Measurement and Navigation Performance for Users of a LunaNet-Compliant Constellation

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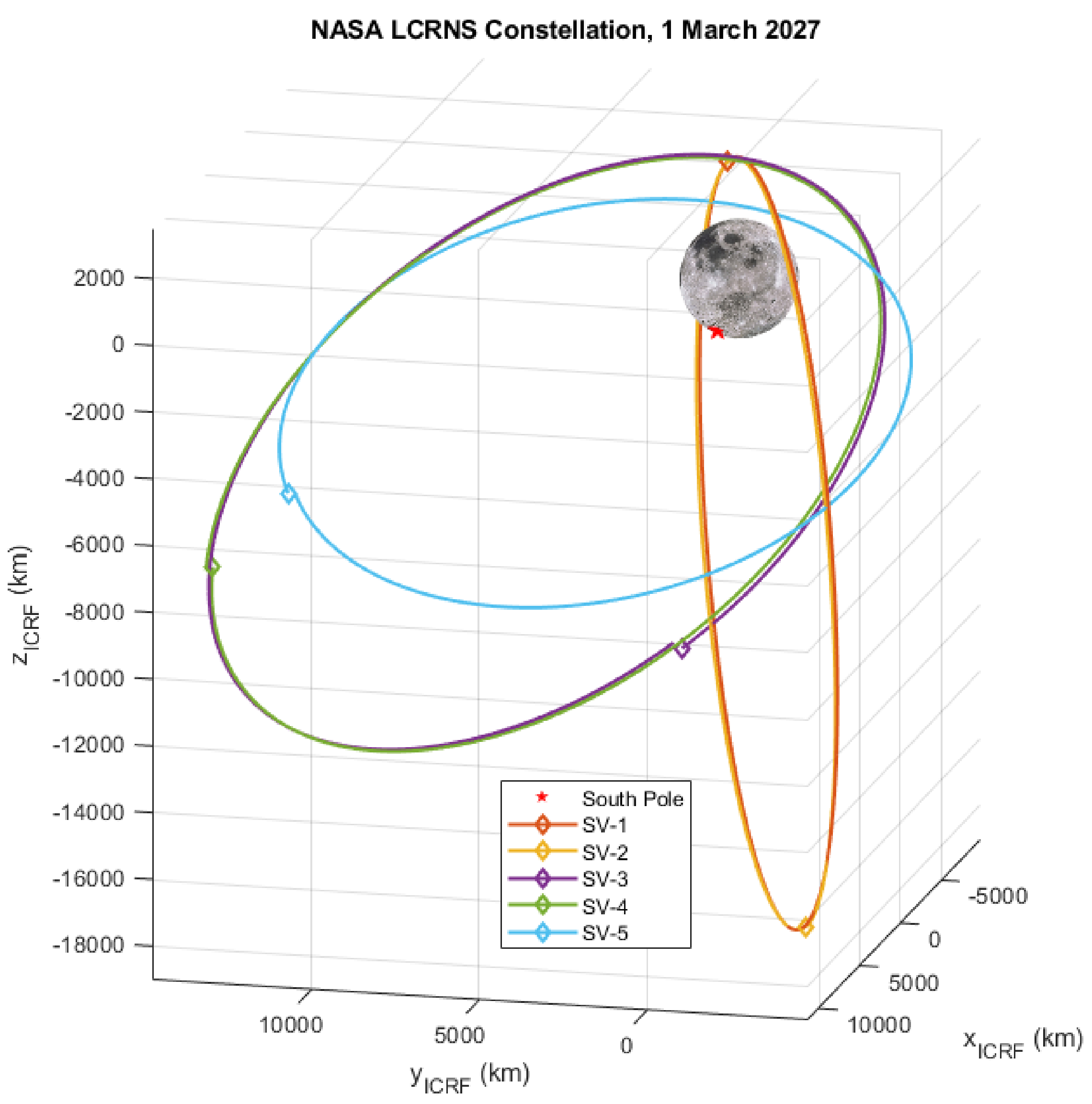
I. Motivation

Global interest is increasing to establish a sustainable human presence on the moon through missions, multilateral cooperation, and infrastructure development [1]. To aid these objectives, several organizations are planning to construct lunar navigation satellite systems (LNSSs) to provide position, navigation, timing (PNT), and communication services for users operating on and above the lunar surface. NASA, the European Space Agency, and the Japanese Space Exploration Agency are collaborating on a unified interoperability specification for this PNT and communications service, dubbed LunaNet [2]. This interoperability specification (LNIS) details communication bands, signal structures, and data formats to ensure functionality across systems. This work explores the achievable measurement performance for users of a LunaNet-compliant LNSS based on the LNIS, decomposing errors by source using state-dependent models for both pseudorange and Doppler measurements. The performance of a lunar receiver is presented during powered descent and landing on the lunar south pole (LSP).

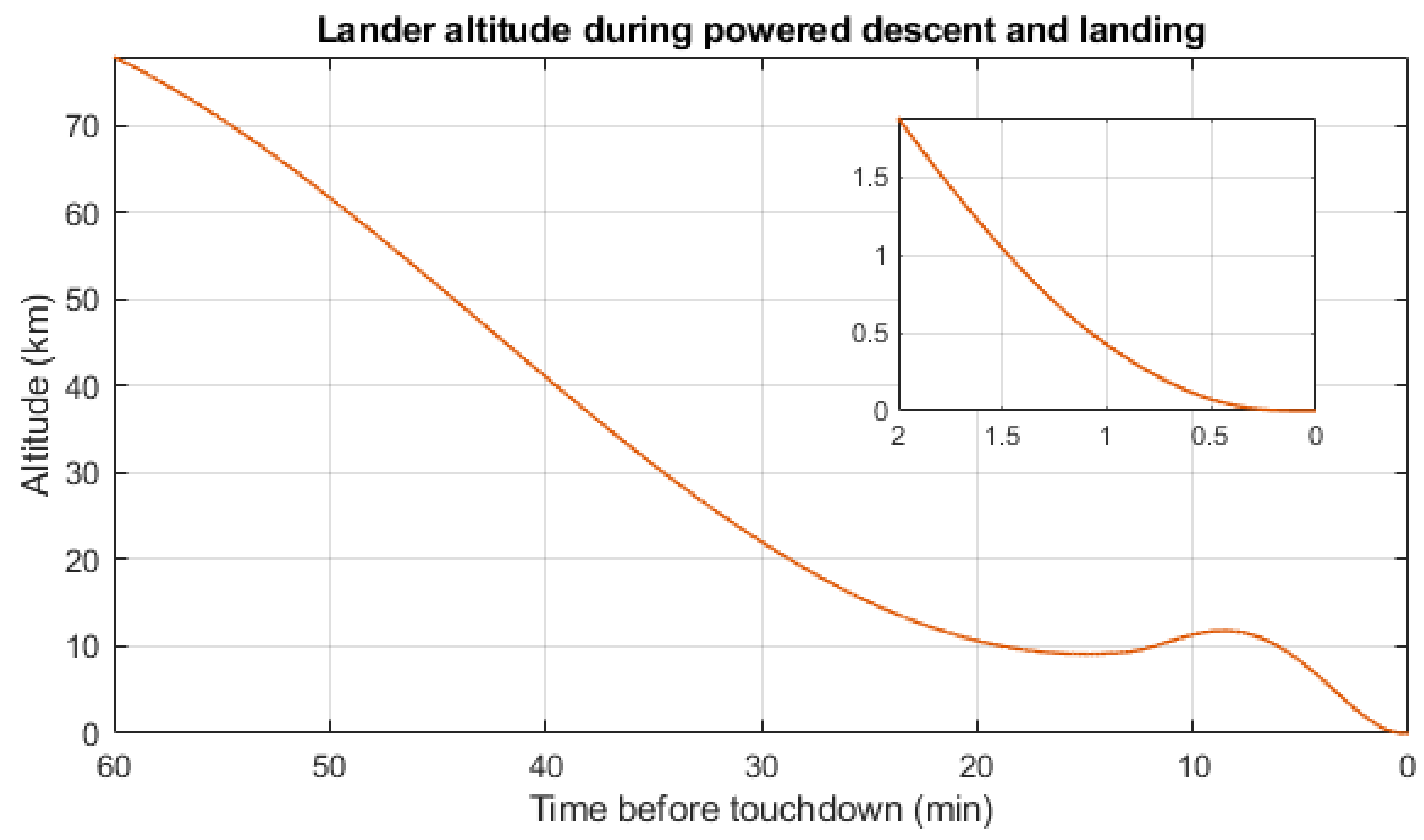
II. LNSS Constellation

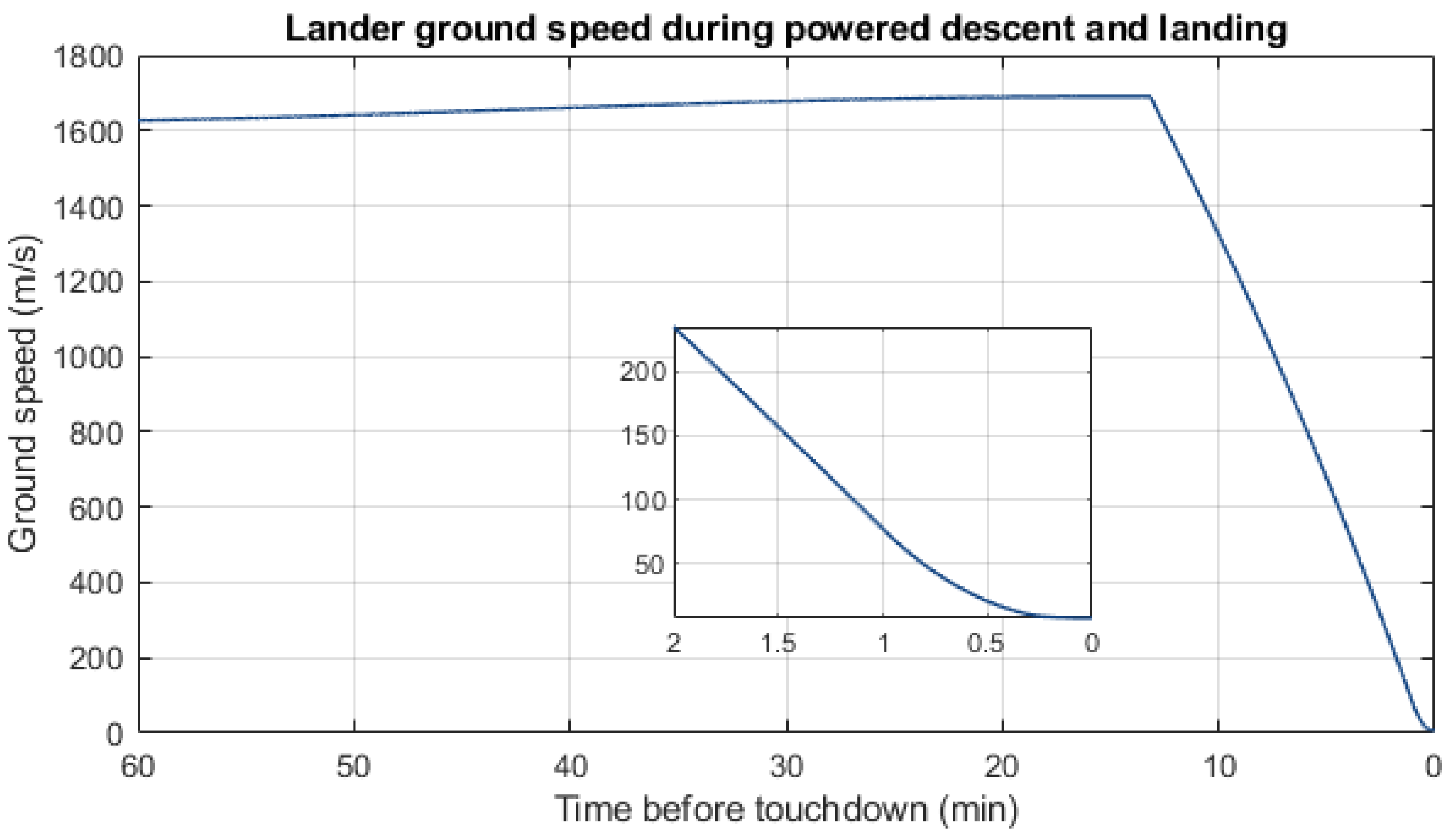


NASA has published details on the nominal Lunar Communications Relay and Navigation System (LCRNS) satellite constellation [3], comprised of 5 satellites in elliptical lunar frozen orbits. These orbits have a period of 30 hours and are optimized to maximize coverage of the LSP while also maximizing the size of continuous coverage windows.

III. Lander Scenario

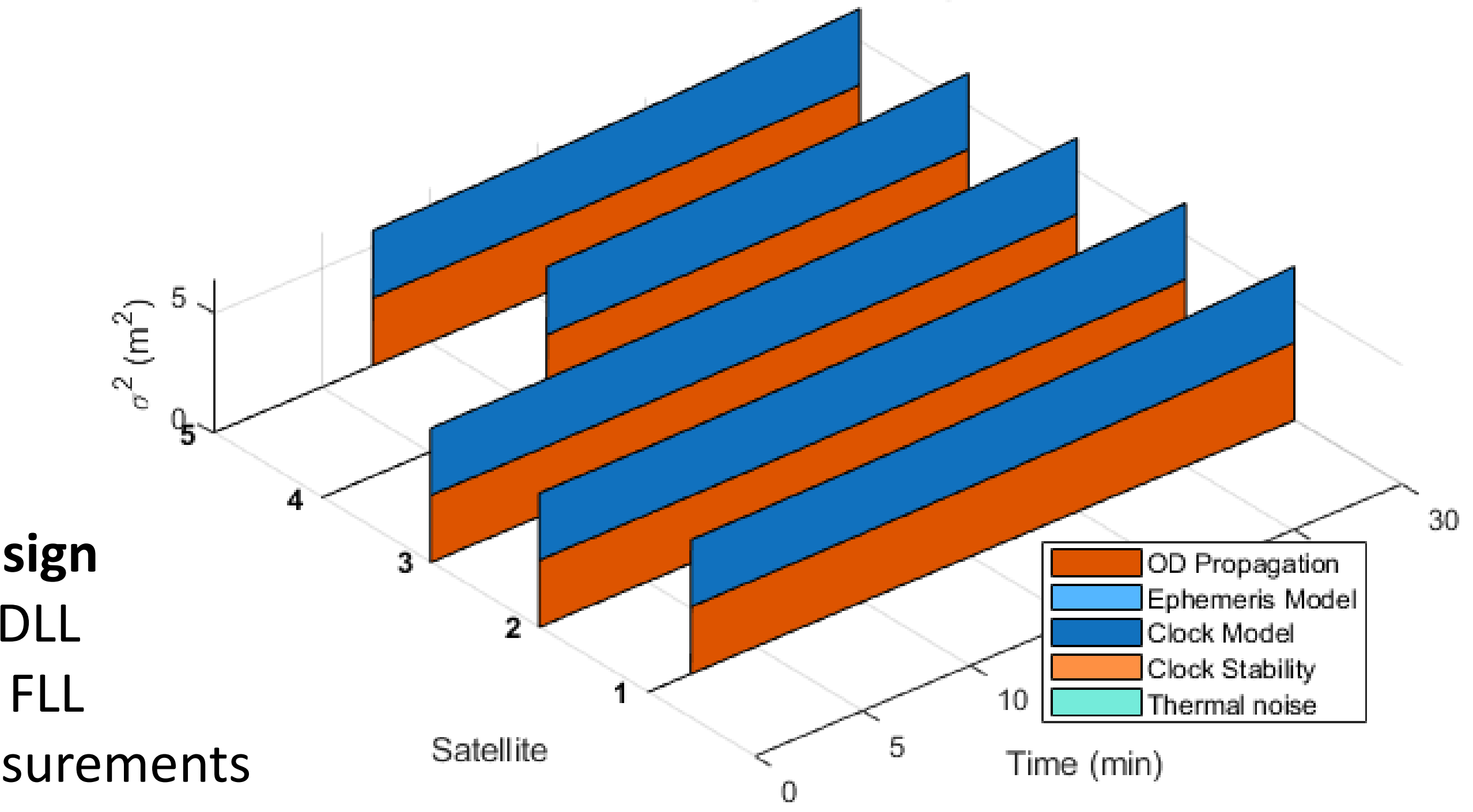
The simulated use case for this work is a lunar lander during powered descent and landing to the region of the lunar south pole. The lander first circularizes into a polar orbit, then drops into a lower elliptical orbit before entering final approach. This simulation considers the final 30 minutes up to touchdown. The lander is equipped with an LNSS receiver to make measurements and provide navigation solutions to the lander navigation system during powered descent.



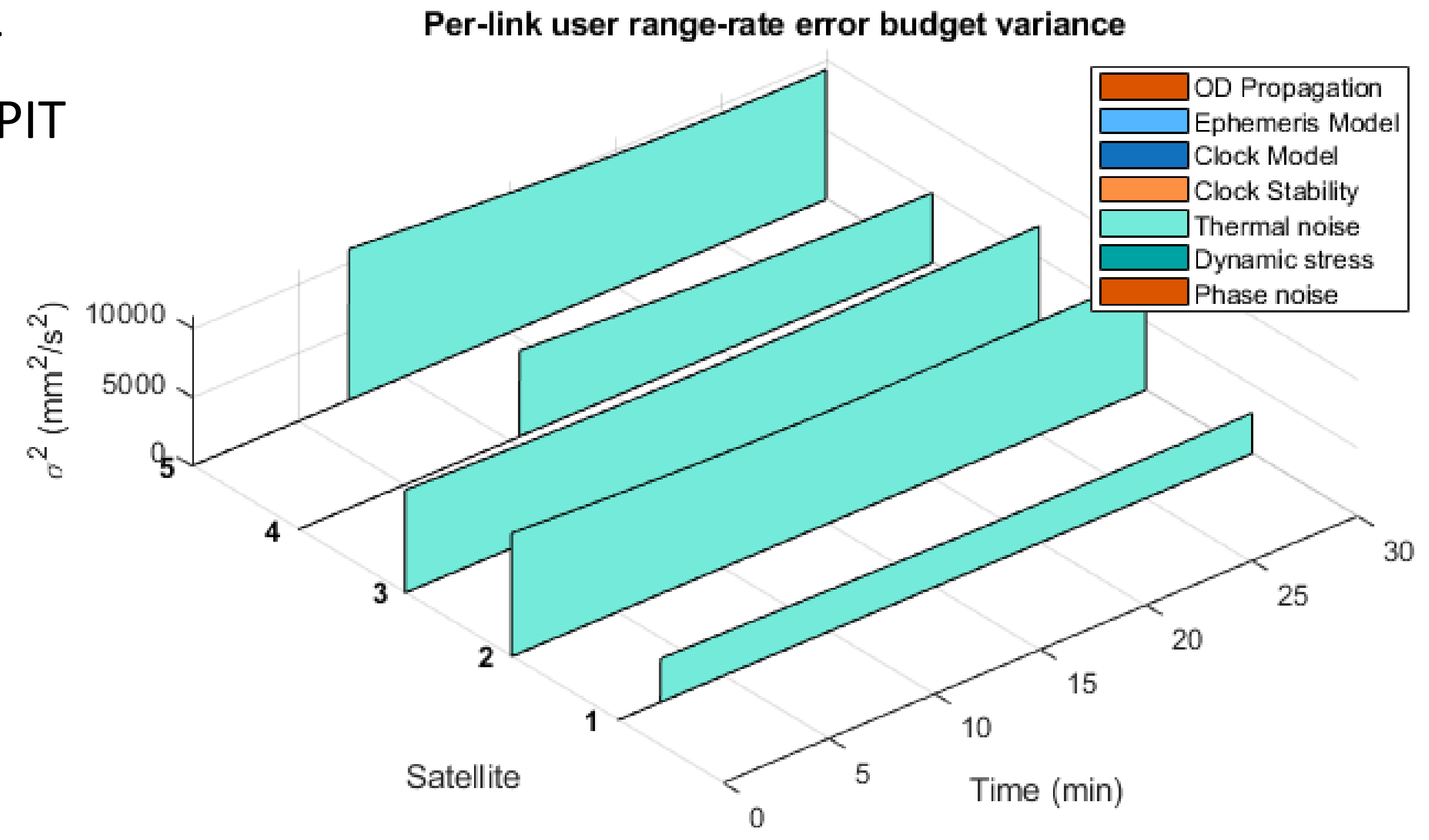


IV. Measurement Error Budget

The LNSS receiver onboard the lander is making pseudorange and Doppler measurements from the Augmented Forward Signals (AFSs) broadcast by the LCRNS satellites. It tracks the dataless AFS Q-channel at 2492.028 MHz and 5.115 Mcps – the simulated signal is fully compliant with [2] and its AFS standard Volume A. Below are plots of the measurement variance over time; the lander is gradually coming into view of the LCRNS satellites, so as a connection is established the measurement variance begins plotting. Specifics of the receiver design are also listed below.

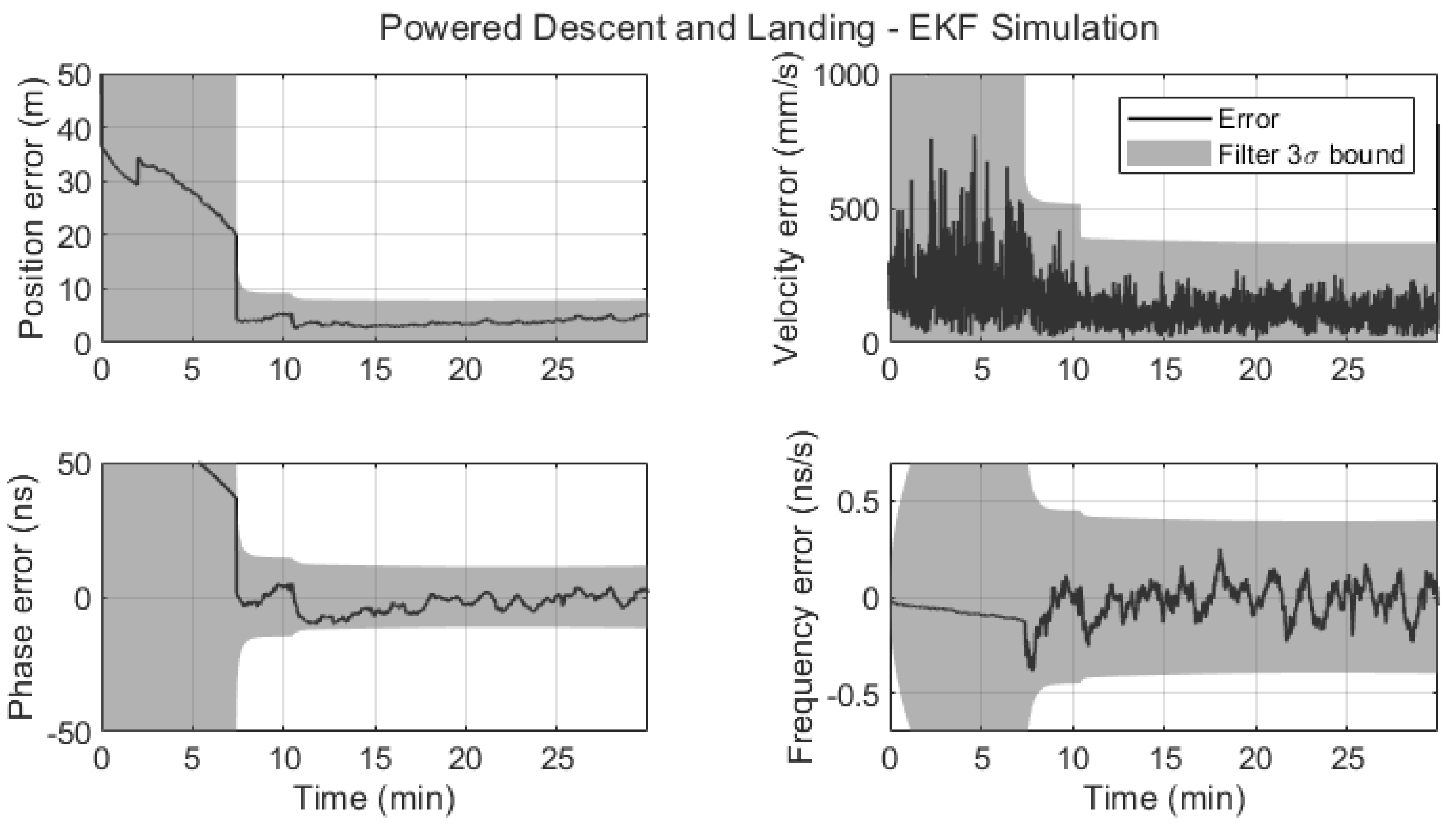


Receiver Design
- 1st order DLL
- 2nd order FLL
- 1 Hz measurements
- 0.1 Hz DLL bandwidth
- 20 Hz FLL bandwidth
- 1s DLL PIT
- 0.01s FLL PIT



V. Navigation Performance and Conclusions

Setup
- Extended Kalman Filter
- Measurements of pseudorange and Doppler at 1 Hz
- Filter covers T-30 minutes up to touchdown
- Tracking lander position, velocity, clock bias, and clock drift
- No knowledge of lander maneuvers



Error (last 20 min.)	Position (m)	Velocity (cm/s)
Mean	3.51	12.7
3σ	7.95	37.9

Conclusions

This research demonstrates the functionality of an end-to-end simulation pipeline to determine end user navigation performance for LunaNet-compliant systems. Future objectives include filter tuning, receiver design changes, and Monte Carlo analysis to validate covariance fitting. Integration of maneuvers and sensors such as an altimeter will also be considered.

VI. References

[1] Salmeri, A., and Jardine, S., "2024 Lunar Policy Snapshot: Key Trends and Implications for a Prosperous Lunar Future," Lunar Policy Platform, Dec 02 2024.
[2] NASA, "LunaNet Interoperability Specification Document," Interoperability Specification LNIS V005, NASA, Goddard Space Flight Center, January 2025. https://www.nasa.gov/wp-content/uploads/2025/02/lunanet-interoperability-specification-v5-baseline.pdf
[3] Ryden, G., and Volle, M., "NASA Lunar Communications Relay and Navigation Systems (LCRNS) Reference Constellation 3.1," NASA Goddard Space Flight Center, March 2025. https://esc.gsfc.nasa.gov/static-files/LCRNS_Reference_Constellation_White_Paper_03_2025.pdf

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