



Dedicated to innovation in aerospace

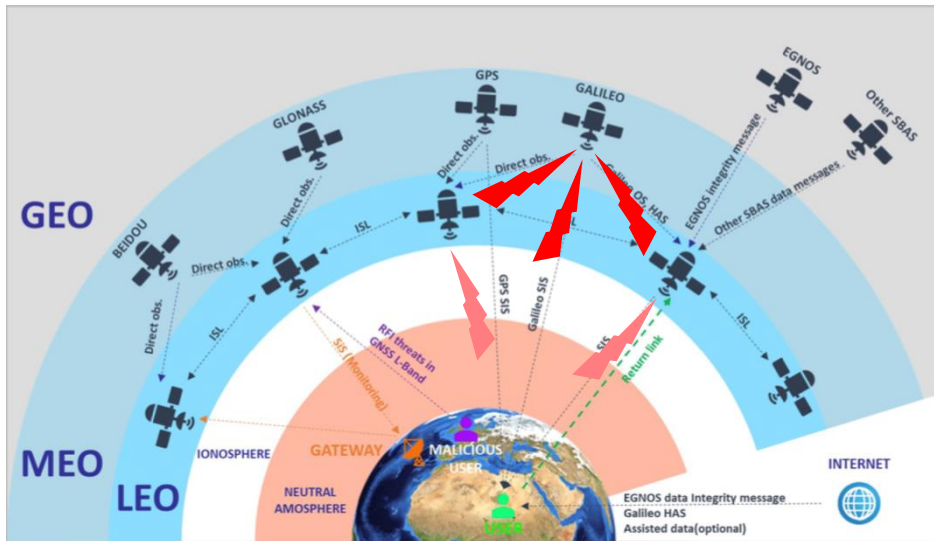
LEO-PNT; PPP and Integrity Test Bench Analysis

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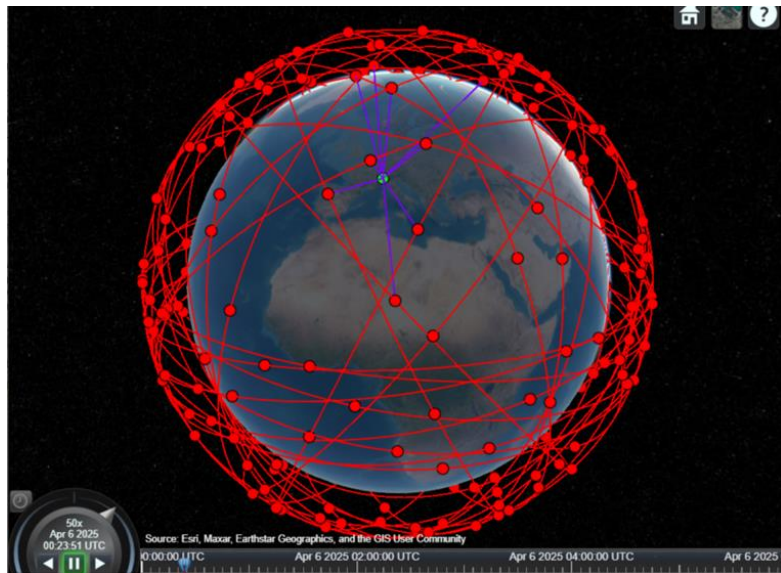
Research Objective



https://www.esa.int/ESA_Multimedia/Images/2023/06/LEO-PNT_within_a_multi-layer_satnav_architecture

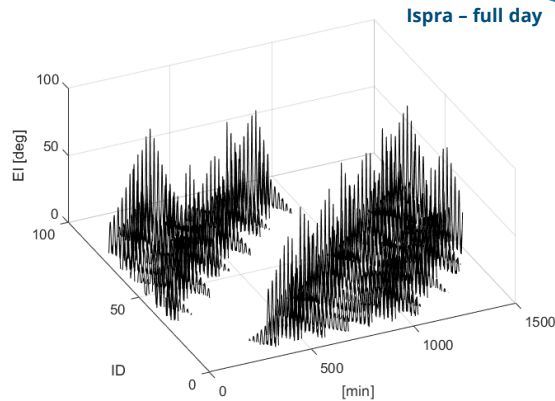
- Augmented LEO PNT
 - Autonomous navigation and signal generation
 - Position Integrity
 - Cascading faults
 - PPP
- Set up LEO-PPP simulation architecture
- LEO signal generator
 - PPP engine
 - Integrity Monitor
 - LEO ODTS behaviour

Constellation Design



- Target site: Ispra (Italy)
- 220 satellites
- 1200 km altitude

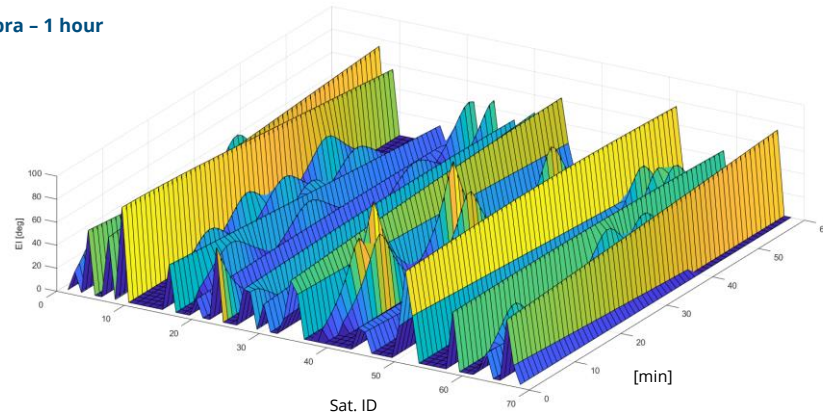
INC	N_SAT	Planes
80	42	6
65	81	9
50	49	7
10	48	8
	220	30



- Fast dynamic and geometry diversity are the main design driver of PPP improved convergence

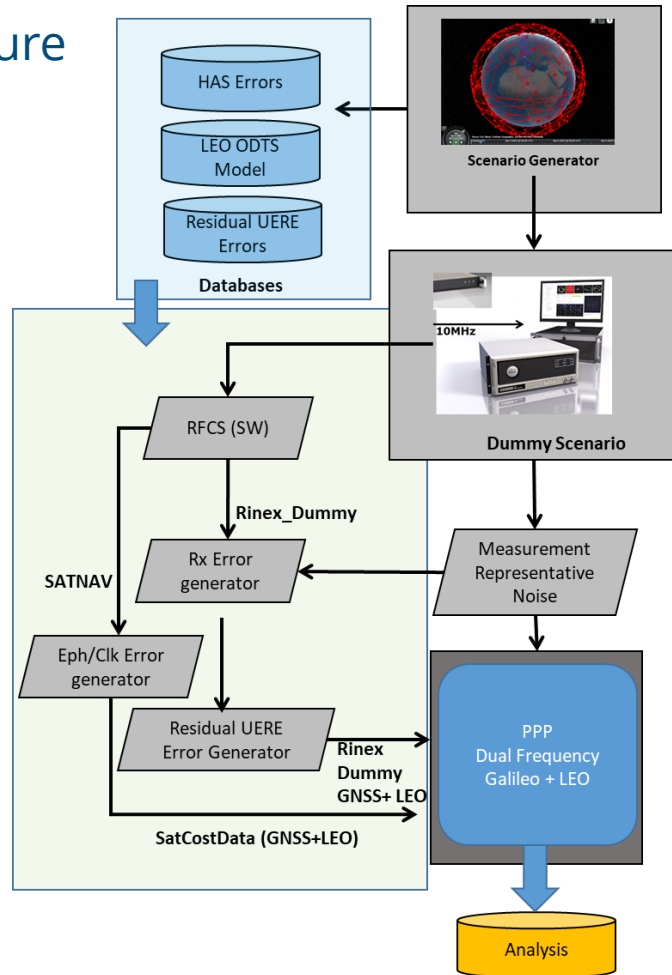
- LEO satellites offer, for a target point on Earth, an **improved random access to good elevation satellite**, which quickly spans a **wide elevation range** over the satellite passages.
- When Galileo and LEO are mixed the **slow/fast pattern** is already well addressed in a **1h scenario**.

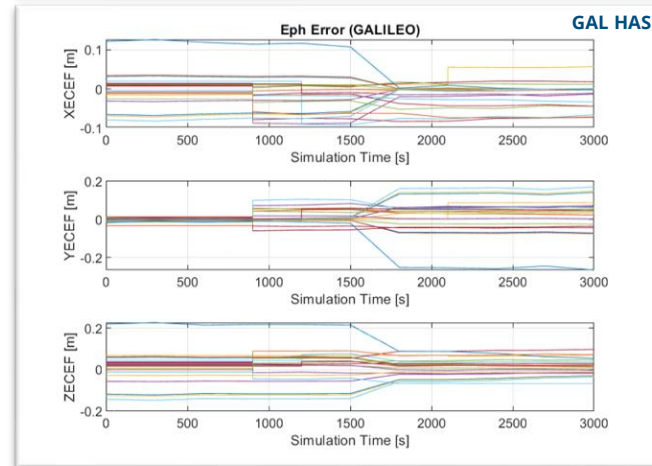
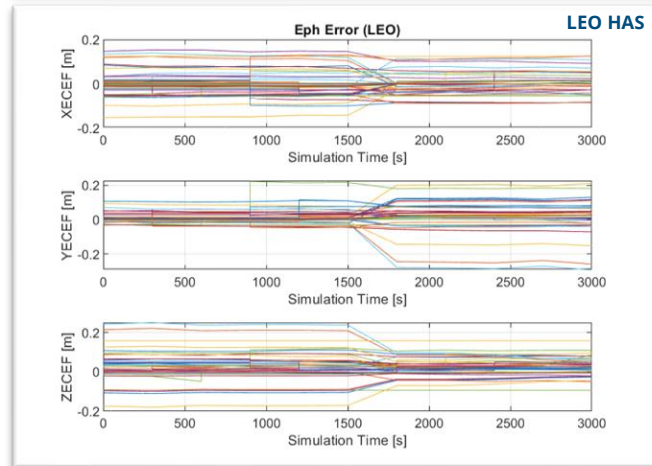
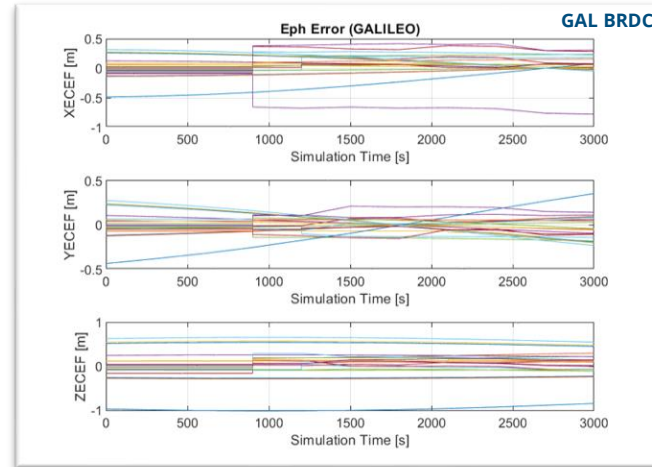
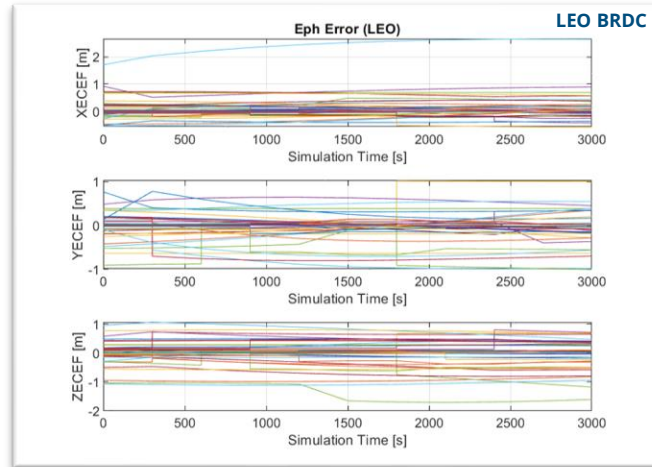
Ispra - 1 hour





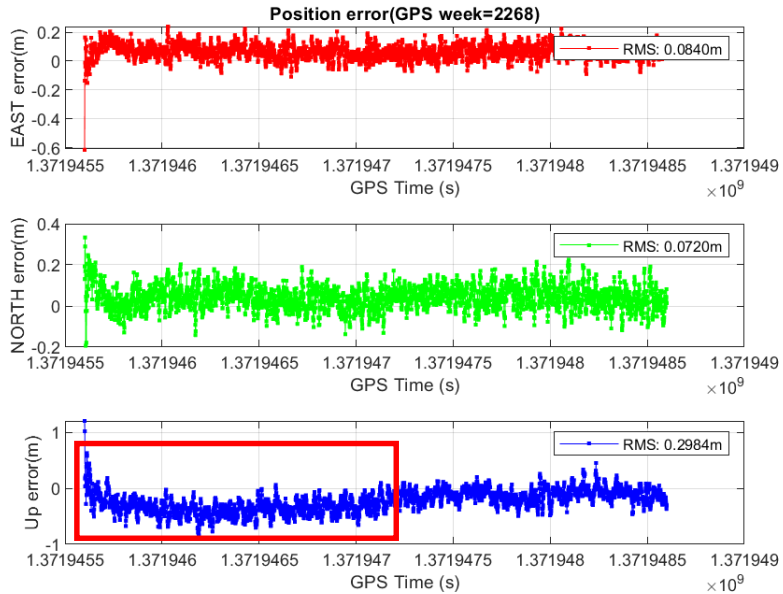
Simulation Architecture



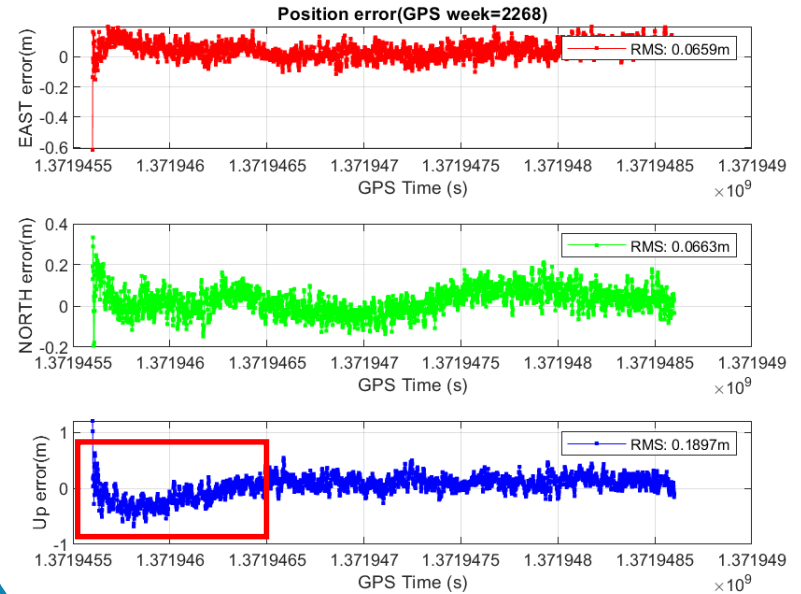


- Tropo/Iono
- Clock Err and ISB
- Receiver/HW Noise
- **Ephemeris Err**
- Filter Tuning Fixed

GAL HAS

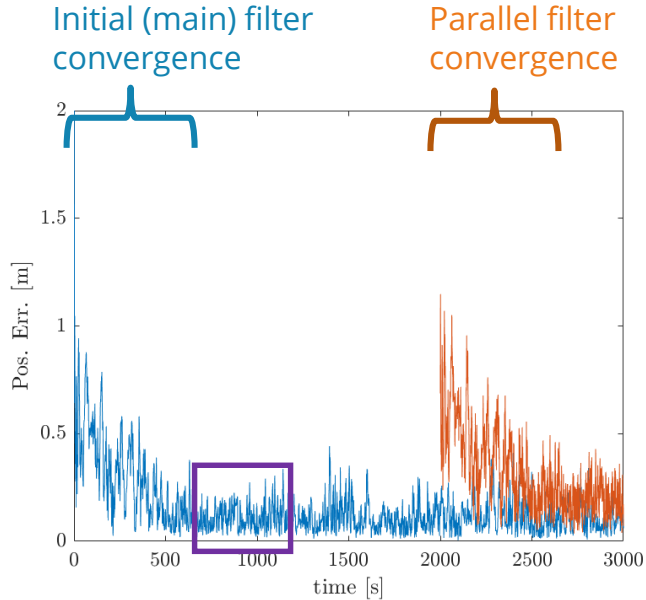


GAL + LEO HAS





Integrity Monitor



Batch Integrity Monitor

- Capture PPP (EKF) behaviour
- Able to capture slowly growing errors
- Adaptable (multiple windows) for cascading faults

Failure detection

$$s_{avg}^2 = y_{avg}^T V_{avg}^{-1} y_{avg}$$

$$s_{avg}^2 \sim \chi^2(n)$$

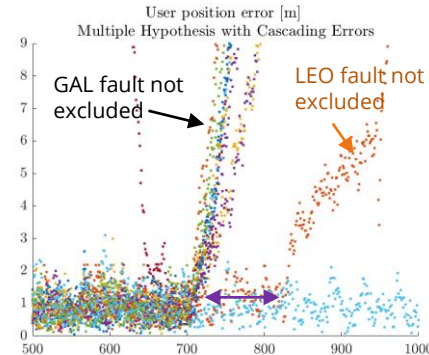
$$T_d = \chi^{-2}(P_{fa}, \nu)$$

Sliding window
batch

$$V_{avg}^{-1} = \sum_{i=k-m+1}^k V_i^{-1}$$

$$y_{avg} = (V_{avg}^{-1})^{-1} \sum_{i=k-m+1}^k V_i^{-1} y_i$$

Failure identification through multiple hypothesis testing



Initial study hypothesis

Inertia of LEO ODTS results in delayed fault injection



Simulation Results; accuracy and integrity

Accuracy	Metric	GAL (BRDC)	GAL (BRDC)+ LEO (BRDC)	GAL (HAS)	GAL (HAS)+ LEO (HAS)
Horizontal [m]	Steady State RMS	0.15	0.24	0.11	0.09
Vertical [m]	Steady State RMS	1.51	0.68	0.29	0.16

Integrity (PL)	Metric	GAL (BRDC)	GAL (BRDC)+ LEO (BRDC)	GAL (HAS)	GAL (HAS)+ LEO (HAS)
Horizontal [m]	95 th prctl	2.92	1.38	1.14	1.30
Vertical [m]	95 th prctl	8.47	2.97	2.78	2.83



Wrap-up

- Augmented LEO architecture
 - Spirent signal generator enabled
 - Implementation of real HAS corrections
 - PPP implemented
 - Integrity monitor implemented
- LEO improvement for
 - Vertical component
 - Convergence time
- Integrity performance without cascading fault on par with HAS.



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