LEO-PNT systems: enablers for navigation & new science

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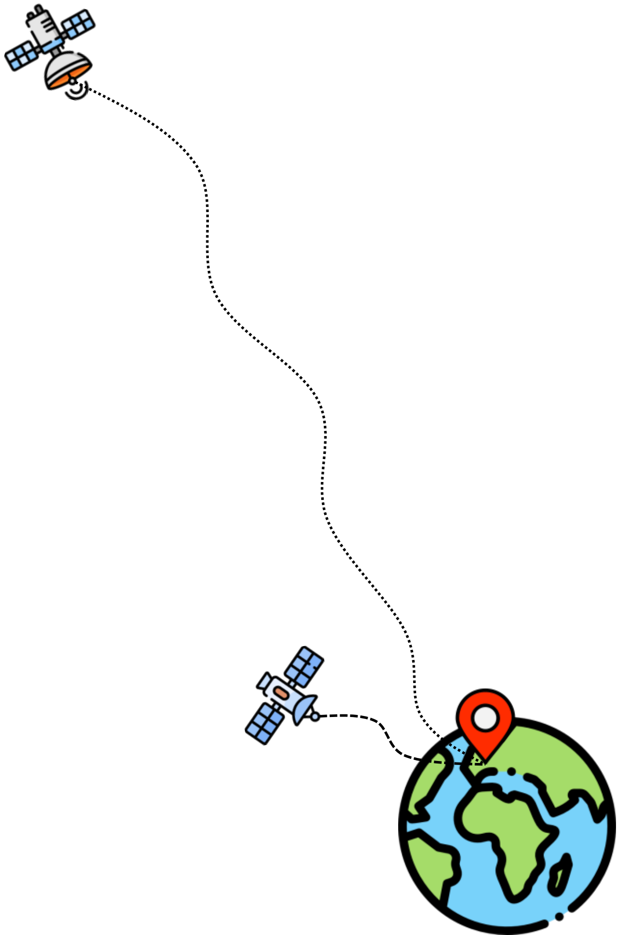

Introduction

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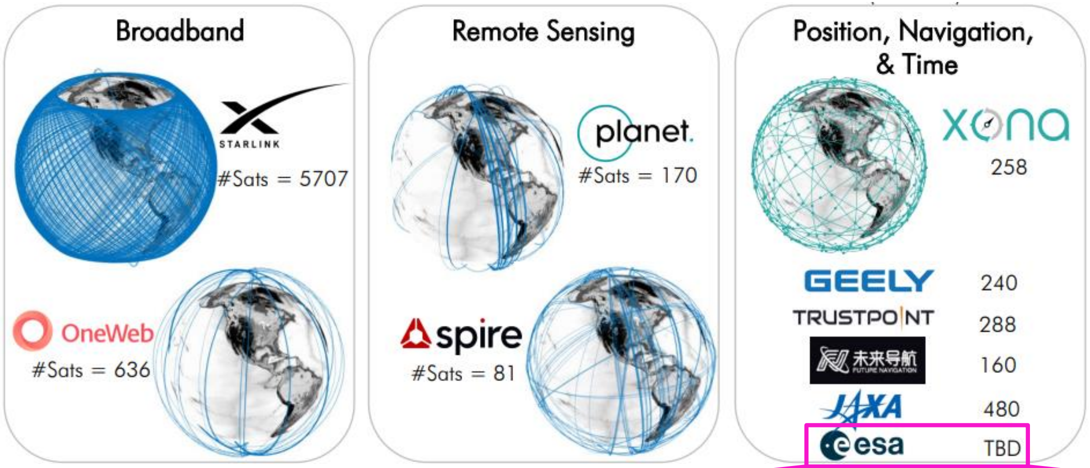
Background information

“Today, the only LEO system with global coverage is the Iridium constellation, used primarily for communications.” (GPS World Staff, June 8, 2017)



Xona Space 2024

Active LEO satellites

2015 → 2025

~1400 ~10000

with 7000 Starlink sats.

Jonathan McDowell (2019) website: planet4589.org/space/stats/stats.html

ESA’s LEO-PNT in-orbit demonstrator

Mini-constellations planned to be deployed by 2027.

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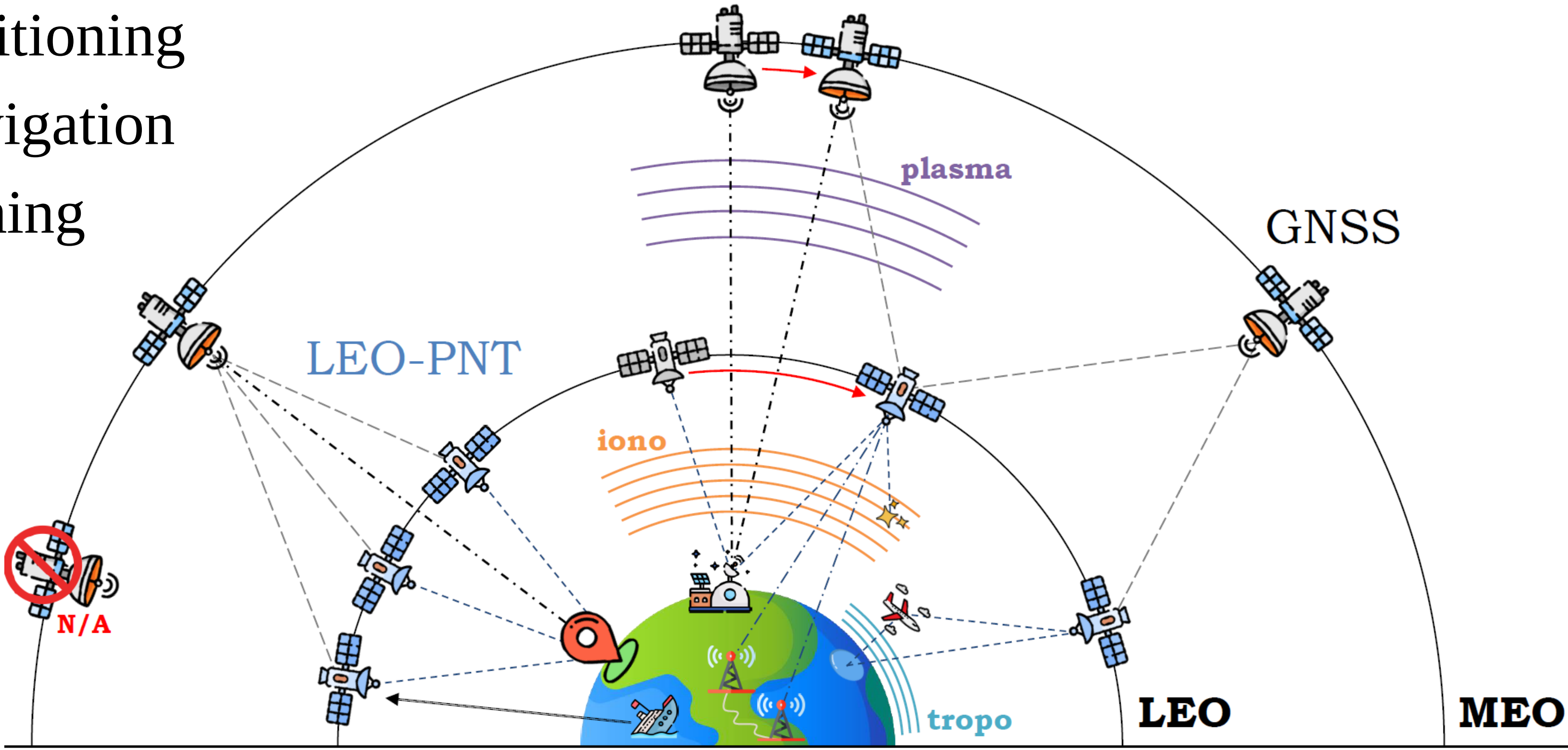
LEO-PNT systems

Several other potential applications linked to Geodesy, Geoscience and Remote Sensing.

Low Earth orbit systems for

- **P**ositioning
- **N**avigation
- **T**iming



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Existing and future constellations

A few dedicated systems are foreseen in low Earth orbit (LEO) for Positioning, Navigation, and Timing applications, also known as ‘LEO-PNT’ systems.

Constellation	C.C.	SVs	Altitude [km]	Bands	Status
STL/Iridium Communications	US	66	780	L	Deployed
PULSAR/Xona Space Systems	US	258	~1000	L	On-going
TrustPoint	US	288	500-800 (?)	C	On-going
Geely/GeeSpace	CN	240	620	L	On-going
CENTISPACE/Future Navigation	CN	190	975-1100	L	On-going
LEO-PNT/ESA	EU	263?	550 (IOD)	UHF/L/S/C	Planned
ArkEdge Space* & JAXA	JP	TBD	TBD	VHF/C	Feasibility
Skykraft Pty Ltd	AU/IN	TBD	TBD	S	Feasibility

*Feasibility study (Phase 1), Oct 2024 – Mar 2025

Navigation-related aspects for LEO-PNT

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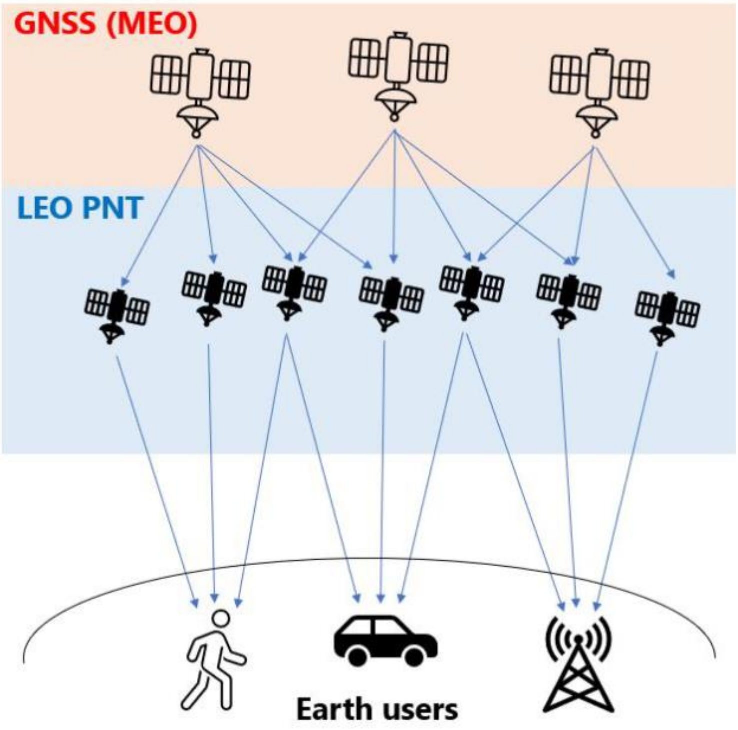
PNT from low Earth orbits

LEO-PNT is expected to introduce

Advantages

- Faster geometry changes
  - e.g. multipath mitigation
  - e.g. better convergence time
- Stronger and/or additional signals
  - e.g. indoor positioning
  - e.g. resilience to jamming/spoofing
- Improved DOP, wider coverage
  - e.g. urban users, polar regions



Murata et al. (2024)

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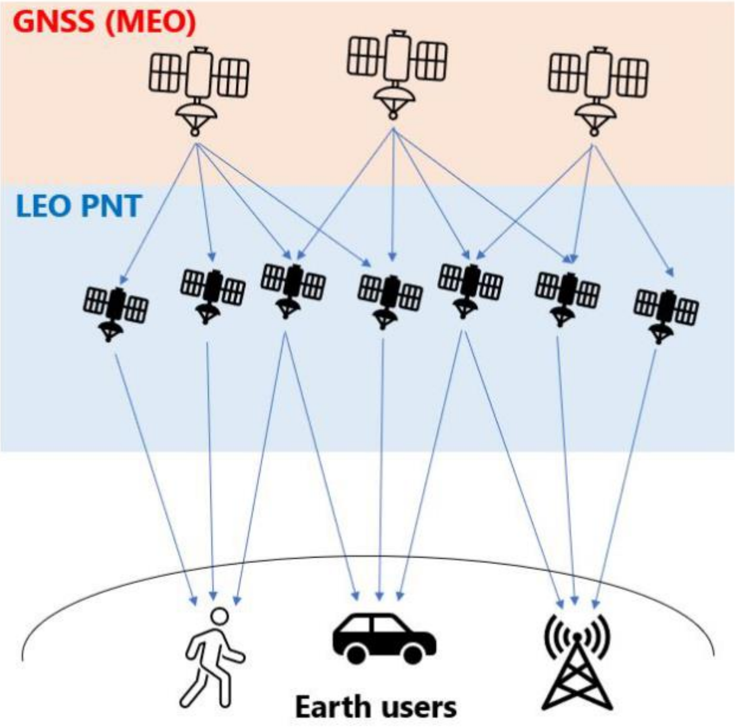
PNT from low Earth orbits

LEO-PNT is expected to introduce

Challenges

- Estimation of real-time orbits/clocks
  - e.g. on-board POD (from MEO)
  - e.g. on-ground ODTS (from GS)
- Provision of LEO satellite products
  - e.g. poor H/W and clocks' stability
- User receiver/algorithm complexity
  - e.g. signal acquisition & tracking
  - e.g. legacy old PPP methods?



Murata et al. (2024)

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Numerical example

Ground user
e.g. REDU:
- 50° lat.
- 5° lon.
- 370m hgt.

Constellations

We consider:

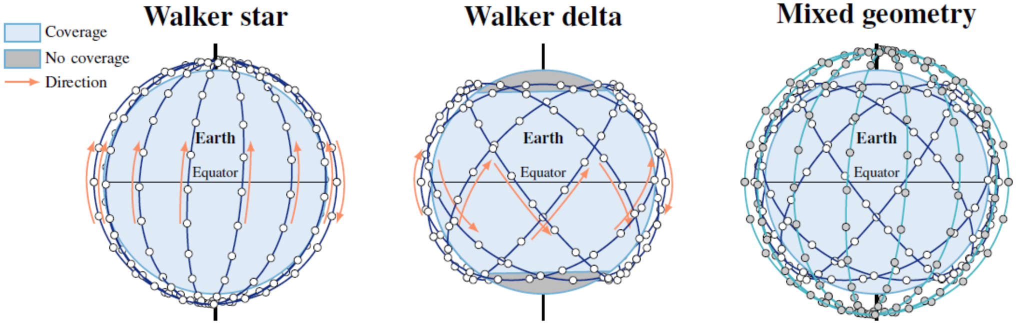
- GPS (G) | 20180 km @55° | 24 satellites / 6 orbital planes
- LEO (La) | 975 km @55° | 120 satellites / 12 orbital planes | *W-star*
- LEO (Lb) | 1100 km @87.4° | 30 satellites / 3 orbital planes | *W-delta*
- LEO (Lc) | 1100 km @30° | 40 satellites / 4 orbital planes | *W-delta*
- …

CENTISPACE

ESAT1 signals
L1+L5

We compute:

➢ Kinematic 30s solution (> 7°)



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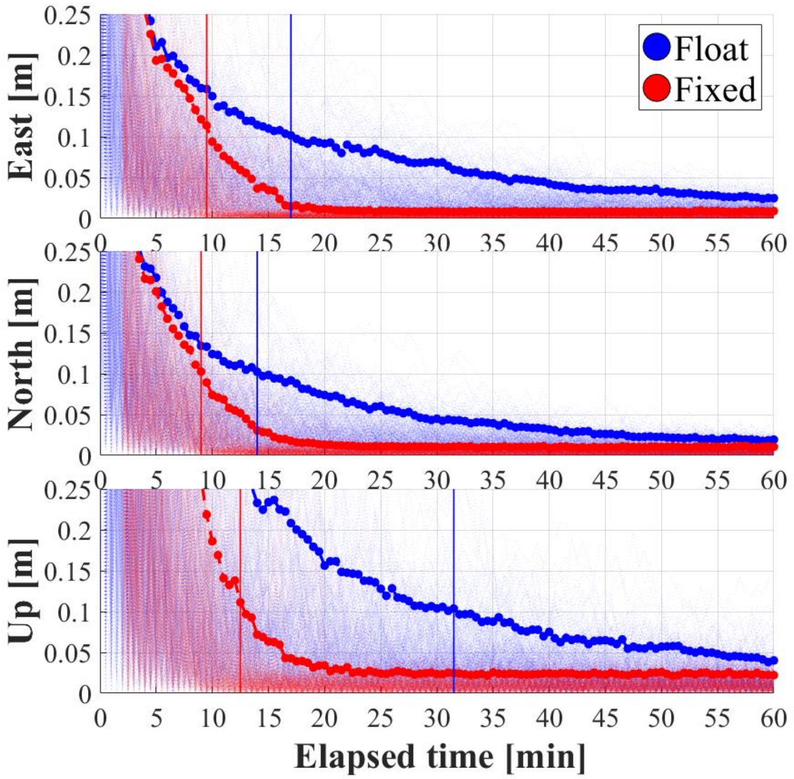
Convergence time – P90 statistics

G



Methodology:

We consider 60 min windows, shifted by 4 minutes over a 24-hour period.

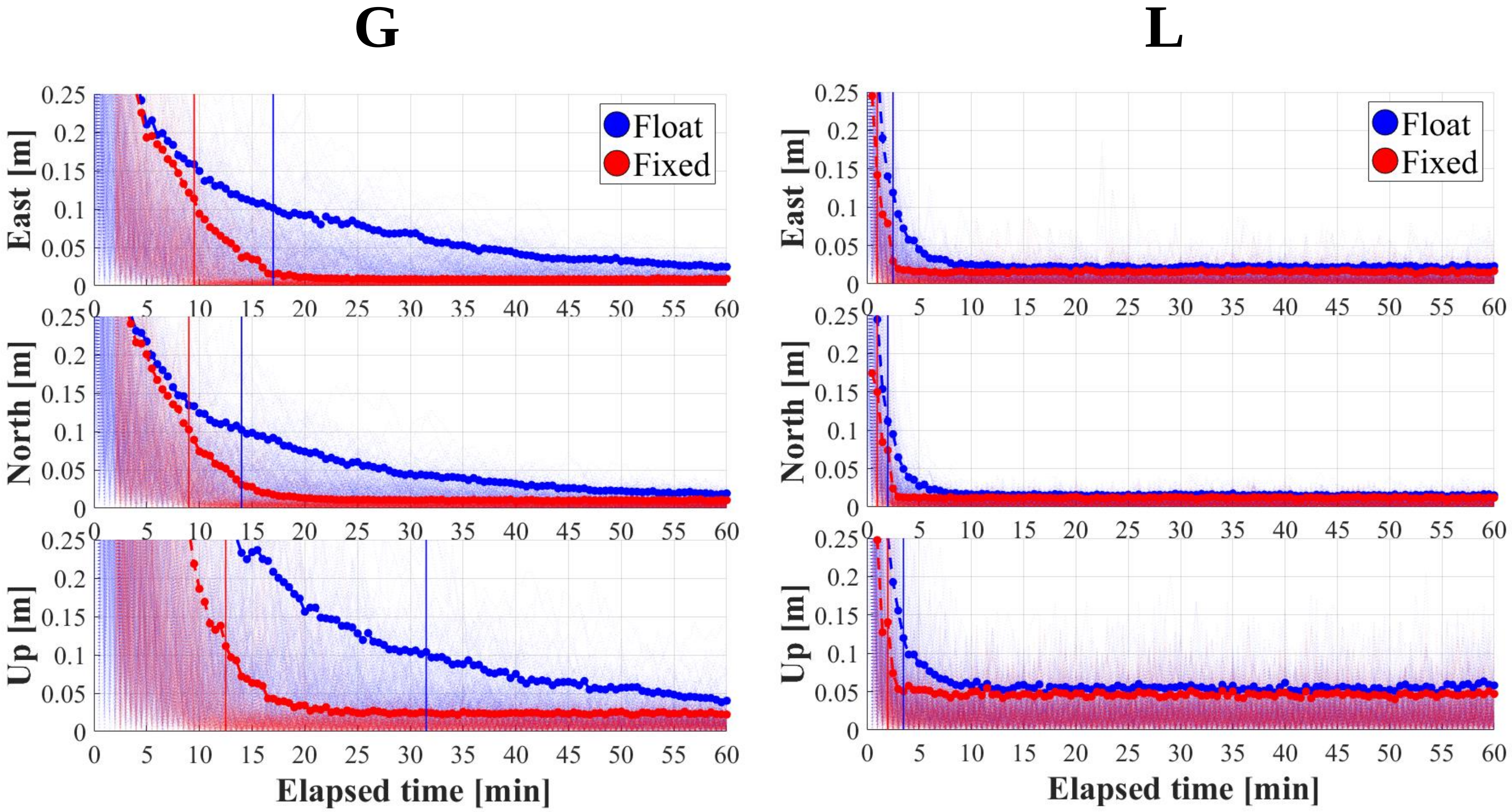
The **90-percentile** is computed using these 360 windows for ENU/2D/3D.

Convergence time is defined based on a 10 cm threshold for ***float*** and ***fixed***.

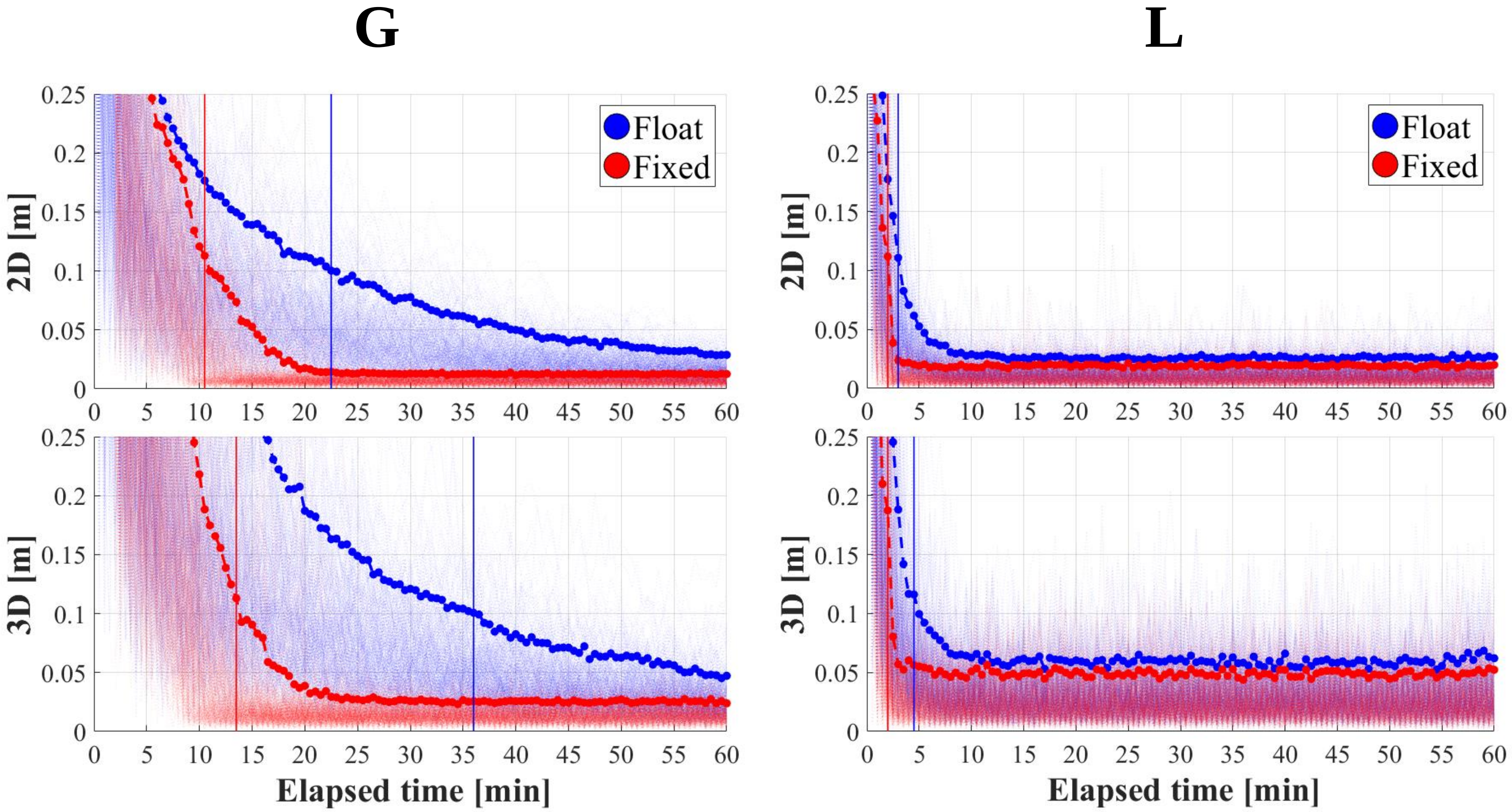
← Single occurrences in lighter color.

Source: Massarweh (2024a, 2024b)

Convergence time – P90 statistics

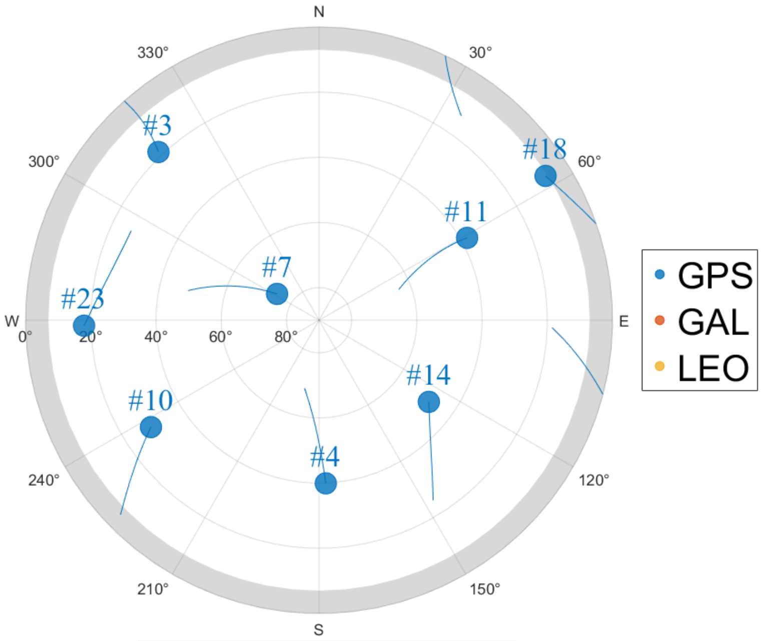


Convergence time – P90 statistics



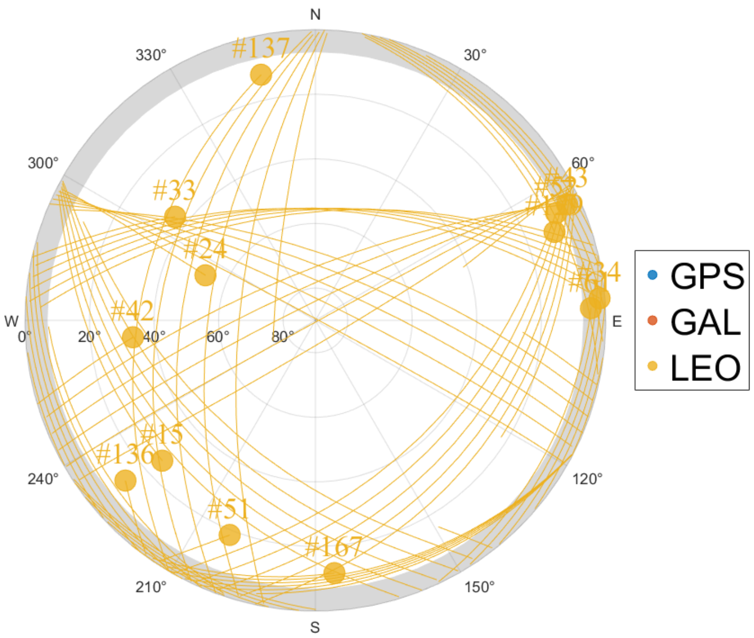
Comparison between skyplots (1h)

G



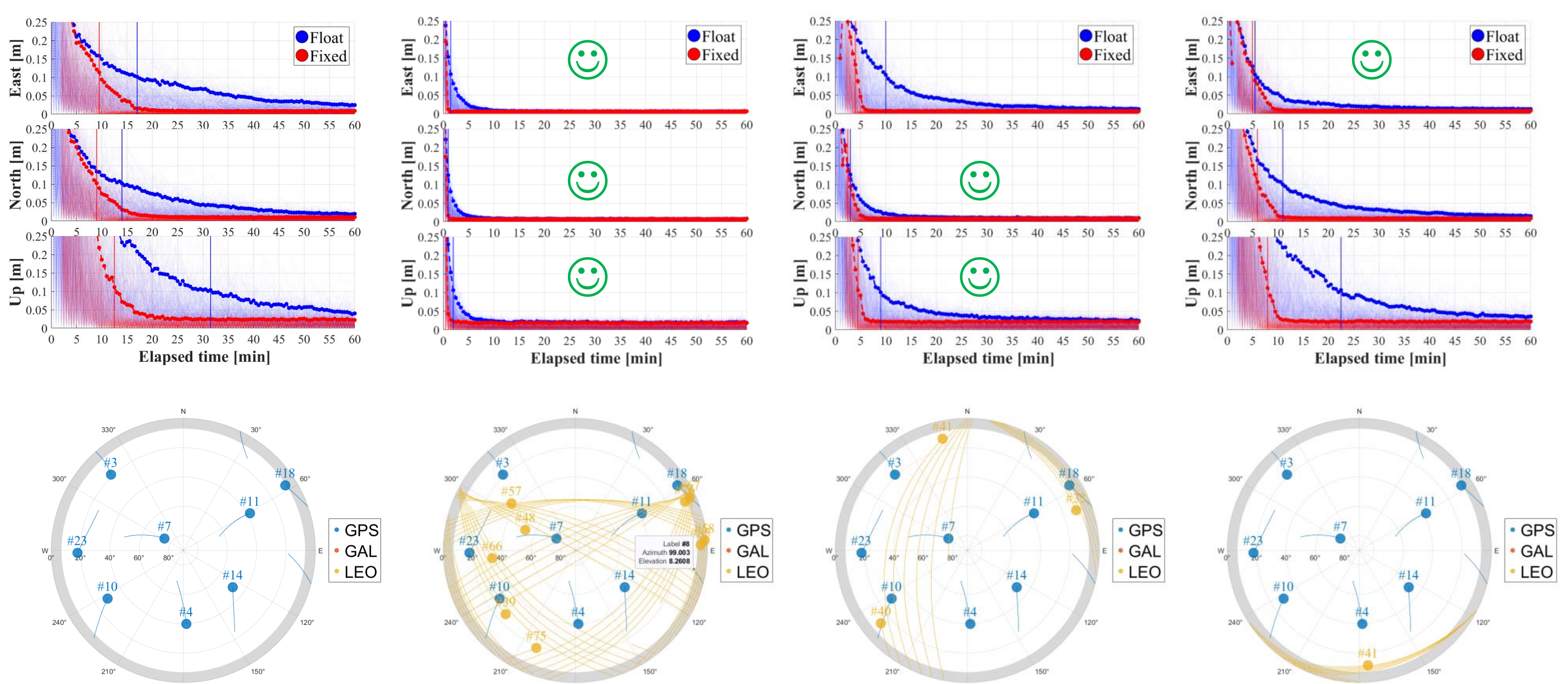
G: 7–8

L



L: 6–11

G	G+La (120)	G+Lb (30)	G+Lc (40)



G: 7–8	**G**: 7–8 **L**: 5–9	**G**: 7–8 **L**: 1–3	**G**: 7–8 **L**: 0–1

Courtesy of Jillian S. Oduber

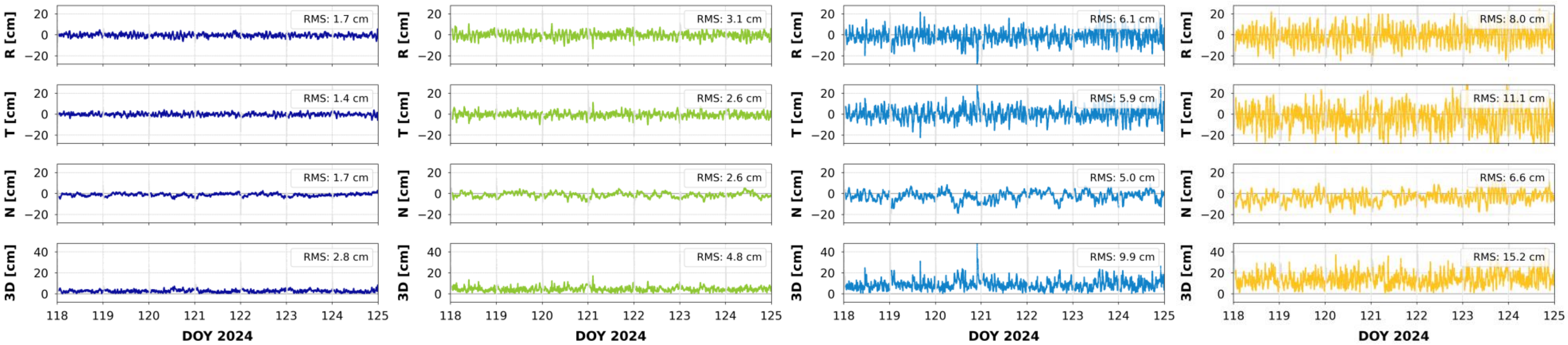
On-board POD capabilities

SISRE(orb):
$w_R = 0.617$
$w_T = 0.556$
$w_N = 0.556$

Case study: Sentinel-6A satellite (degraded models)

Reduced-dynamics GE-2f solution, using

CODE Final | CNES RT | Galileo HAS | Broadcast-only



SISRE(orb): **1.7 cm** | SISRE(orb): **2.9 cm** | SISRE(orb): **5.6 cm** | SISRE(orb): **9.1 cm**

Potential real-time capabilities

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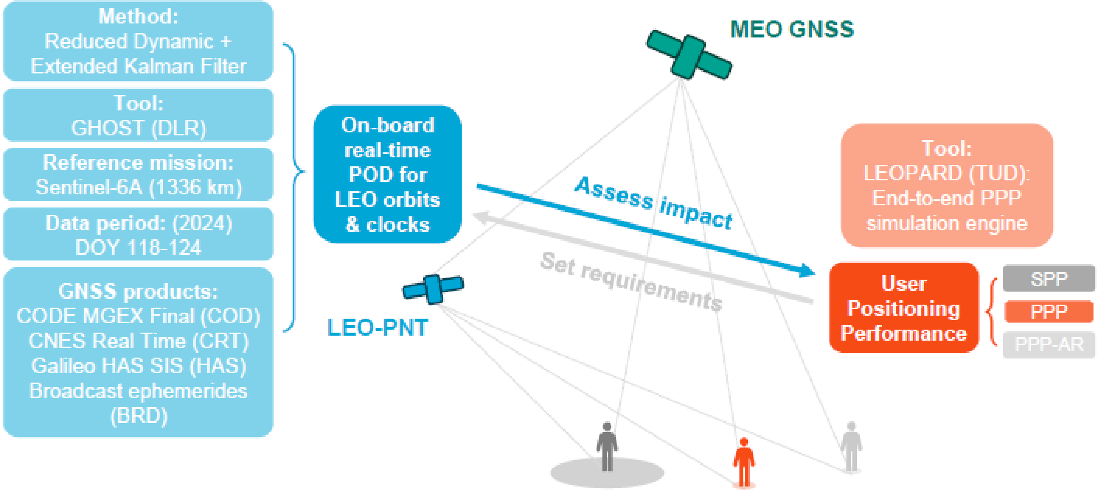
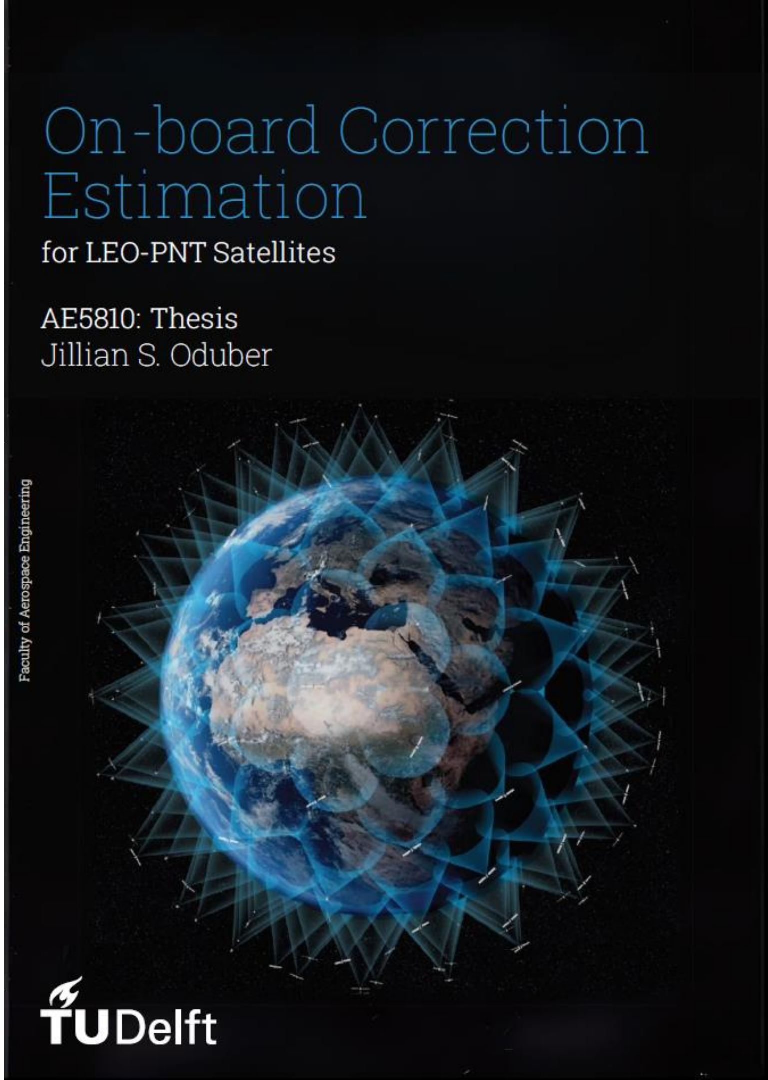
MSc Thesis (2025)

Objective:

➢ Quantify the impact of on-board POD for LEO-PNT systems used in kinematic PPP.

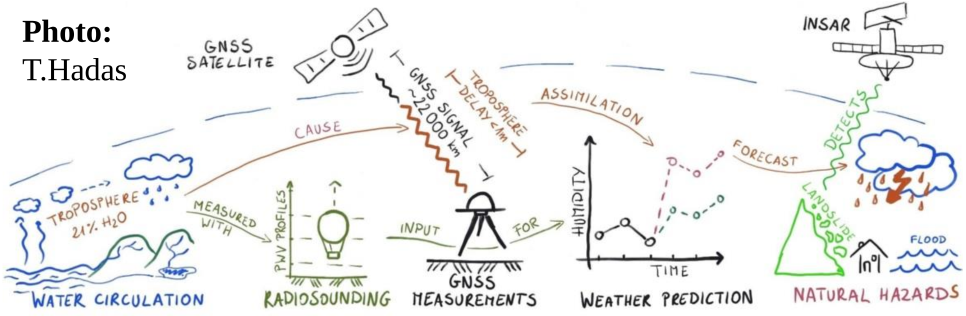


Credits: Oduber (2025)



Other scientific opportunities

Photo:
T.Hadas



Applications, some examples…

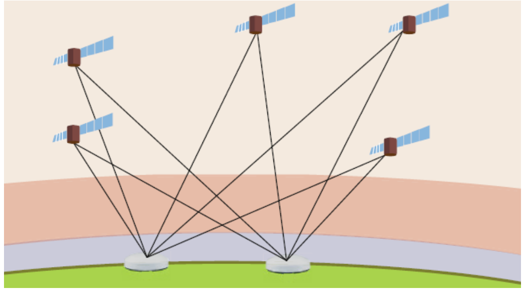
Surveying,
e.g. geodetic (datum), along with other types as land, engineering, and hydrographic surveying.

© eFarmer B.V.

Understanding of Geodynamics,
e.g. earthquake mechanics, volcano deformation, plate tectonics and surface loading.

© GlobalCDA

Monitoring of Atmosphere,
e.g. ionosphere real-time tomography, weather forecast and reflectometry-based applications.



Handbook of GNSS (2017)

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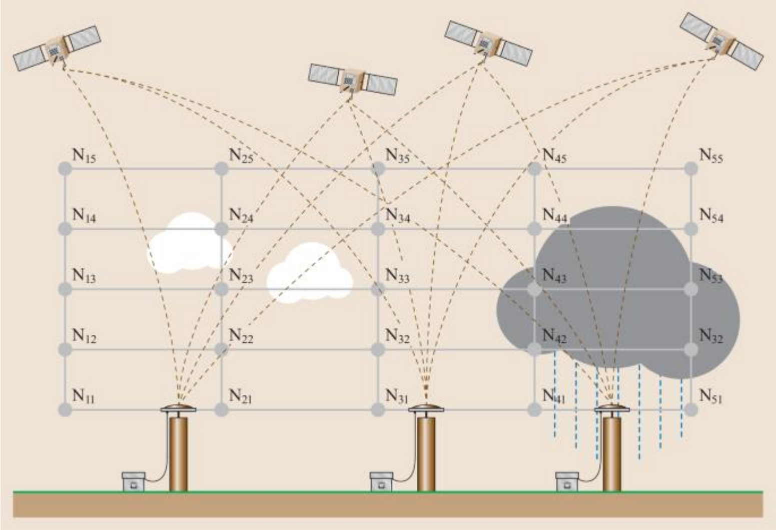
Remote Sensing systems

LEO-PNT lead to improved spatial-temporal coverage.

Water Vapor Tomography

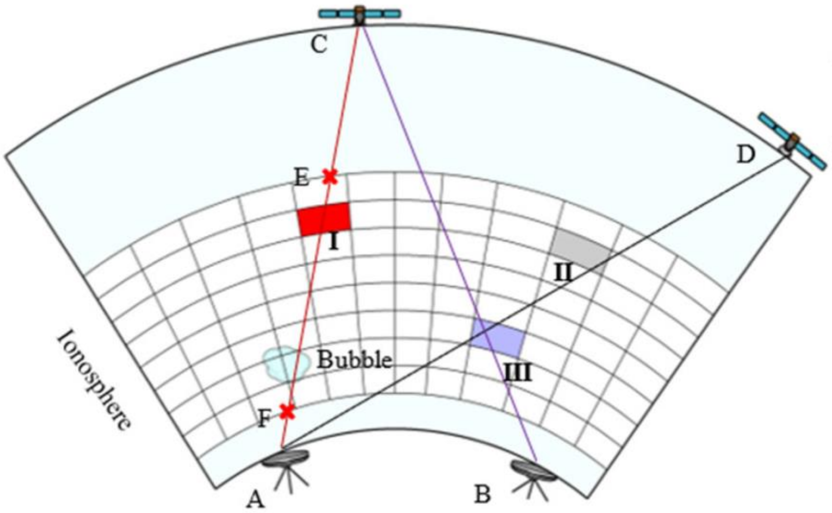
e.g. large-scale humidity monitoring.



Source: Bender, M., Dick, G. (2021).

Ionosphere Tomography

e.g. real-time ionosphere monitoring.

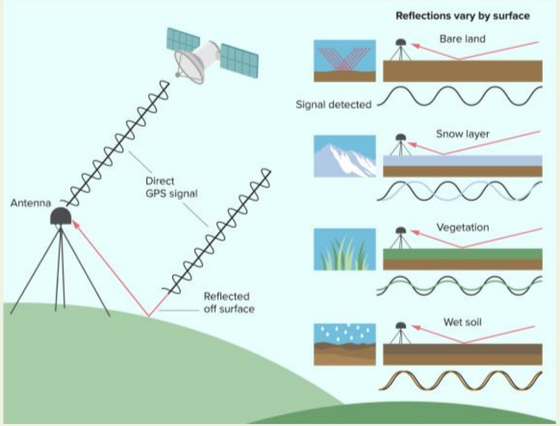


Source: Zhang et al. (2022)

Reflectometry systems

Ground-based applications

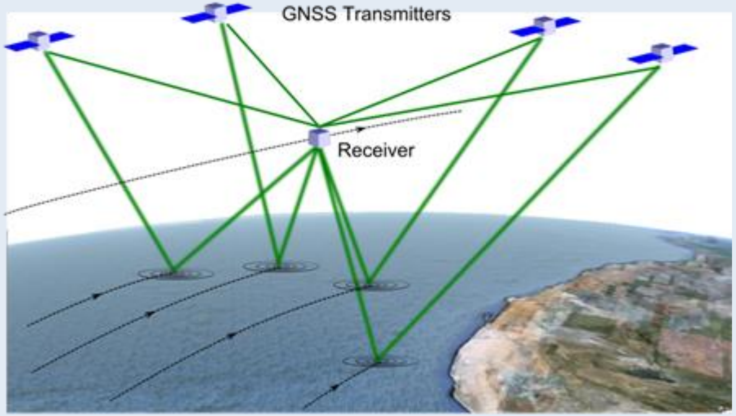
- Soil moisture content;
- Vegetation biomass sensing;
- Snow depth retrieval.



Source: UNAVCO GPS Reflections Group

Space-based applications

- Sea surface altimetry;
- Sea surface scatterometry;
- Sea surface permittivity.



Source: Measurement of Earth Reflected Radio-navigation signals By Satellite (MERRByS) website

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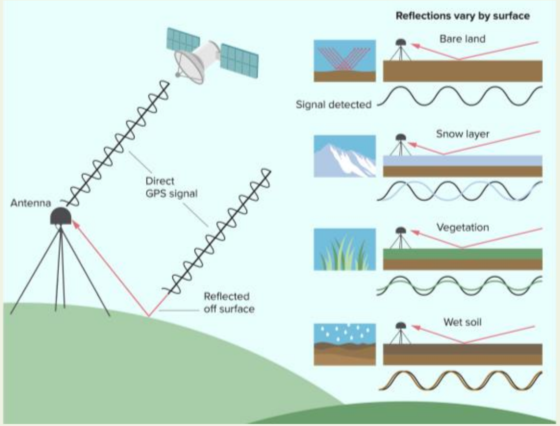

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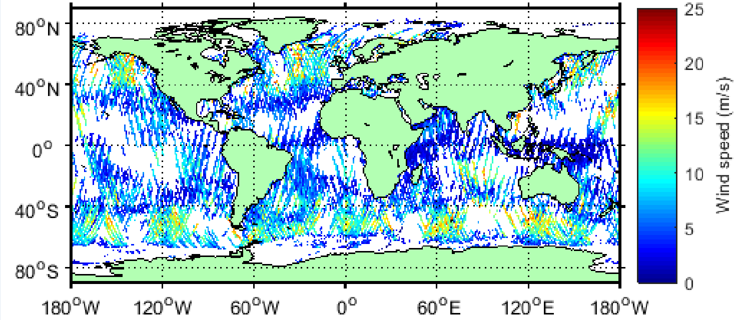

Source: Measurement of Earth Reflected Radio-navigation signals By Satellite (MERRByS) website

Conclusions

Summary

- Around **10000+ satellites** currently active in low Earth orbit.

- Dedicated LEO constellations for Positioning, Navigation, & Timing will **most likely revolutionize GNSS technology**.

- Several are the scientific opportunities enabled/enhanced by these future LEO-based constellations → **new science!**

More Dutch investments foreseen for Ministerial Council 2025?

Questions?

Thanks for your attention

Courtesy of ASI (Agenzia Spaziale Italiana)