SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

# Global Differential GPS System (GDGPS) & Galileo High Accuracy Service (HAS) Comparison

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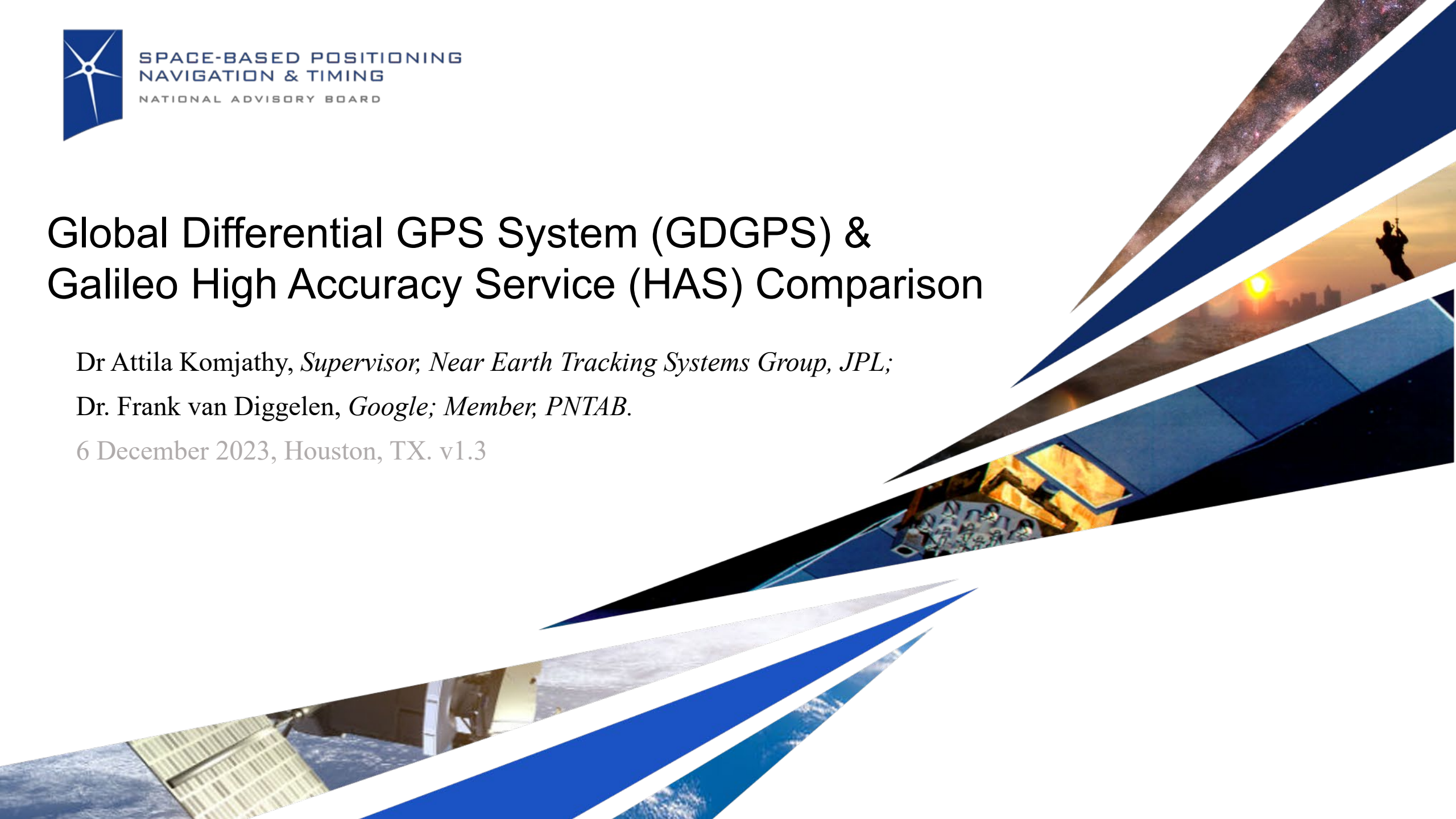
6 December 2023, Houston, TX. v1.3



# Outline

- PPP and Real Time DGNSS
- DGNSS review: SSR and OSR
- How we test with phones
- Global Coverage
- Correction components
- Test results
- Proposed data standards

# PPP and Real-time DGNSS

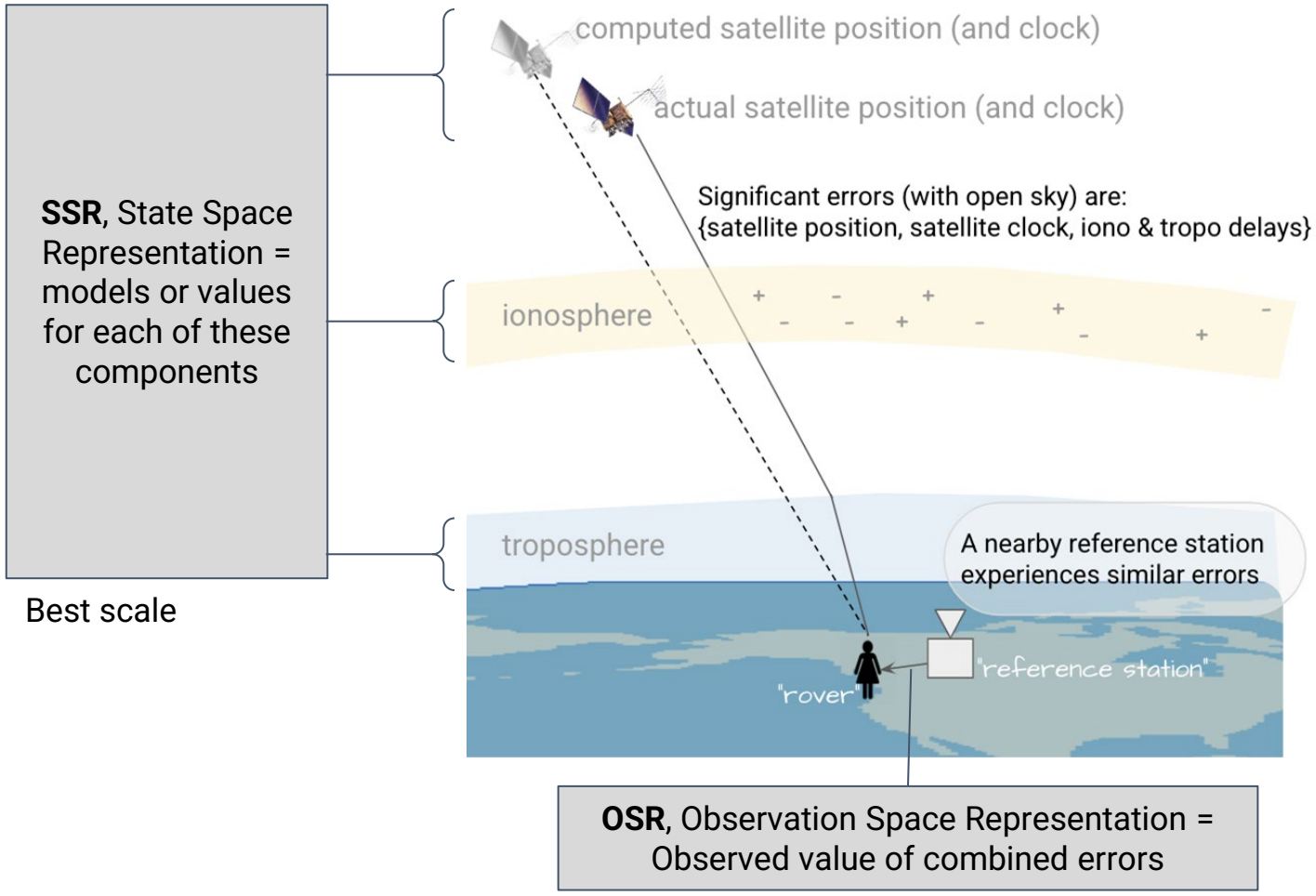
**Precise Point Positioning (PPP)**
Static (usually)
Survey-grade antennas (usually)
Minutes of convergence
Decimeters

Benchmark by Galileo HAS and GDGPS

**Real-time Differential GNSS (DGNSS)**
Kinematic
Embedded antennas in phones
1Hz updates
Meters


Consumer experience for phones, watches, cars

# DGNSS review: SSR & OSR



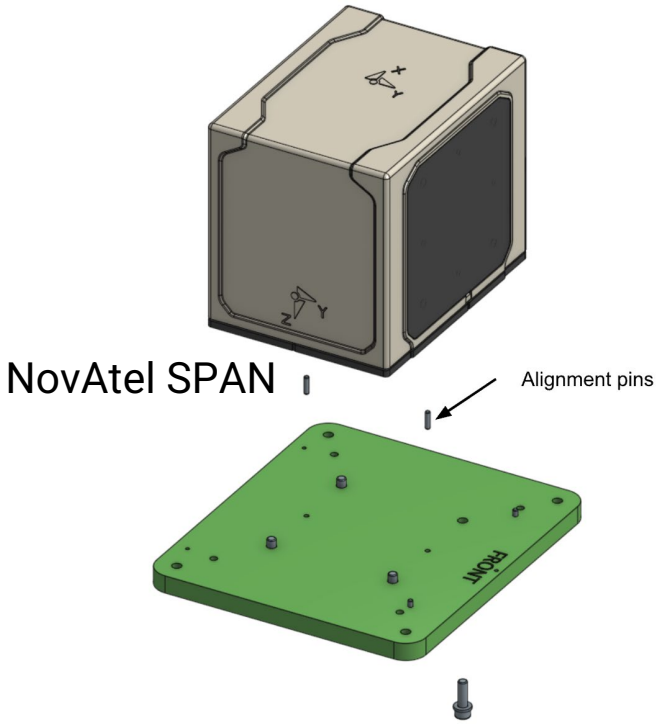

GDGPS, GPS HAS, and Galileo HAS are all SSR,
we use OSR as a reference: an unachievable lower bound on accuracy

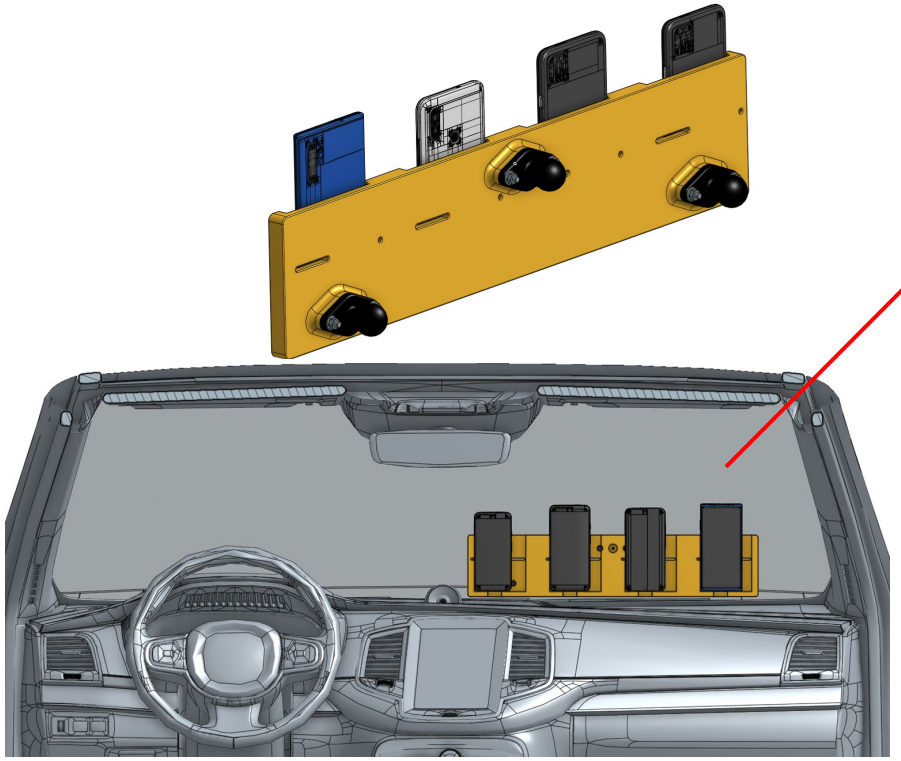
animated slide

# Precisely Coordinated Test Vehicle

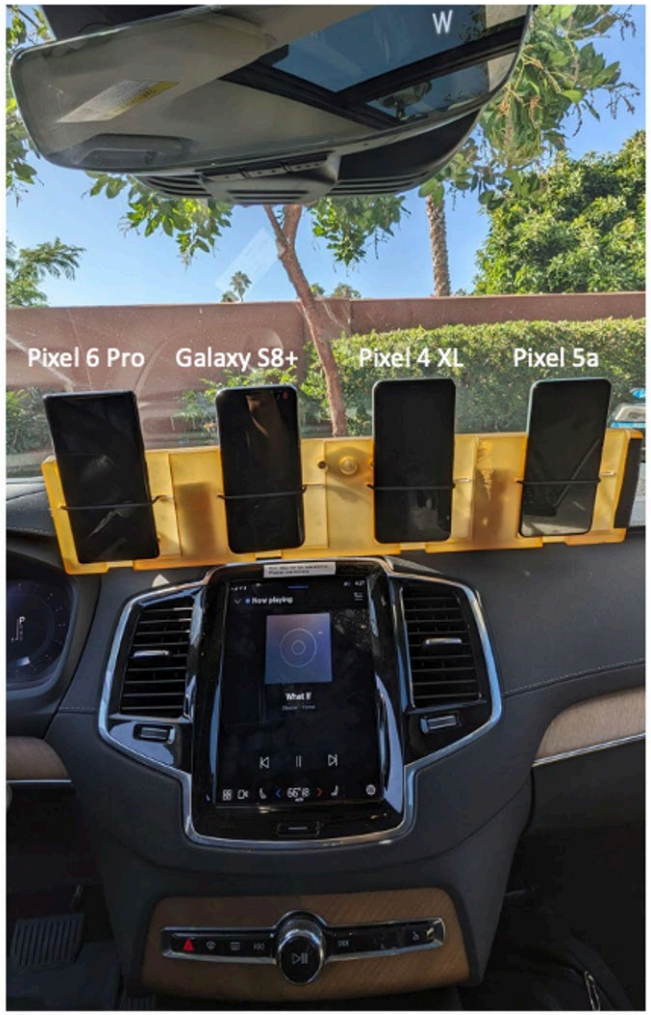
Customized cars with:

- stable mount for the reference receiver
- 3D printed phone mounts
- mm-level lever arm compensation using robotic arm



# Drive Tests setup


25 drive traces in SF Bay area,
from 2023-09-05 to 2023-09-07.
7 different phone models.
3 different GNSS chip vendors.

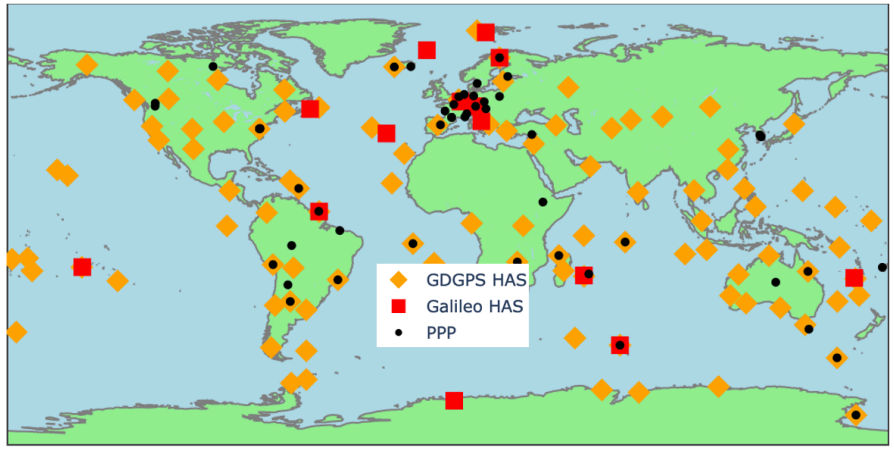
| Manufacturer | Model | GNSS Vendor |
|---|---|---|
| Google | Pixel 7 Pro | Broadcom |
| Google | Pixel 6 Pro | Broadcom |
| Google | Pixel 4 XL | Qualcomm |
| Google | Pixel 5a | Qualcomm |
| Google | Pixel 5 | Qualcomm |
| Samsung | Galaxy S8+ | Broadcom |
| Samsung | Galaxy S22 Ultra | Samsung LSI |

# Coverage

**Stations Used for Comparing PPP Performance Using GDGPS HAS and Galileo HAS**

Jet Propulsion Laboratory
California Institute of Technology

- Over 2700 independent overlapping 3-hour Galileo HAS and GDGPS HAS datasets used to compute combined GPS+GAL solutions at 50 stations
- 7-days' worth of GDGPS HAS and Galileo HAS data analyzed

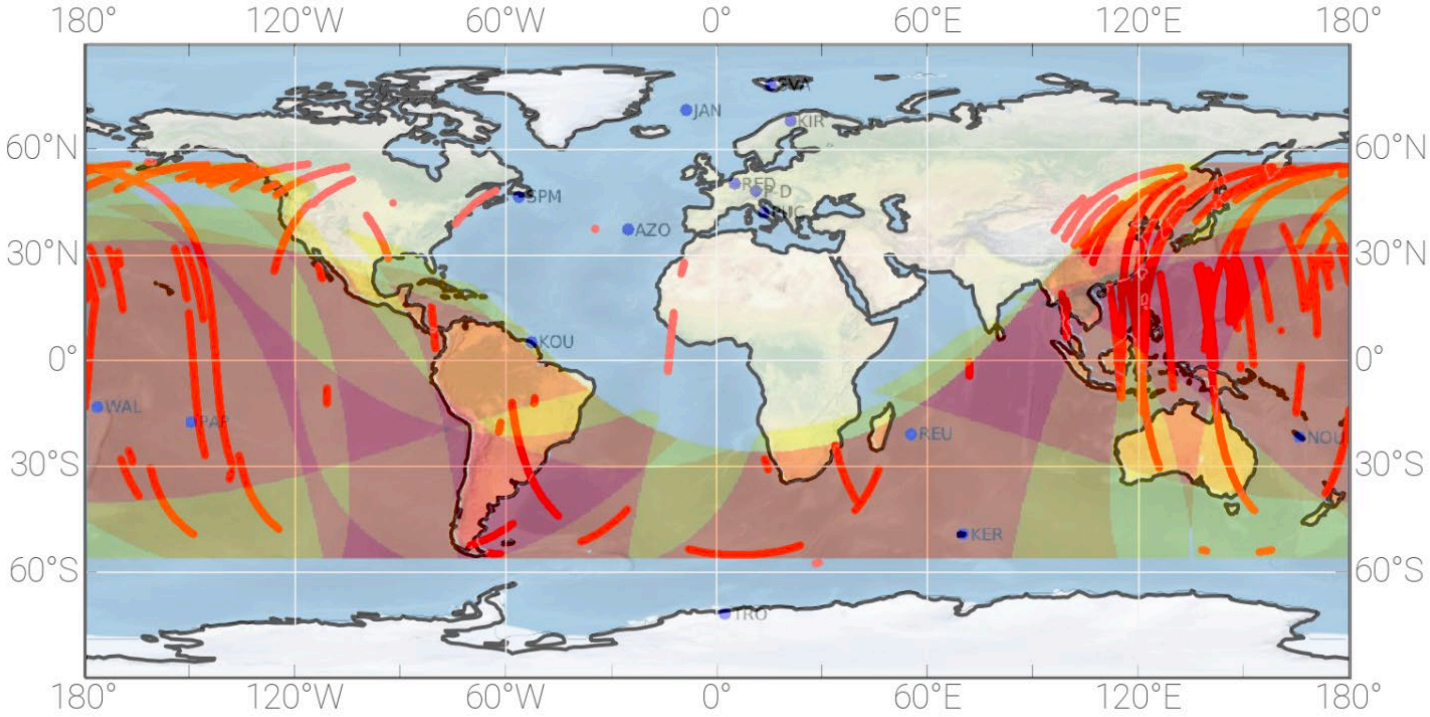



50 stations used globally to compare HAS performances

5 jpl.nasa.gov



# Galileo HAS gaps

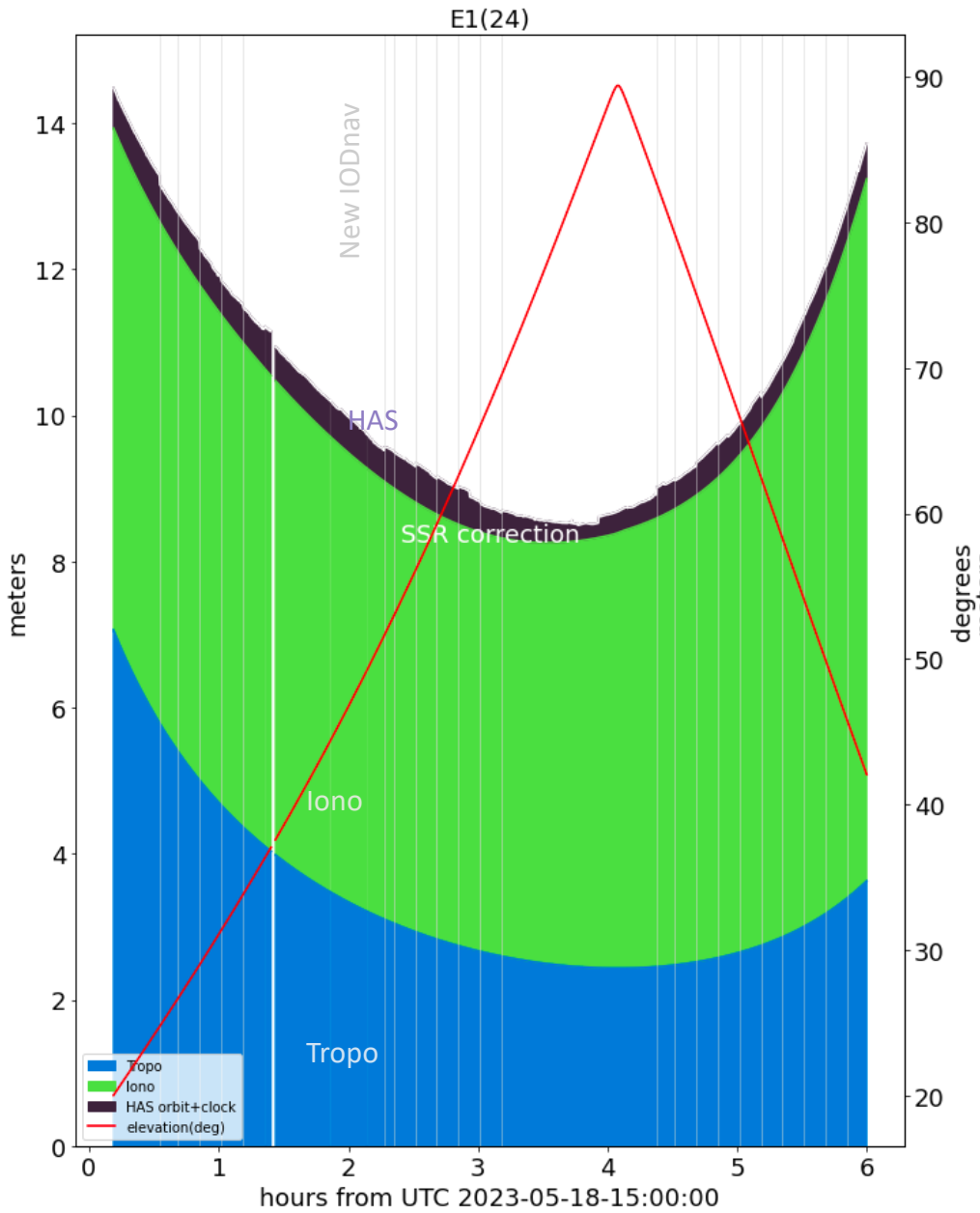


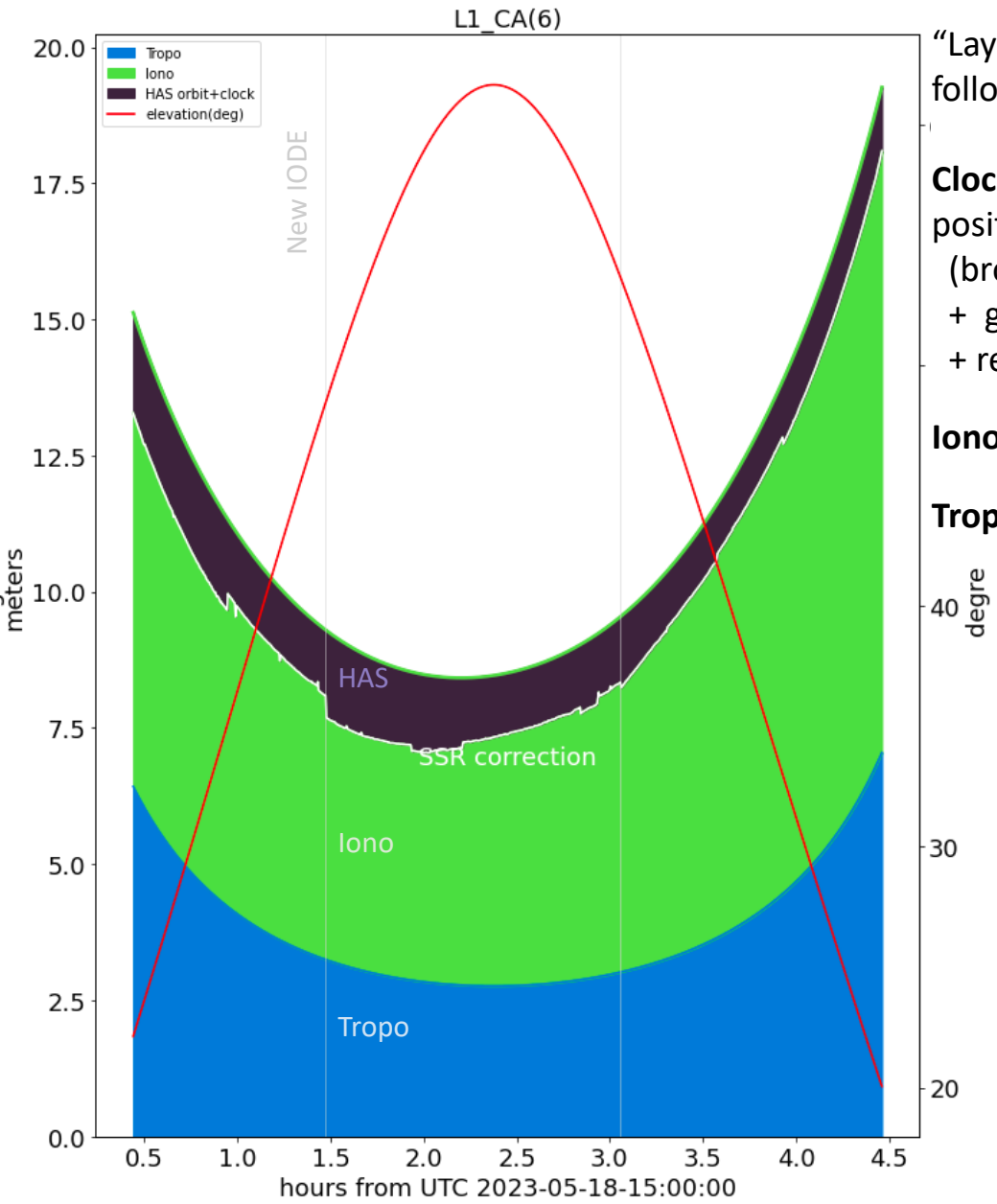

Shading => number of Galileo ground stations with satellite view

Traces of satellites during gaps in HAS corrections

24h of ground trace on 2023-09-07 (UTC)

# Components of SSR: HAS, iono, and tropo corrections




"Layer Cake"
following RTCM 10423:

**Clock & orbit:** corrections to ephem
position and clock:
(broadcast error $af_0$,$af_1$,$af_2$
+ group delay
+ relativistic offset)

**Iono:** entire iono delay

**Tropo:** entire tropo delay

# Drive Test Results, all traces

| | 2d errors (**50%, meters**) | 2d errors (**95%, meters**) | Cross-track errors (**50%, meters**) | Cross-track errors (**95%, meters**) |
|---|---|---|---|---|
| Chipset | 1.85 | 3.42 | 1.06 | 2.49 |
| Galileo HAS SSR | 1.18 | 2.31 | 0.58 | 1.57 |
| GDGPS SSR | 1.15 | 2.24 | 0.58 | 1.46 |
| DGNSS OSR | 0.98 | 2.07 | 0.48 | 1.30 |

Comparative results, each using the same set of GPS & Galileo satellites (L1 + L5).
SSR corrections includes IGS GIM ionosphere model and Saastamoinen tropo model.
25 drive traces in SF Bay area collected from 2023-09-05 to 2023-09-07.
7 different phone models.

# Data Standards

## Galileo HAS


Galileo High Accuracy Service - Internet Data Distribution Interface Control Document (HAS IDD ICD)

Data format follows RTCM 10403.3 Differential GNSS *

Using NTRIP defined in RTCM 10410.1

* RTCM 10403.3 Differential GNSS defines SSR for GPS not other constellations. Galileo HAS uses an unpublished draft of 10404.3 that includes Galileo corrections:
"Proposal of new RTCM SSR Messages SSR Stage 1: Galileo, QZSS, SBAS, BDS for RTCM STANDARD 10403.3, 2018-06-07, ssr_1_gal_qzss_sbas_bds_v08"

NTRIP: Networked Transport of RTCM via Internet Protocol

## GPS HARS

We propose maximum compatibility with existing standards and approaches, to make adoption easy and robust for all device manufacturers.



https://www.gsc-europa.eu/electronic-library/programme-reference-documents#ACCURACY

# Summary

- Both Galileo HAS and GDGPS provide similar accuracy:
  - Takes phone accuracy most of the way to OSR
  - From multi-lane accuracy (GNSS chip native solution) to single-lane

- GDGPS provides worldwide coverage