;
- LCNS satellites monitoring, by collecting the satellites ranging and observable data;
- Station operation performance during day and night conditions, through power distribution, telemetry and command exchange, thermal control, etc.

The FMS related activities were conducted according to the following steps:

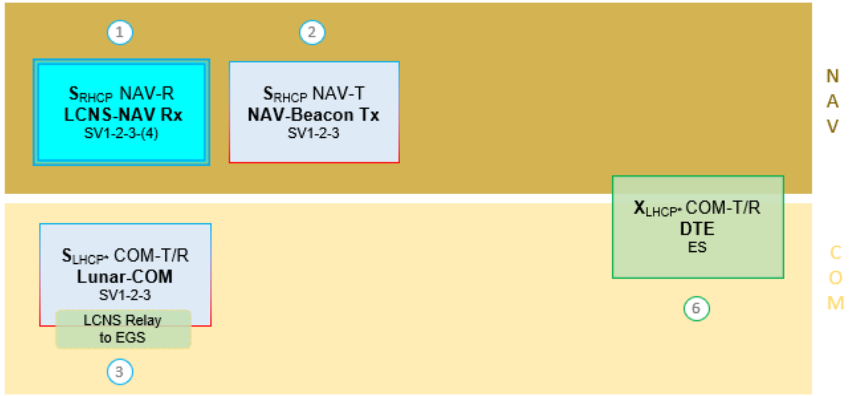
- SoA Survey
- Functional Analysis
- Operational Analysis
- Concept Architecture
- Concept Design
- Preliminary Specification Definition
- Preliminary Desing
- Design Justification Analyses
- Development Plan



Nav/Comm links and P/L modularity

The FMS system consists in the complete payload system. The payload has been designed assuming that it is housed onboard a CLPS lander platform for a continuous operation in a lunar south pole landing site. The P/L includes the modules:

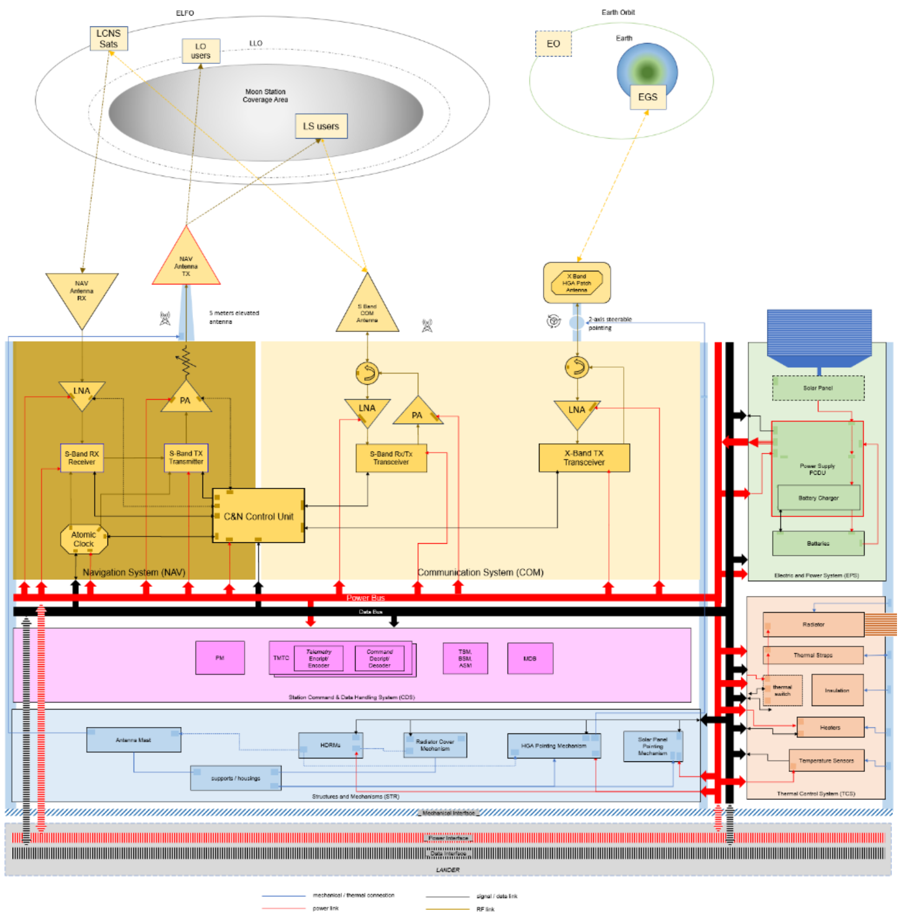
- The LCNS-NAV Receiver module, comprising all the equipment needed for the receival and processing of the LCNS satellites ranging signals.
- The NAV-Beacon Transmitter module, comprising all the equipment needed for the transmission of the FMS navigation beacon to the users in the lunar surface, in the Low Lunar Orbit (LLO), and to lander/ascent vehicles.



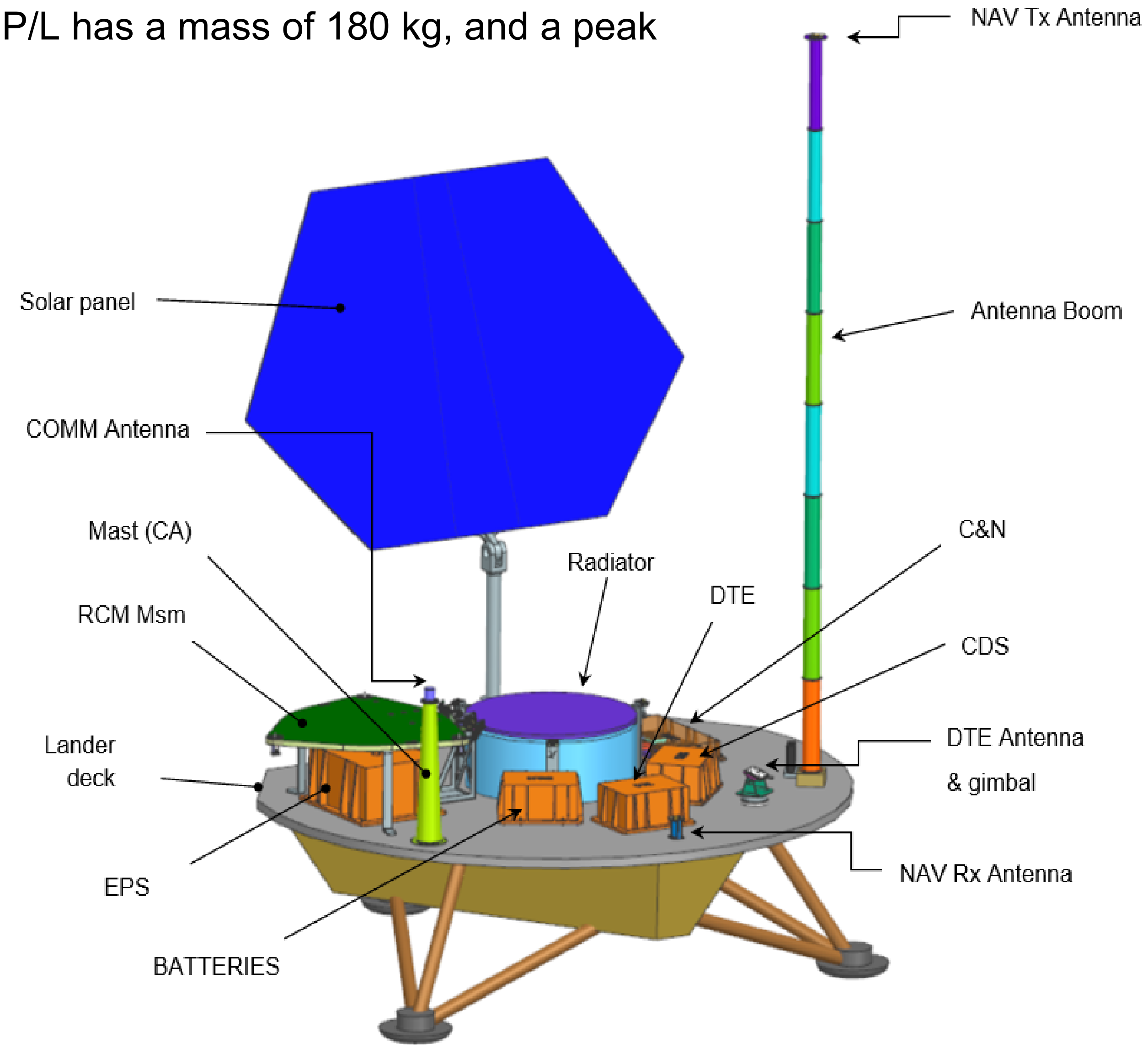
- The Lunar-COM Module, comprising all the equipment for the bidirectional exchange of communication data from and to the FMS, up to the LCNS satellite orbit, and to the lunar surface users.
- The Direct to Earth (DTE) Module, comprising all the equipment needed for the bidirectional communication with ground station on Earth.

Preliminary design

The FMS layout is displayed in the deployed configuration. The P/L has a mass of 180 kg, and a peak power of 440 W, including subsystem and system margins.



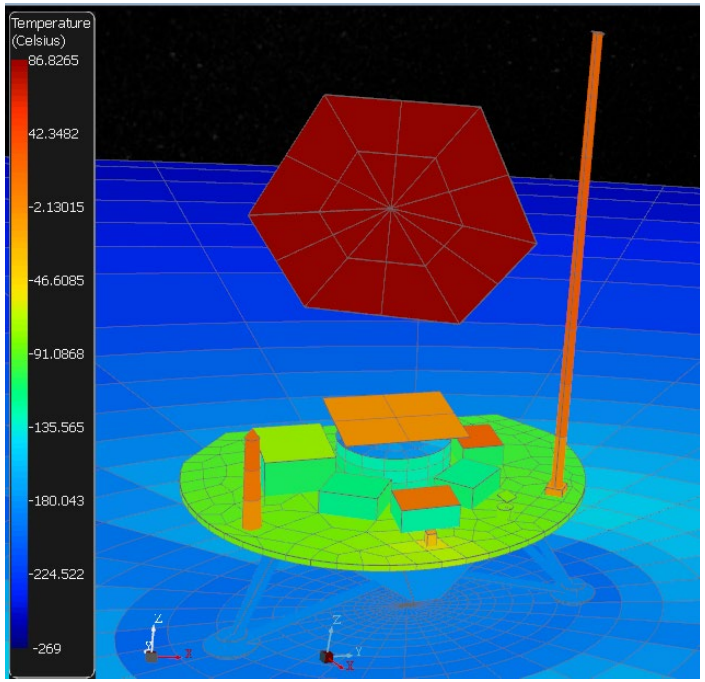
FMS Physical Architecture



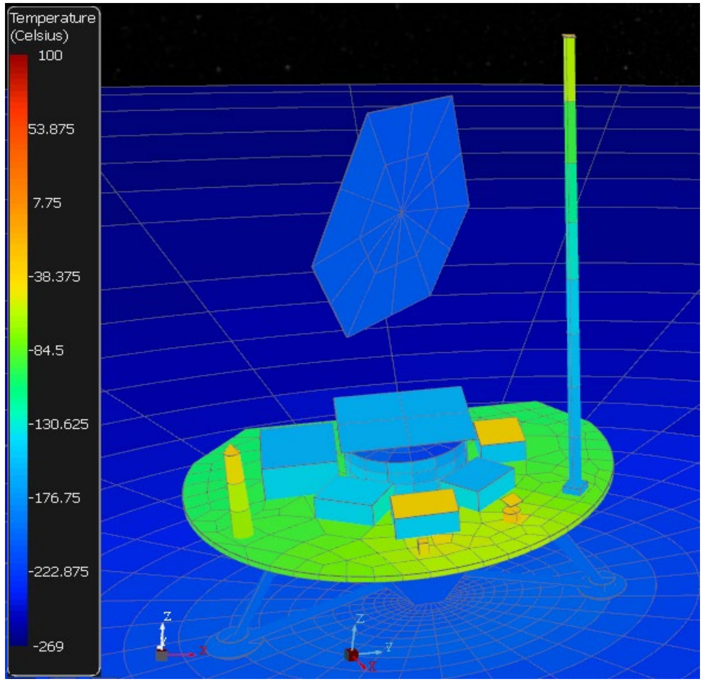
FMS Layout

Thermal analysis

Following the definition of the communication and navigation, and the ancillary subsystems identification and sizing, a special consideration was dedicated to the definition of the thermal design, given the harsh conditions expected in the lunar environment, and the night survival capability requirement.



Thermal analysis in lunar day conditions

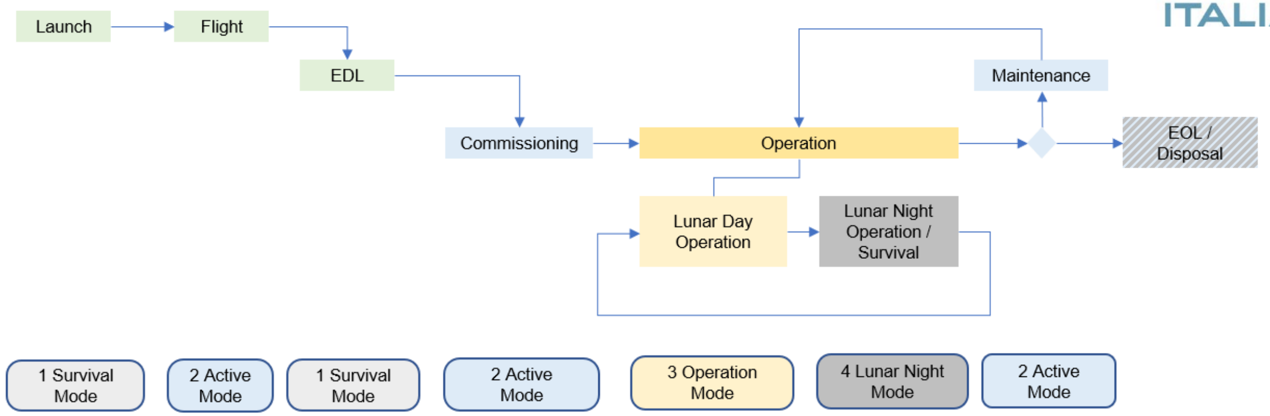


Thermal analysis in lunar night conditions

FMS Operation

Different modes have been identified for the P/L during the different mission phases:

- Survival Model
- Active Mode
- Operative Mode
- Night Mode



Mode	Description
Survival	During the critical phases of launch and landing, all the functionalities shall be kept at minimum. The Payload is off. It can be switched on by the lander on-board computer. The survival heating, when needed, is provided and controlled by the lander.
Active	During flight a reduced set of telemetry data are exchanged between the payload and the lander, the lander provides the power and the communication link to Earth Ground Station (EGS).After landing, a set of tests and checkout are performed to ensure that all the equipment is working properly, collect the relevant data, and send it to EGS before starting the station operation. The active mode includes two sub-modes: - Stand-by sub-mode: the P/L Electronic Unit is on and ready to receive TC from Earth (via the Lander); this mode can be activated during flight cruise. - Ready sub-mode: the P/L is under control of the P/L EU; the P/L can exchange data with the Lander and the Earth, can manage operations schedule/sequence in autonomous or semi-autonomous operations, can perform check-outs. The two sub-modes cannot be run at the same time.
Operative	During the lunar day operation, all the implemented functions and services are active, including navigation service to the users, LCNS satellite monitoring, communications with EGS. The Moon Station activity is under control of the payload Command and Data Handling System.
Night	During the lunar night, environmental temperatures drop to values down to -150 °C ÷ -200 °C depending on latitude and location, for a duration up to 14 clock days. The Moon Station has to survive the lunar night, and energy provision systems shall grant the necessary heating power. Minimum equipment operation during the night shall include clock and control system supervision, collecting intermittent telemetry data and overseeing the switching to different modes or activation of selected operations. Additionally, a reduced set of service operations can be activated between intervals (e.g., every 24 hours), depending on the necessity and power capabilities. The power provision is either in charge to the lander, if available, or integrated as a payload unit.

Moon Station Testbed Development

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

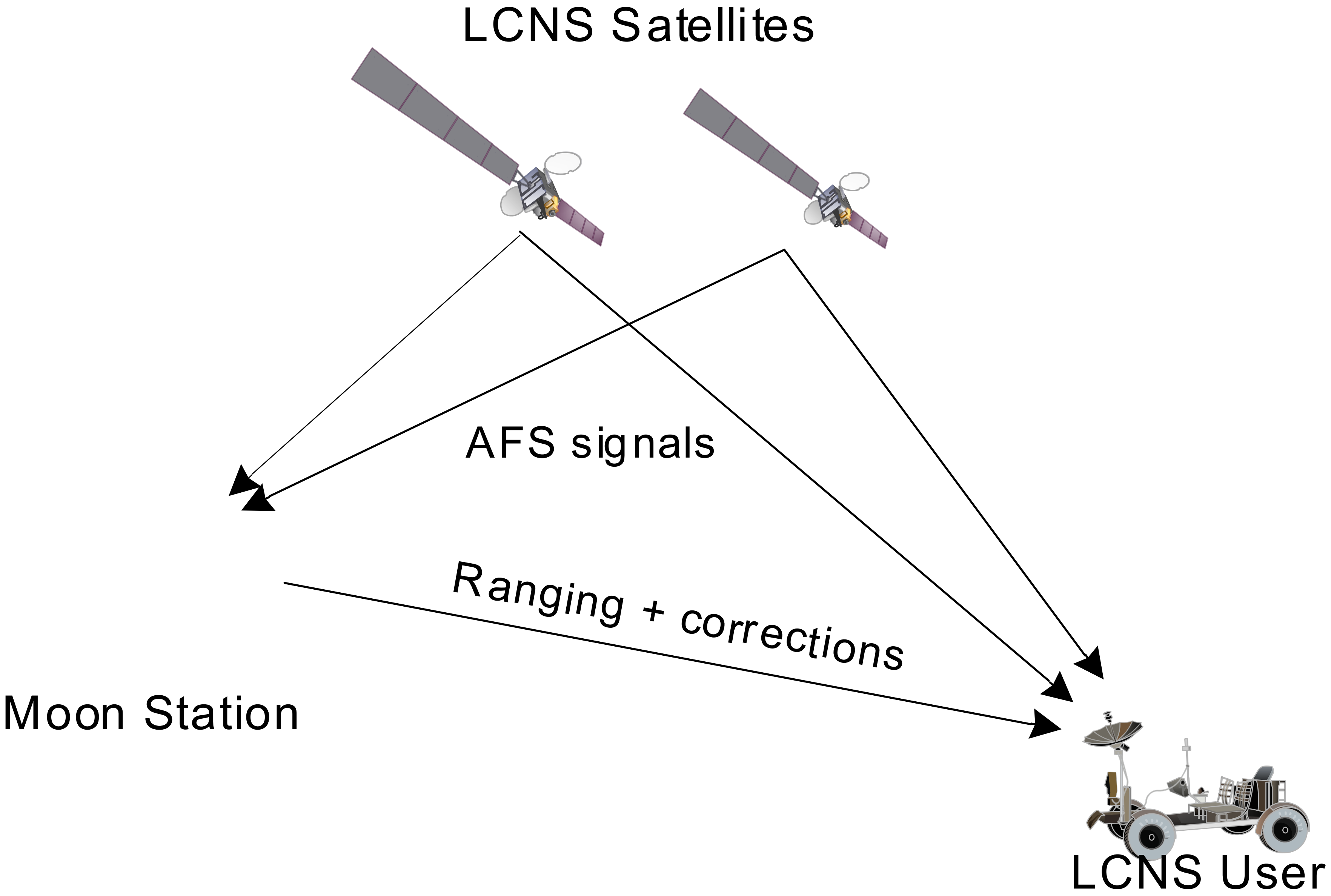
- LCNS receiver prototype (S-band)
- LCNS AFS-I – BPSK(1), data
- Demodulation of time information of AFS navigation message (first ICD)
- PPS aligned to system time
- External navigation engine: LS, EKF, differential corrections, DEM
- TRL 6

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

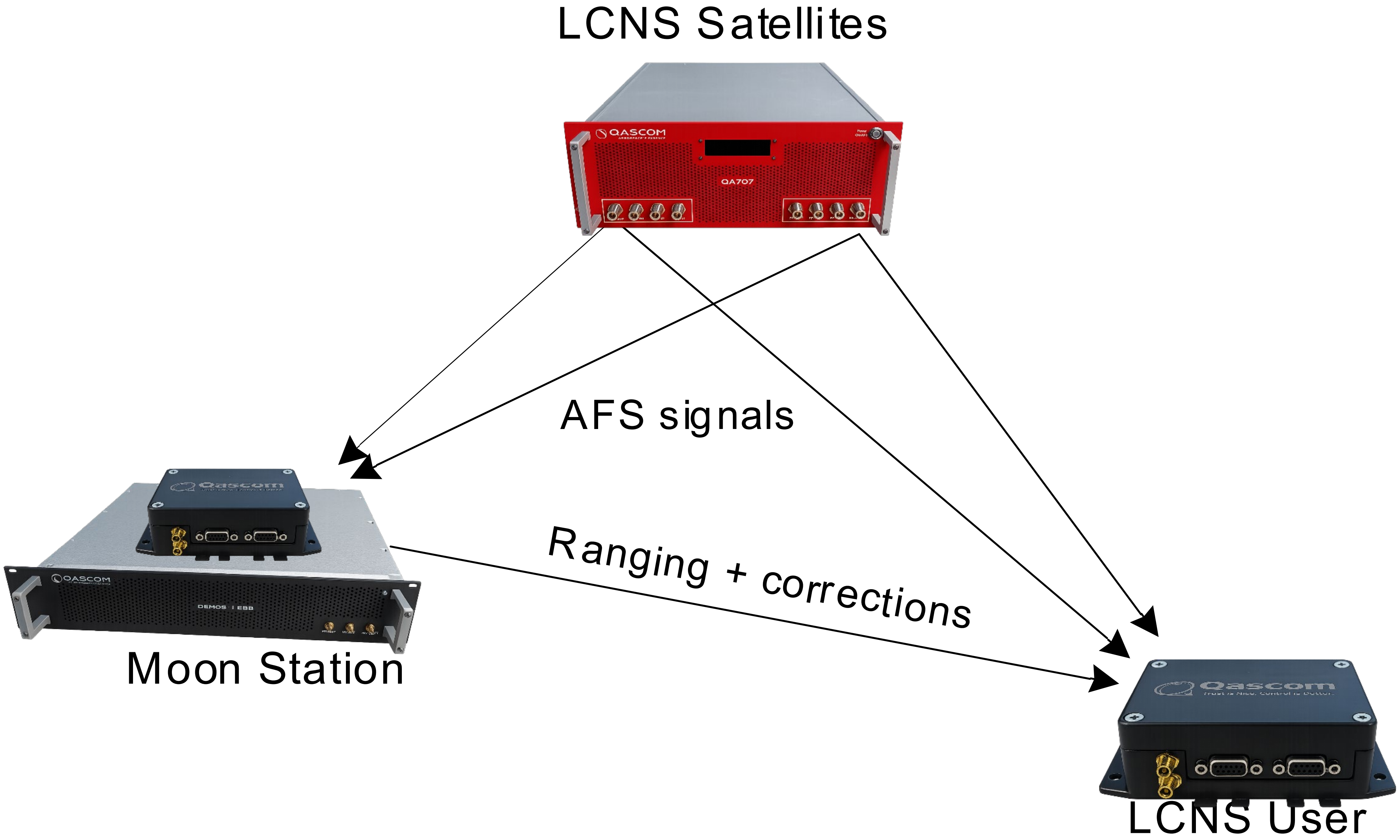
Developed Technology

- 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

Testbed Setup



Testbed Setup



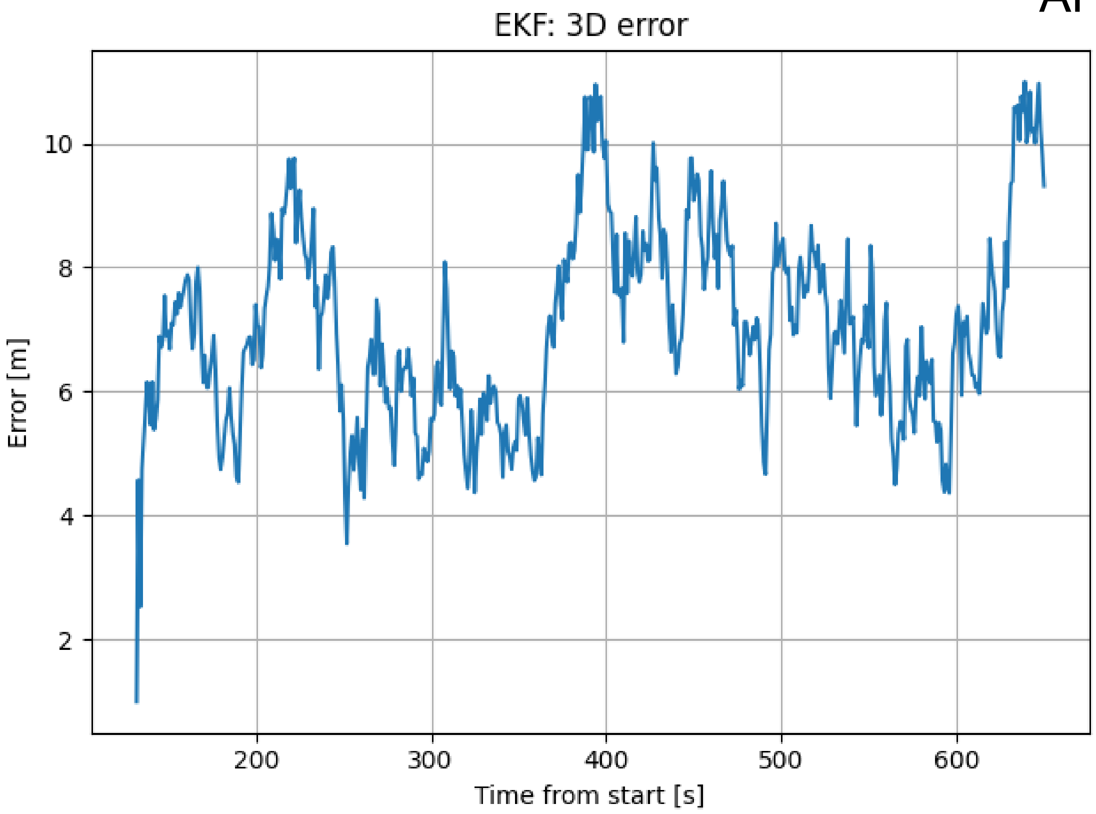
Testbed Picture

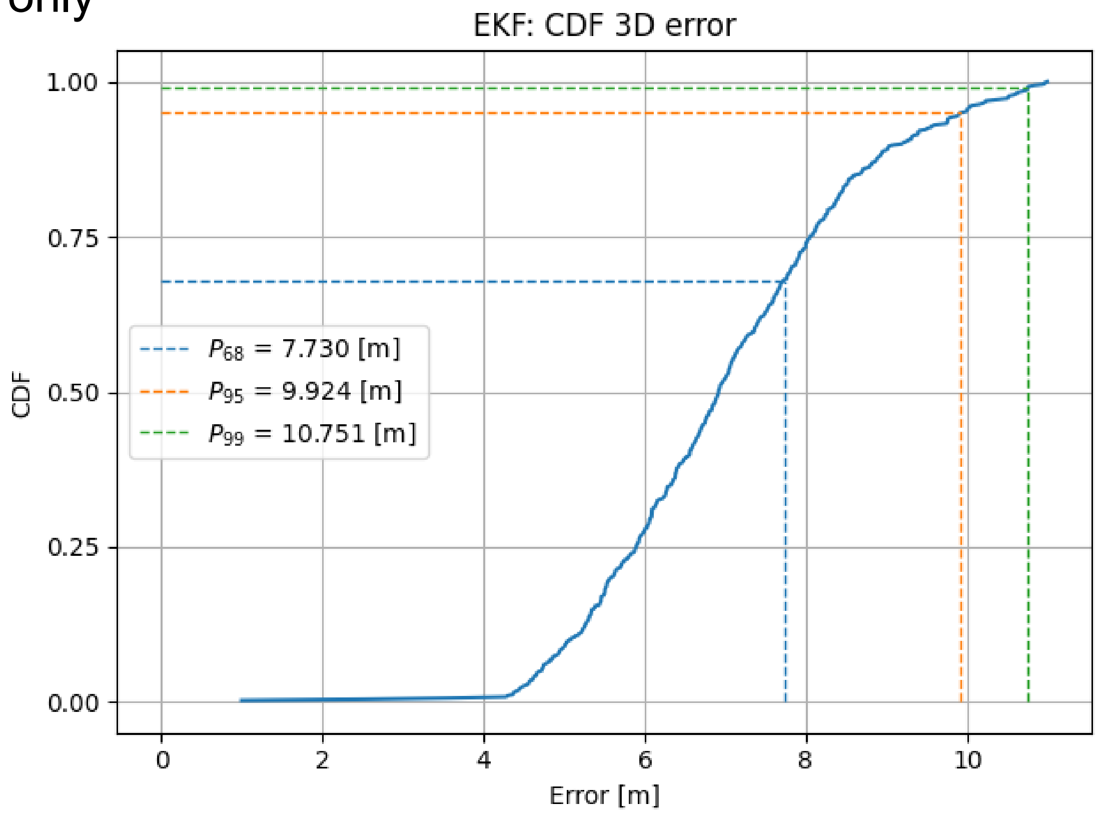
Main Results from the Experimentation

AFS-I vs AFS-I + beacon ranging signal

- Simulation scenario with 4 LCNS satellites broadcasting AFS
- Static user exploits satellites trajectories affected by OD error → URE affecting rx observables

AFS-I only

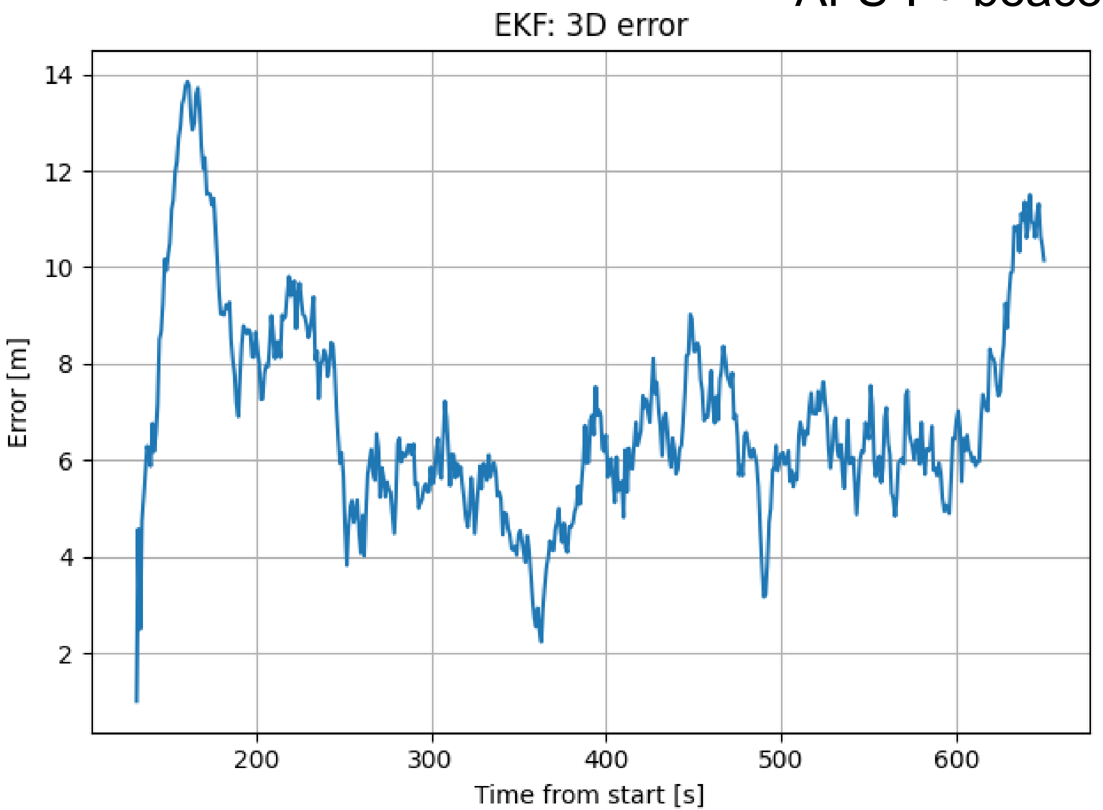


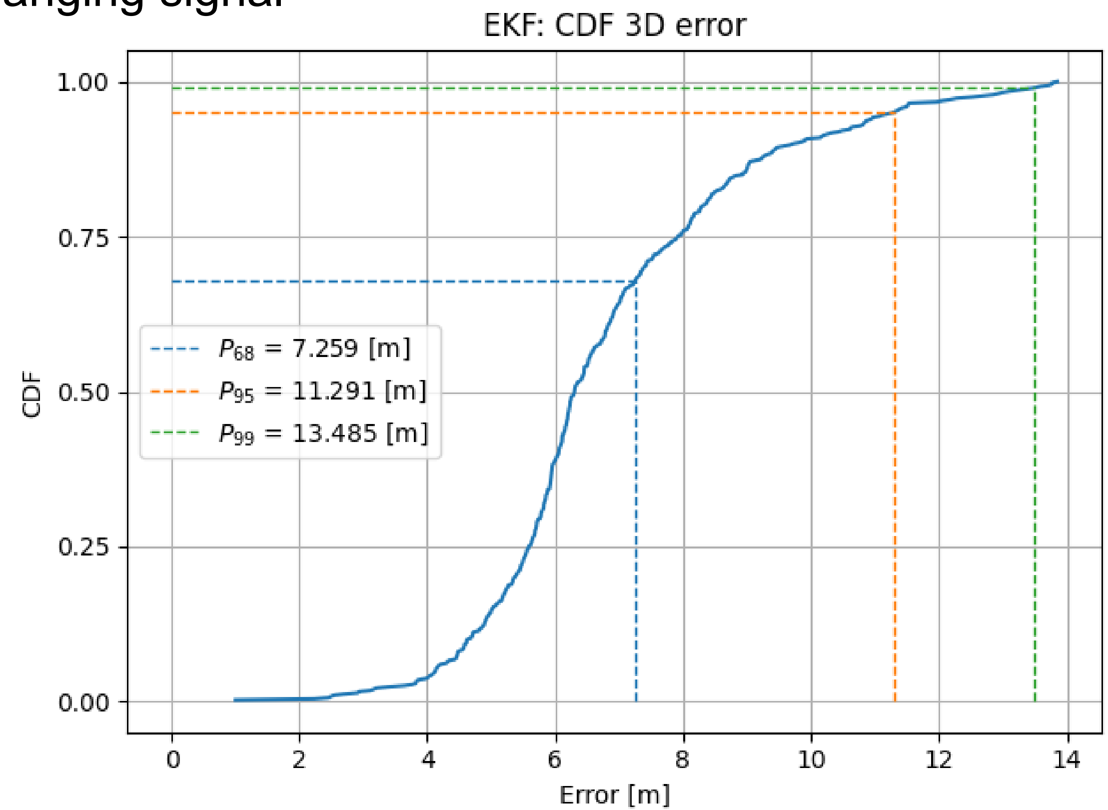


AFS-I vs AFS-I + beacon ranging signal

- Same scenario
- Now the Moon Station broadcasts the ranging signal → exploited by the user along LCNS AFS

AFS-I + beacon ranging signal

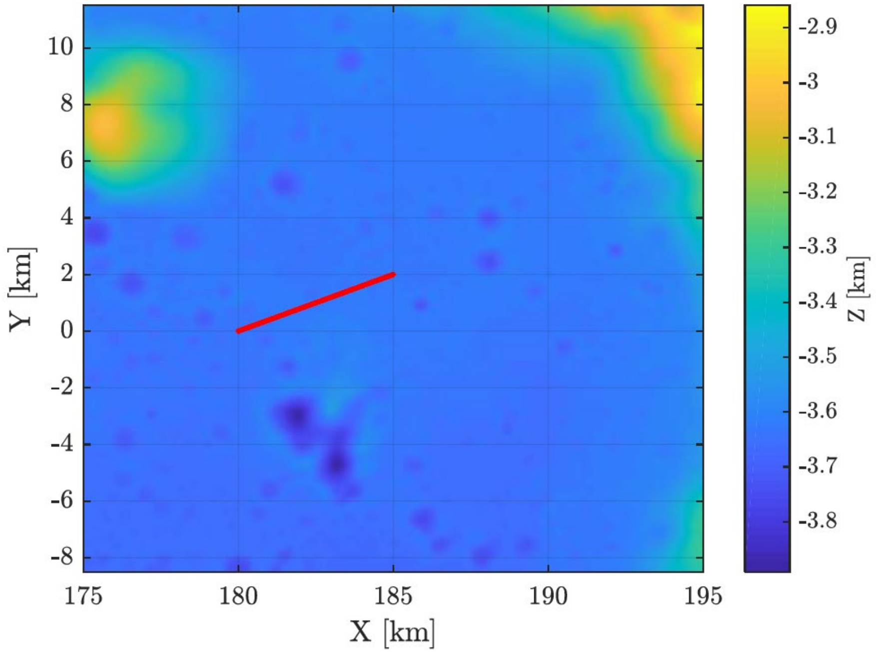




- Improvement covered by initial transient and negative impact of OD errors
- User needs to estimate the beacon tx offset (like GGTO for GPS-GAL PVT)

Exploiting differential corrections

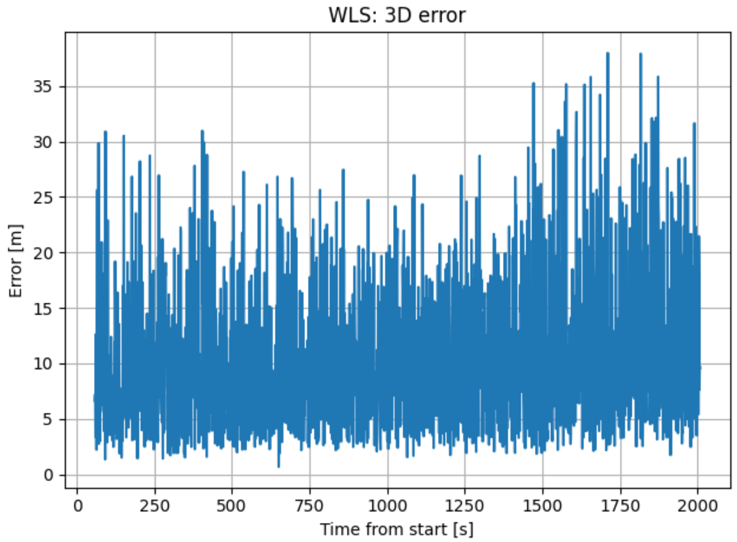
- New scenario, moving user over the Moon surface
- Simulation scenario with 4 LCNS satellites broadcasting AFS
- User exploits satellites trajectories affected by OD error
  - URE affecting rx observables
- Positioning performance using:
  - AFS only
  - AFS + DEM
  - AFS + differential corrections
  - AFS + DEM + differential corrections



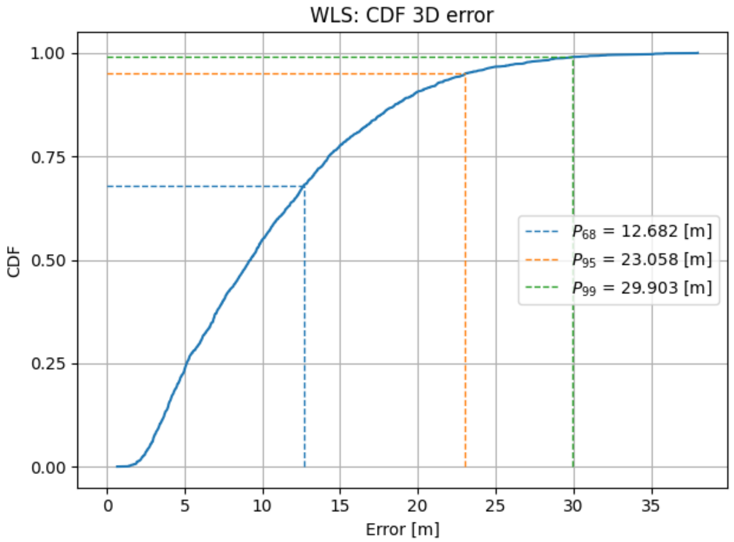
- Comparison between WLS and EKF
- Comparison between rx observables (AFS-I) against observables with theoretical measurements errors coming from tracking of AFS-Q (from analysis expected 1.2-1.3 degradation factor w.r.t. rx observations)

$$\sigma_{DLL} = \lambda_C \sqrt{\frac{B_L d}{2 \cdot CN0}\left(1 + \frac{1}{T_i \cdot CN0}\right)}$$

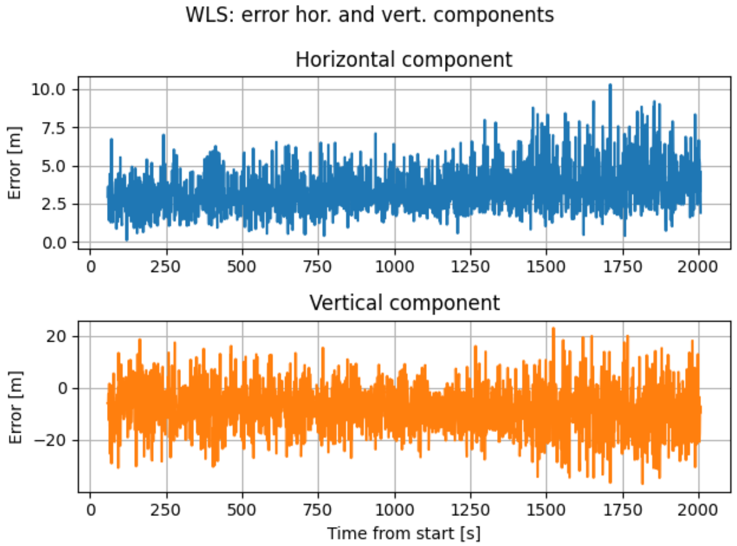
AFS-I only



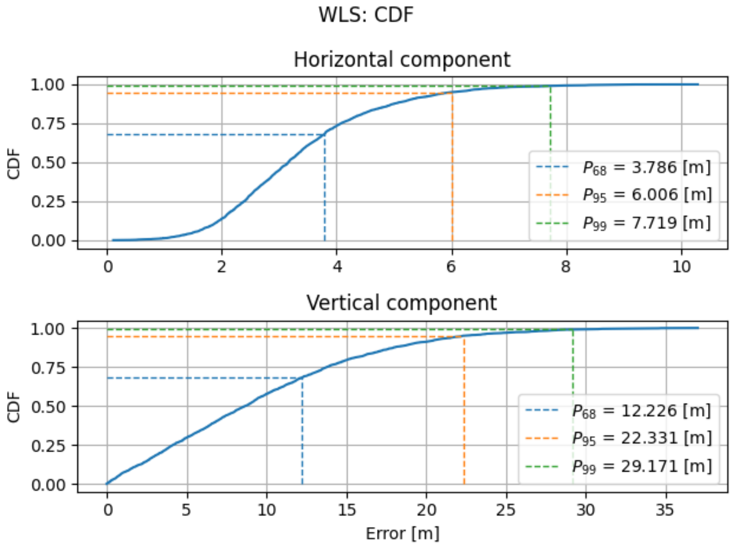
WLS: 3D error
Error [m]
Time from start [s]



WLS: CDF 3D error
CDF
Error [m]
P_{68} = 12.682 [m]
P_{95} = 23.058 [m]
P_{99} = 29.903 [m]

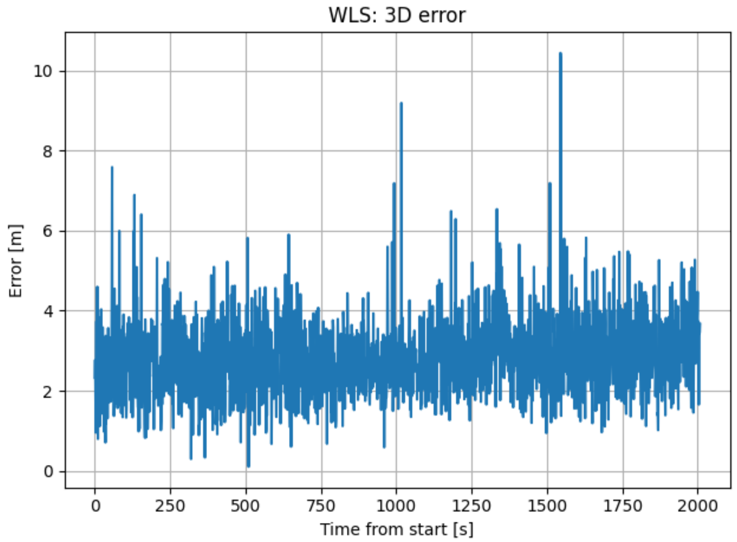


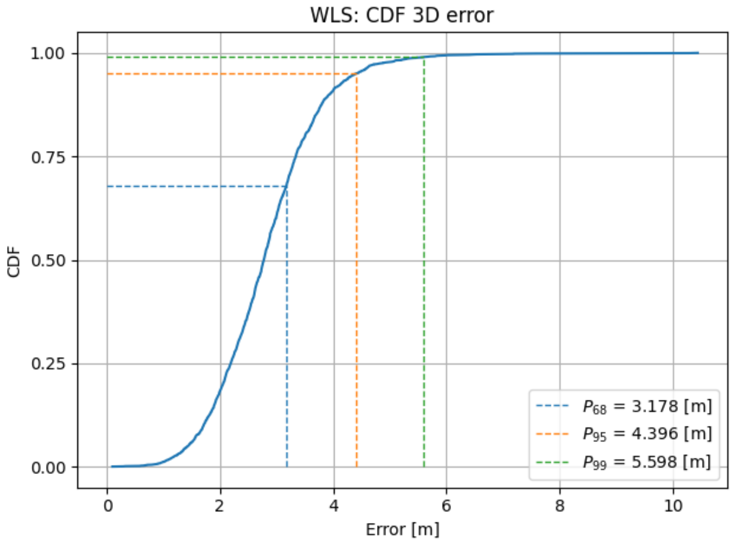
WLS: error hor. and vert. components
Horizontal component
Error [m]
Vertical component
Error [m]
Time from start [s]

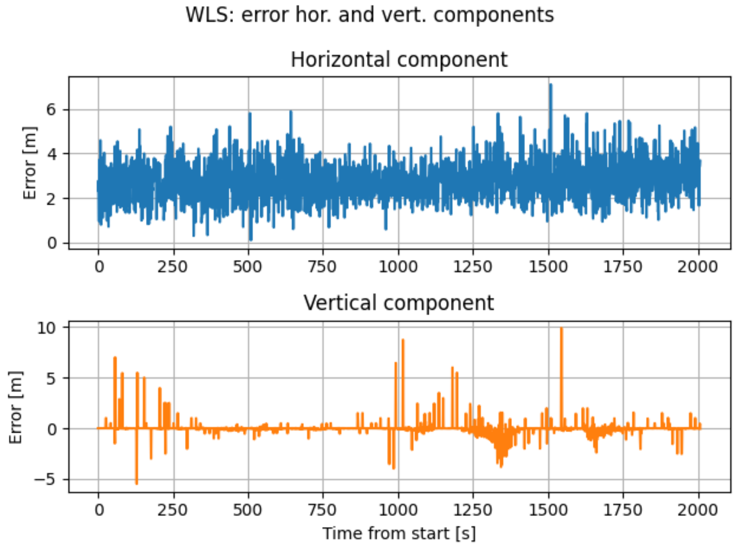


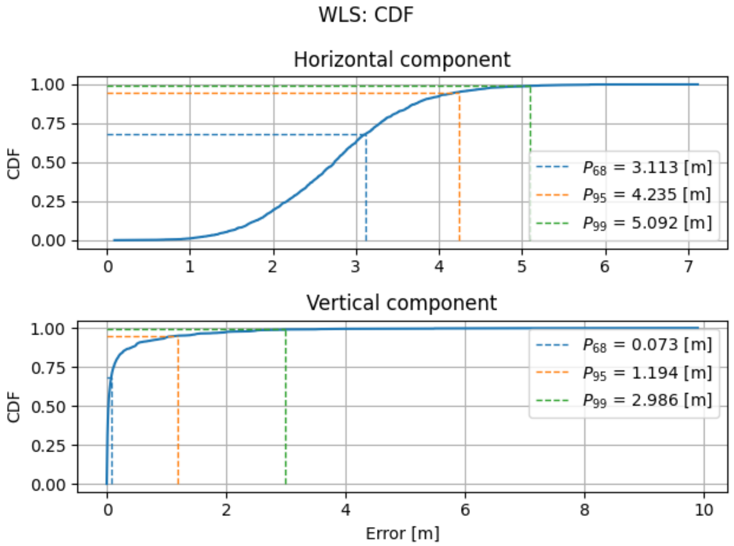
WLS: CDF
Horizontal component
CDF
P_{68} = 3.786 [m]
P_{95} = 6.006 [m]
P_{99} = 7.719 [m]
Vertical component
CDF
P_{68} = 12.226 [m]
P_{95} = 22.331 [m]
P_{99} = 29.171 [m]
Error [m]

AFS-I + DEM

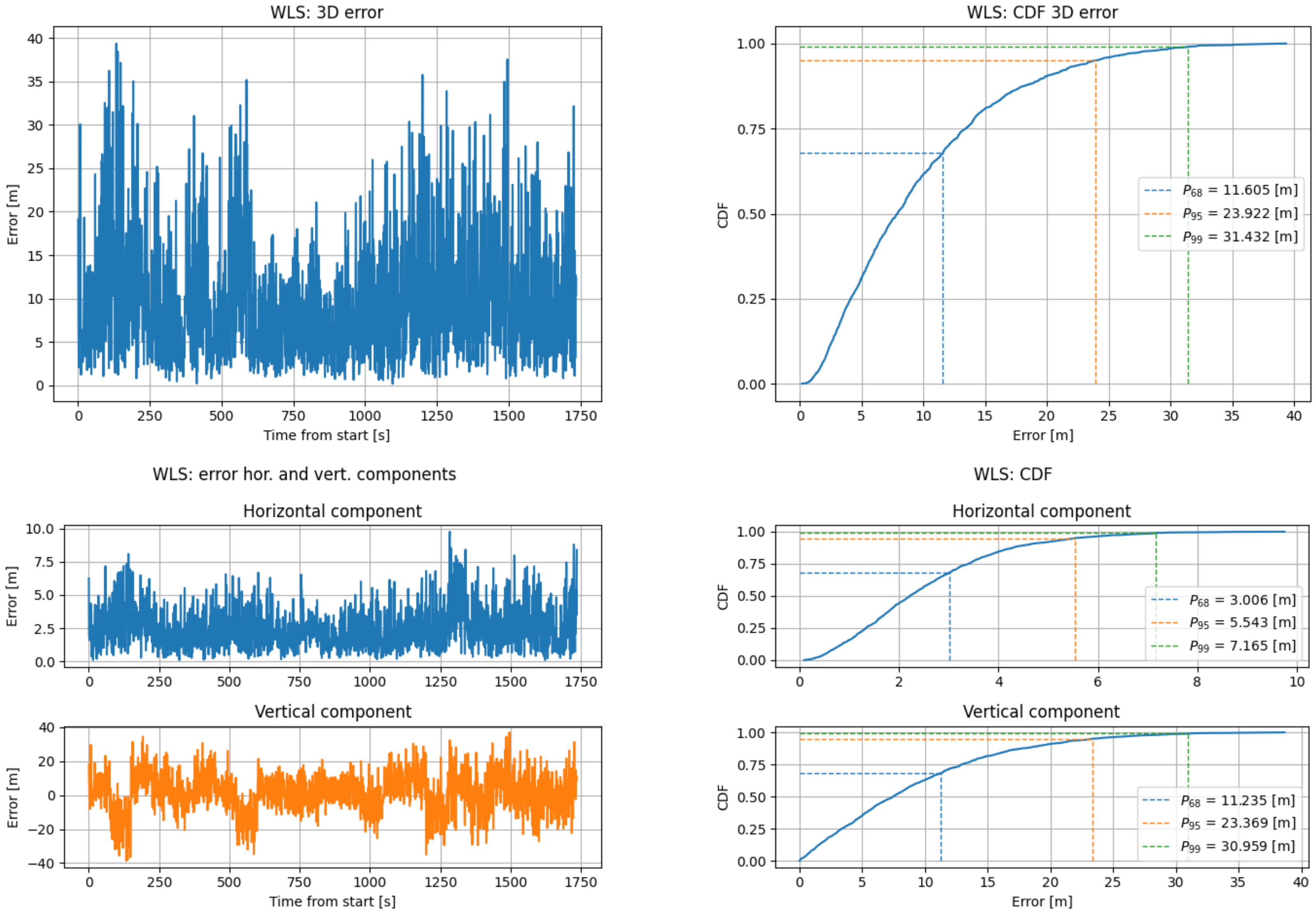

WLS: 3D error
Error [m]
Time from start [s]


WLS: CDF 3D error
CDF
Error [m]
P_{68} = 3.178 [m]
P_{95} = 4.396 [m]
P_{99} = 5.598 [m]

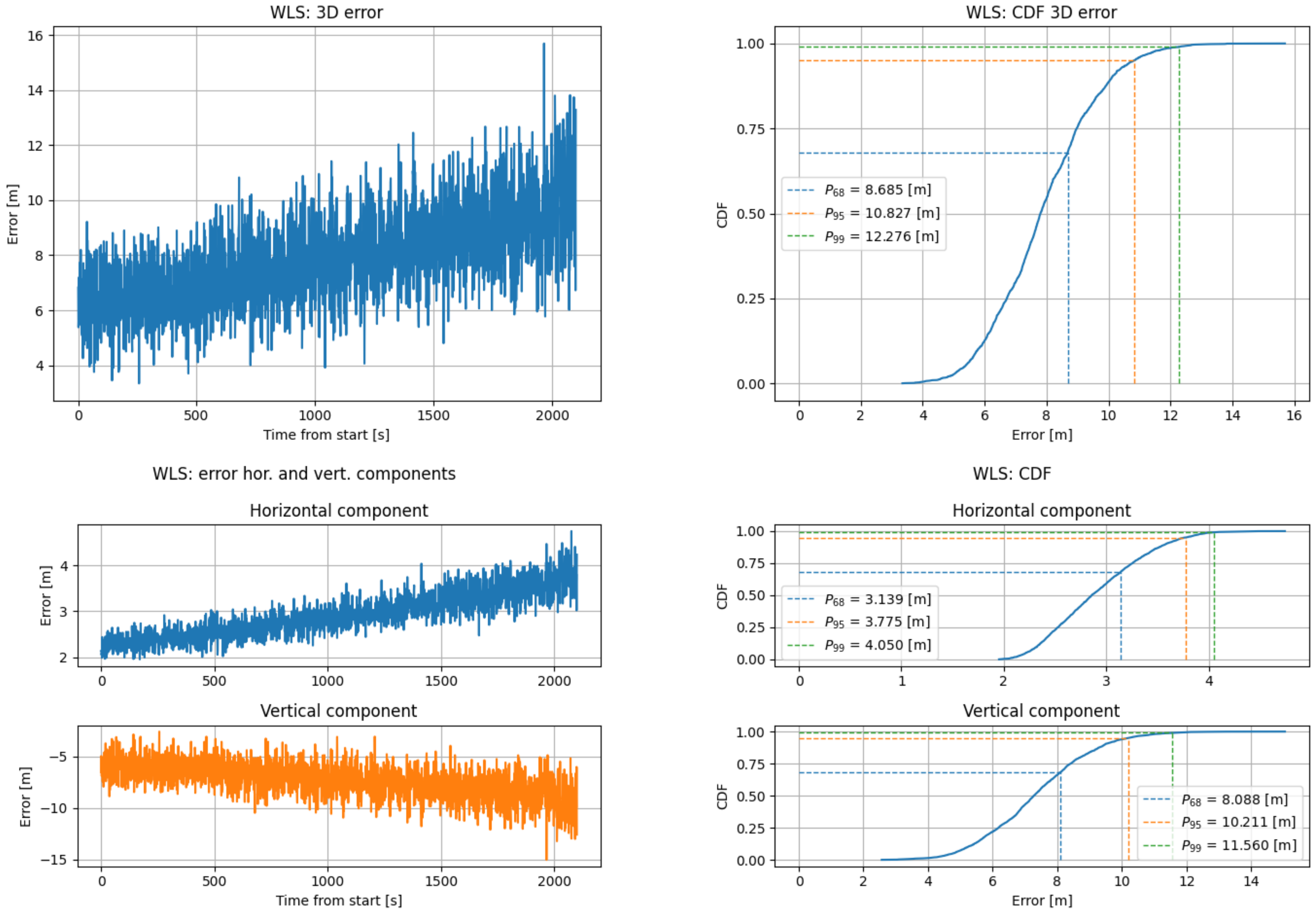

WLS: error hor. and vert. components
Horizontal component
Vertical component
Error [m]
Time from start [s]


WLS: CDF
Horizontal component
CDF
P_{68} = 3.113 [m]
P_{95} = 4.235 [m]
P_{99} = 5.092 [m]
Vertical component
P_{68} = 0.073 [m]
P_{95} = 1.194 [m]
P_{99} = 2.986 [m]
Error [m]

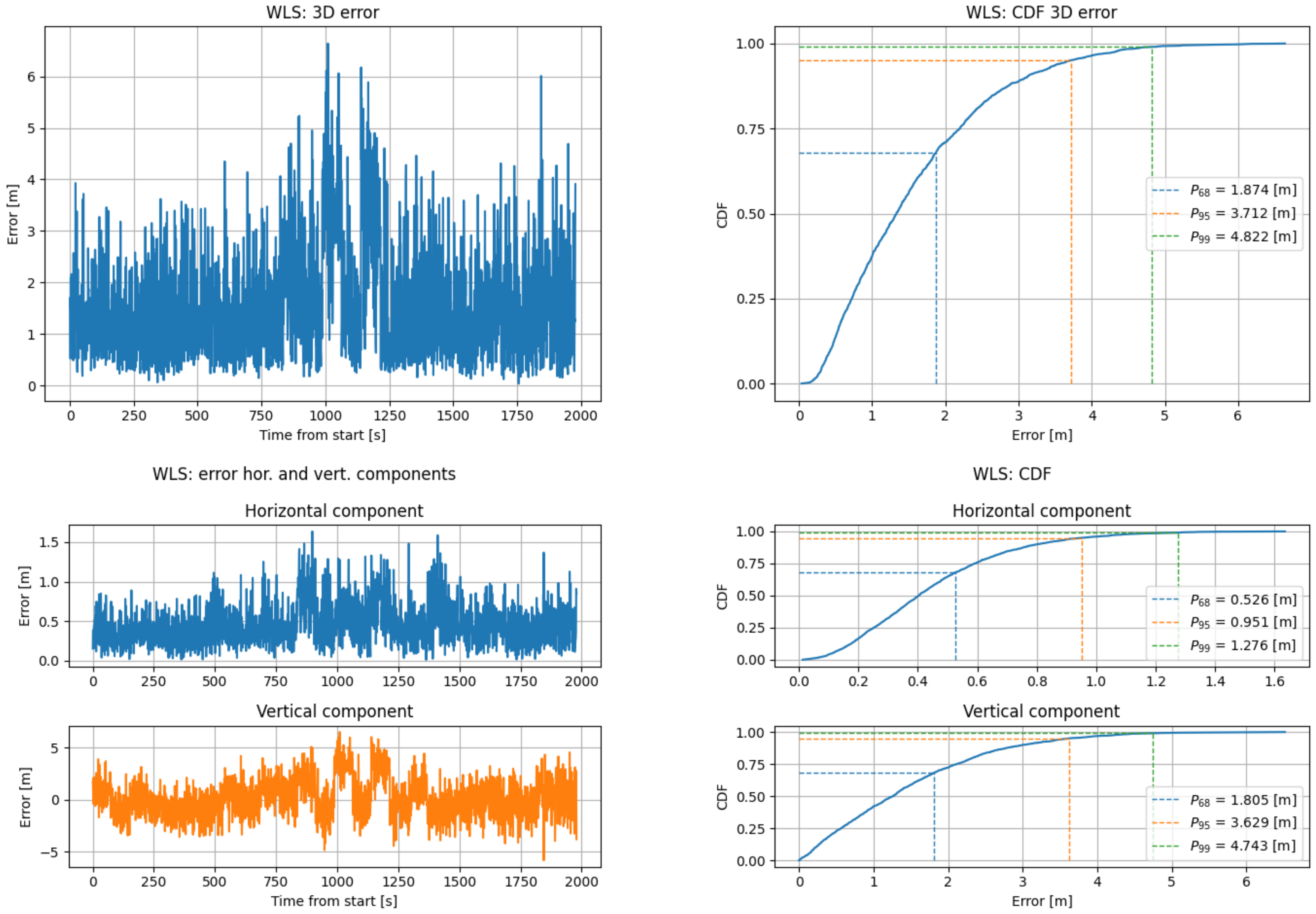
AFS-I + differential corrections



AFS-Q only


WLS: 3D error
Error [m]
Time from start [s]
WLS: CDF 3D error
CDF
Error [m]
P_{68} = 8.685 [m]
P_{95} = 10.827 [m]
P_{99} = 12.276 [m]
WLS: error hor. and vert. components
Horizontal component
Error [m]
Vertical component
Error [m]
Time from start [s]
WLS: CDF
Horizontal component
CDF
P_{68} = 3.139 [m]
P_{95} = 3.775 [m]
P_{99} = 4.050 [m]
Vertical component
CDF
P_{68} = 8.088 [m]
P_{95} = 10.211 [m]
P_{99} = 11.560 [m]
Error [m]

AFS-Q + differential corrections



Summary tables and comparisons

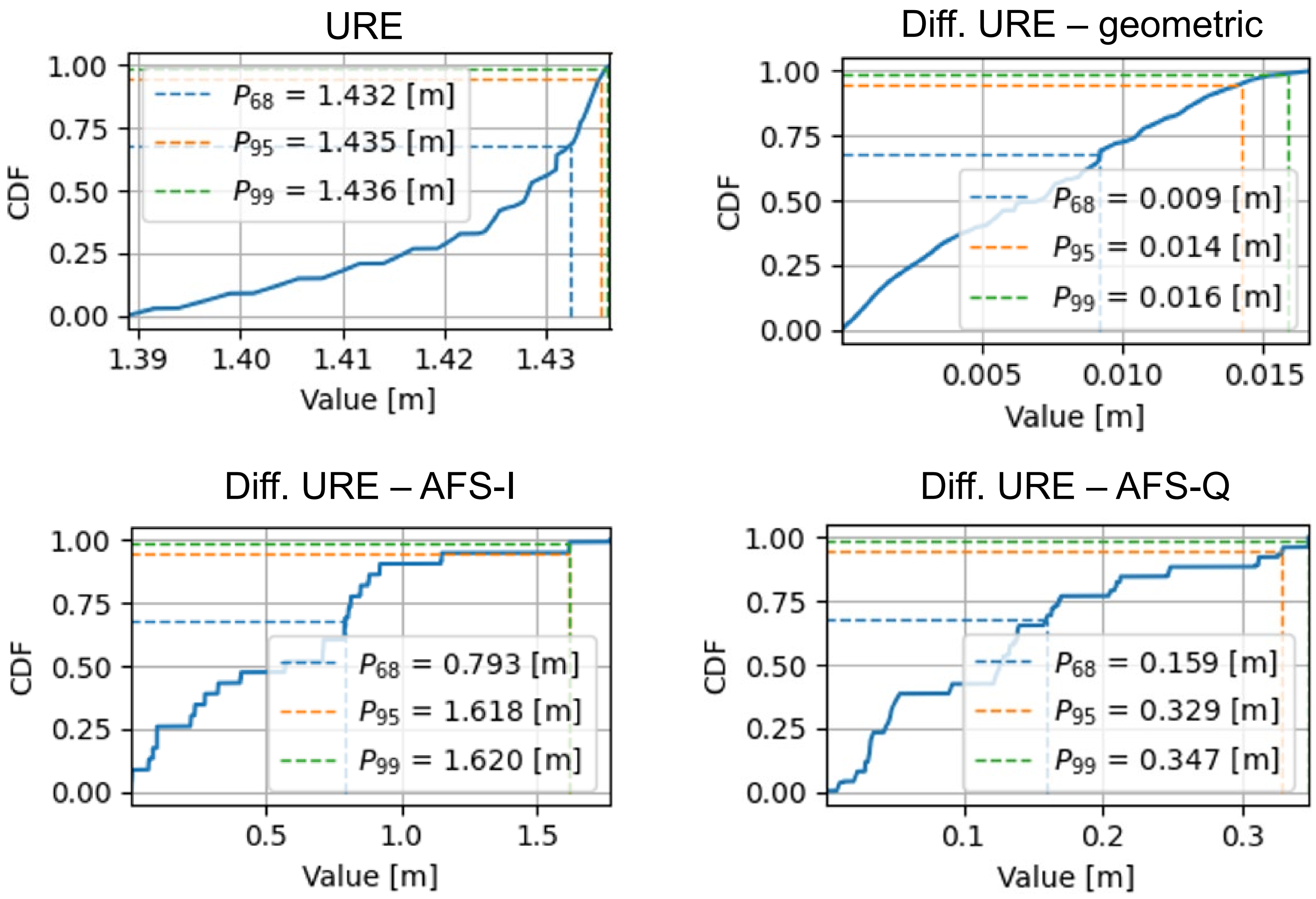
- 1-sigma accuracies

AFS-I	Horizontal		Vertical		3D	
	WLS	EKF	WLS	EKF	WLS	EKF
AFS-I only	3.786	3.330	12.226	9.562	12.682	10.096
AFS-I+DEM	3.113	2.823	0.073	0.129	3.178	2.870
AFS-I + diff. corr.	3.006	2.416	11.235	8.489	11.605	8.913
AFS-I + DEM + diff. corr.	2.243	1.995	0.273	0.315	2.390	2.141

AFS-Q	Horizontal		Vertical		3D	
	WLS	EKF	WLS	EKF	WLS	EKF
AFS-Q only	3.139	3.143	8.088	7.927	8.685	8.528
AFS-Q+DEM	2.622	2.617	0.073	0.113	2.648	2.654
AFS-Q + diff. corr.	0.526	0.487	1.805	1.479	1.874	1.561
AFS-Q +DEM +diff. corr.	0.453	0.439	0.528	0.465	0.703	0.672

- DEM strong improvement along vertical directions
- AFS-I: EKF provides significant improvement w.r.t. WLS due to large measurements errors
  - $\sigma_{rx,AFS-I} \sim 1\ m$
  - $\sigma_{DLL,AFS-Q} \sim 15\ cm$
- Differential corrections benefits clearly visible when using AFS-Q

URE reduction brought by differential corrections



AFS-Q

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Conclusions

Conclusions

- Preliminary design of a complete flight model Moon Station
- 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 provides limited advantages when the data signal component is used, but significant advantages are expected by using the pilot signal component
  - Differential corrections are more effective than an additional ranging signal and are useful 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!