Update on GPS HAS Based on GDGPS and Recent Results

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Motivation and Objective

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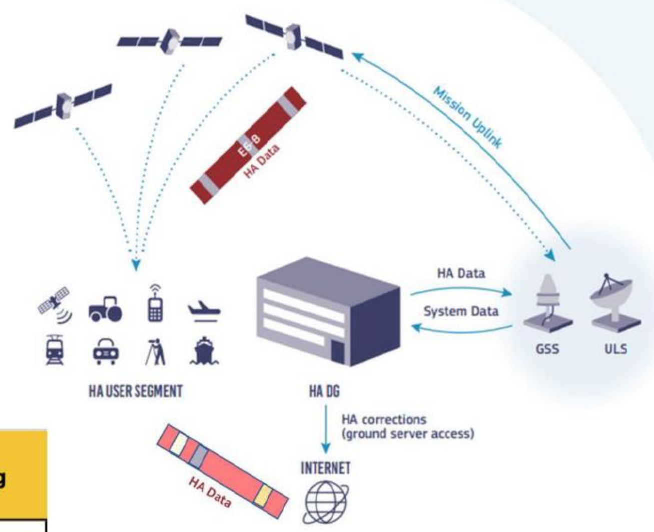
- **Motivation:** Seek a government partner to *sustain* and *distribute* GPS HAS in alignment with PNT AB and PNT Subcommittee guidelines

- **Objective:** Highlight JPL's advanced technical contributions to improve GPS performance through High Accuracy Service (HAS) and associated applications using GDGPS

Galileo HAS vs GPS HAS Using GDGPS

Simplified view of the **Galileo HAS high-level architecture** →

- main elements involved in the broadcasting of HAS data.



GPS HAS in par in capabilities with Galileo HAS

	Phase 1 Initial Service	Phase 2 Full Service	GPS HAS Using GDGPS
Coverage	EU+ →	Global	Global
Orbit corrections	Y	Y	Y
Clock corrections	Y	Y	Y
Code biases	Y	Y	Y
Phase biases	Y	Y	Y
Galileo corrected signals	E1, E5a, E5b, E5, E6	E1, E5a, E5b, E5, E6	E1,E5a,E5b (++)
GPS corrected signals	L1, L2C	L1, L2C, L5	L1W, L2W, L5Q (++)
Signal Quality indicator	N	Y	TBA
Horizontal accuracy requirement 95%	> 20 cm	20 cm	< 10 cm
Vertical accuracy requirement 95%	> 40 cm	40 cm	< 20 cm
Convergence time requirement Global, no ionosphere (Service Level 1)	> 300 s	300 s	TBA
EU, ionosphere corrections (Service Level 2)	N/A →	100 s	300 sec
Ground channel	Y	Y	Y
Ground reference stations	14 (GSS)	To be defined	100+
Max. sat. downlinks (448 bps)	20	To be defined	N
Authentication	N	Y	Possible
Phase Start	2022 →	2024+	Unplanned

Fernandez-Hernandez et al., 2022 ↑

++ supporting different signals at the same frequency via code biases

Service Level 1 (SL1):

- global coverage
- high accuracy corrections (orbits, clocks) and biases (code and phase)
- Galileo and GPS L1/L5/L2 signals

Potential GPS HAS with GDGPS vs GAL HAS

Potential GPS HAS Features

- GDGPS is **fully capable** of providing global high-accuracy corrections for a potential GPS HAS
- **Global network** of GDGPS monitoring-stations available (100+ stations globally)
- **Two** geographically separated GDGPS Operations Centers (GOCs) with independent processing and distribution, highly tested redundant and robust architecture
- Meets and exceeds **accuracy requirements** set for GAL HAS Phase 2 (horizontal 20 cm (95%) and vertical 40 cm (95%))
- **Latency** including internet distribution consistently measured approximately 6 sec

Differences with Galileo HAS

- **Ground-based distribution of solution**, over internet and other land lines (available for GAL HAS)
- **No Signal-in-Space** (SIS) for GPS HAS available in present or planned GPS architecture

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

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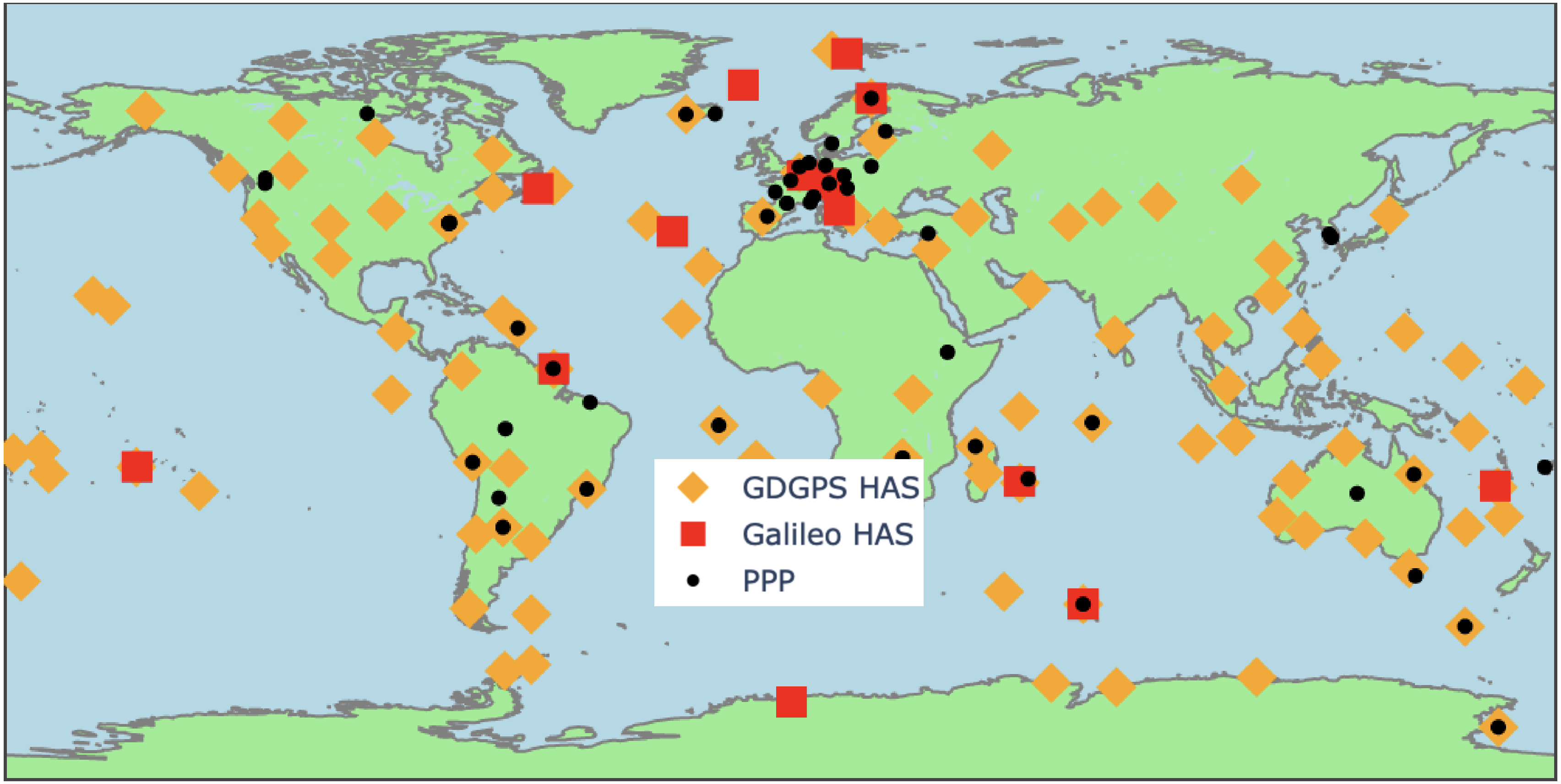
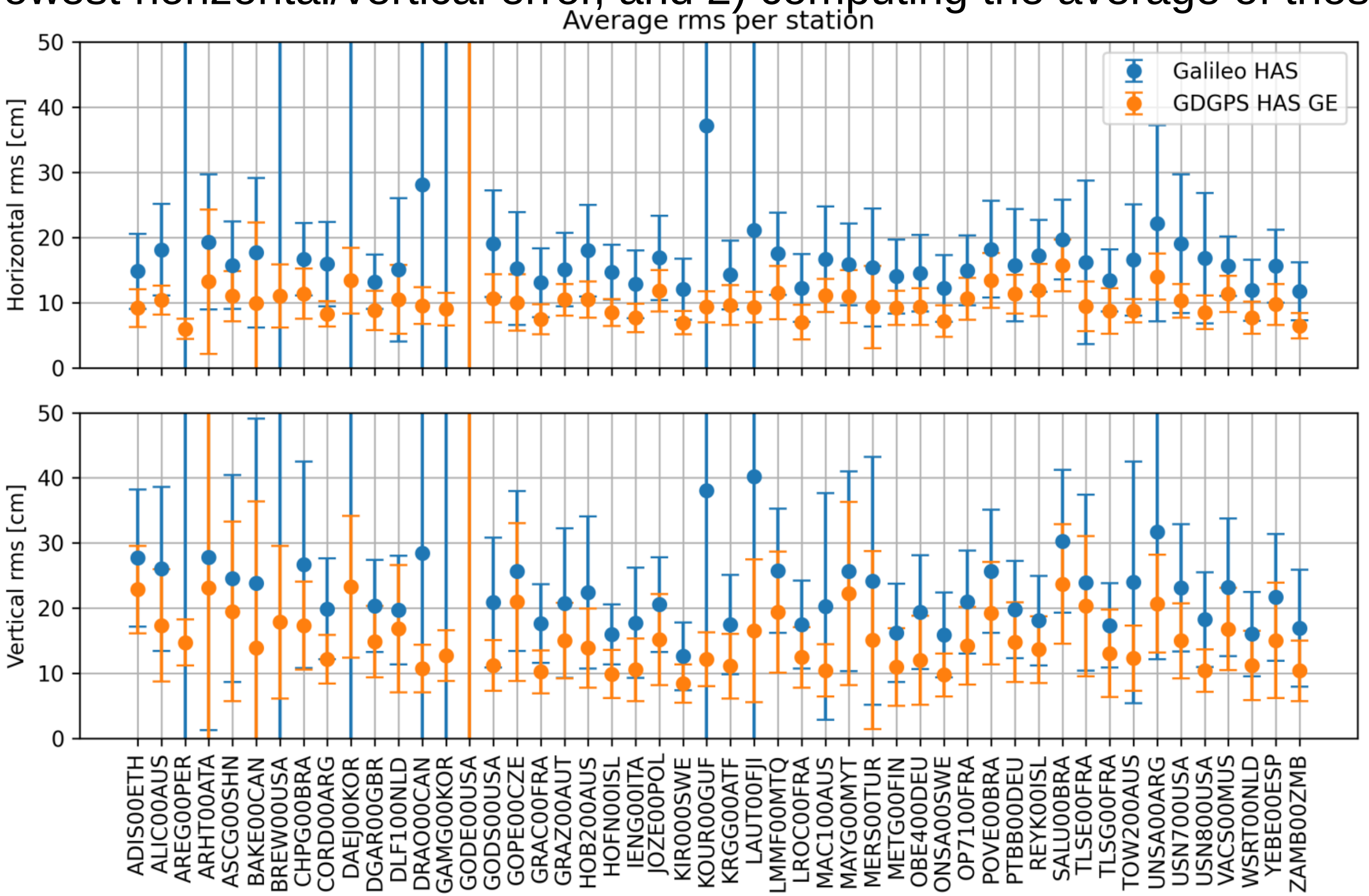
- Over 2700 independent overlapping 3-hour Galileo HAS and GDGPS HAS datasets used to compute combined GPS+GAL solutions at 50 stations
- 7-days' worth of GDGPS HAS and Galileo HAS data analyzed



50 stations used globally to compare HAS performances

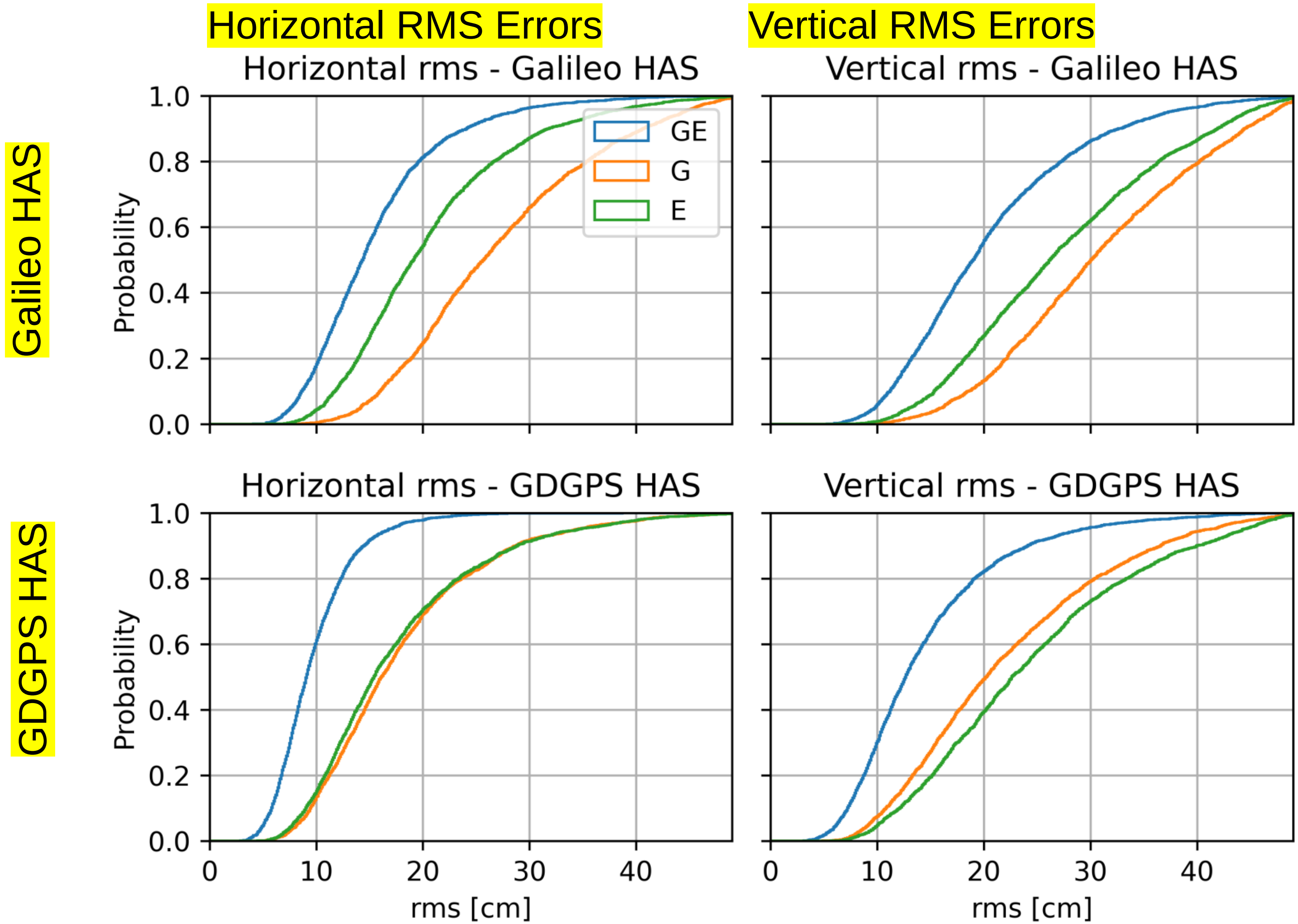
Average RMS Errors for All Stations Investigated

- Computed at each epoch by 1) taking the 95% datasets (out of ~2,700) with the lowest horizontal/vertical error, and 2) computing the average of those.



Average and 1-sigma error bars of RMS for horizontal and vertical components for individual stations investigated

Cumulative Histograms for Vertical and Vertical Errors



GPS-only and Galileo-only performance with GDGPS HAS agree well

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GDGPS HAS vs GAL HAS Error Distribution

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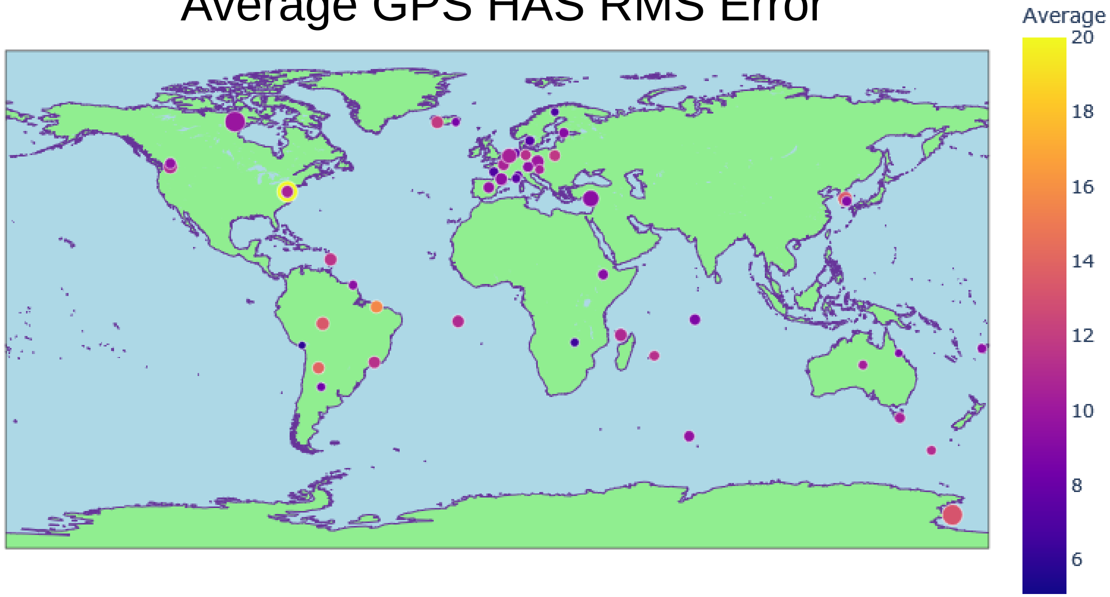
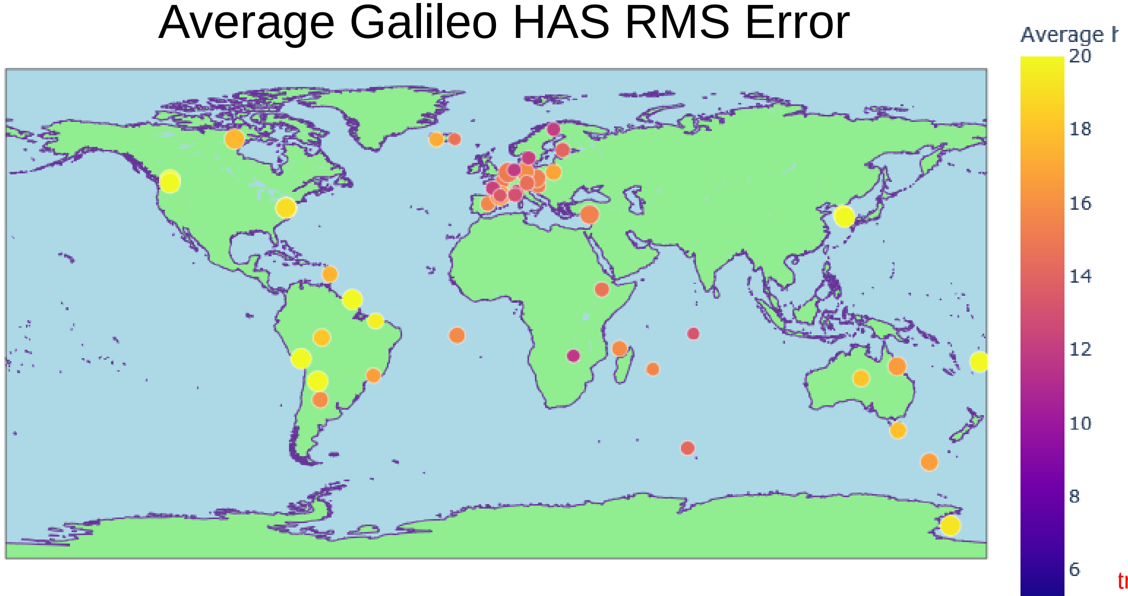
Average GPS HAS RMS Error



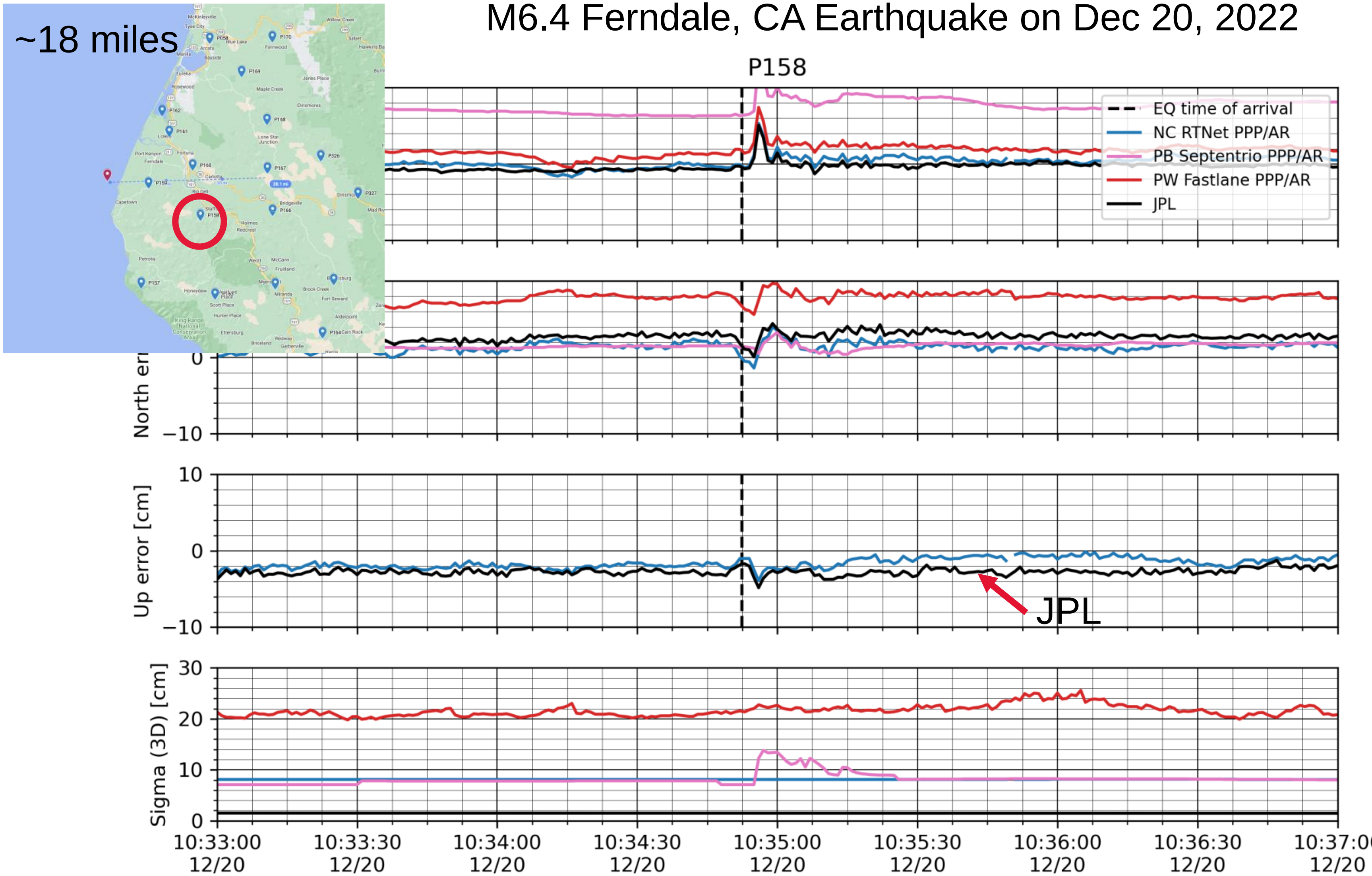
Average Galileo HAS RMS Error



- The sizes of the dots are based on the standard deviations of the rms
- Horizontal component only shown
- All solutions are GPS+Galileo

Galileo HAS RMS error seems larger in the Asian Sector due to lack of coverage

Comparisons with Public PPP Solutions at P158 for M6.4 Ferndale Event on Dec 20, 2022



Good agreements among ShakeAlert GNSS solutions for P158

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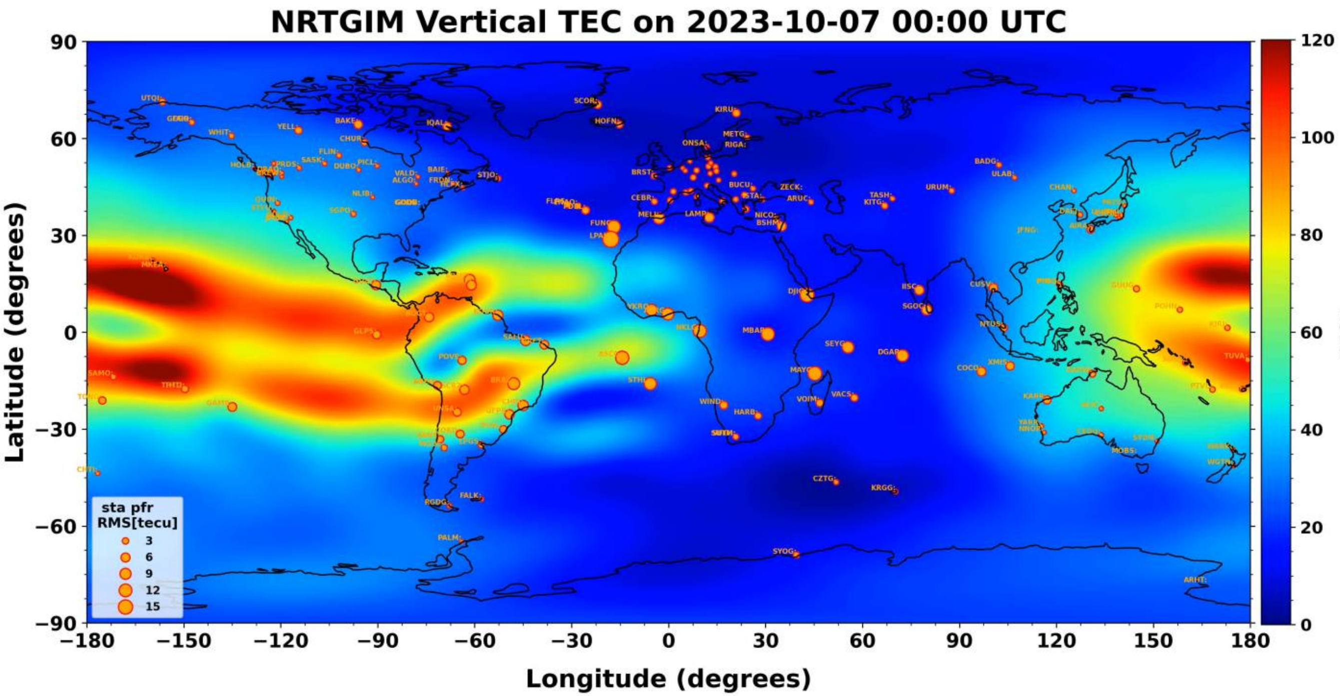
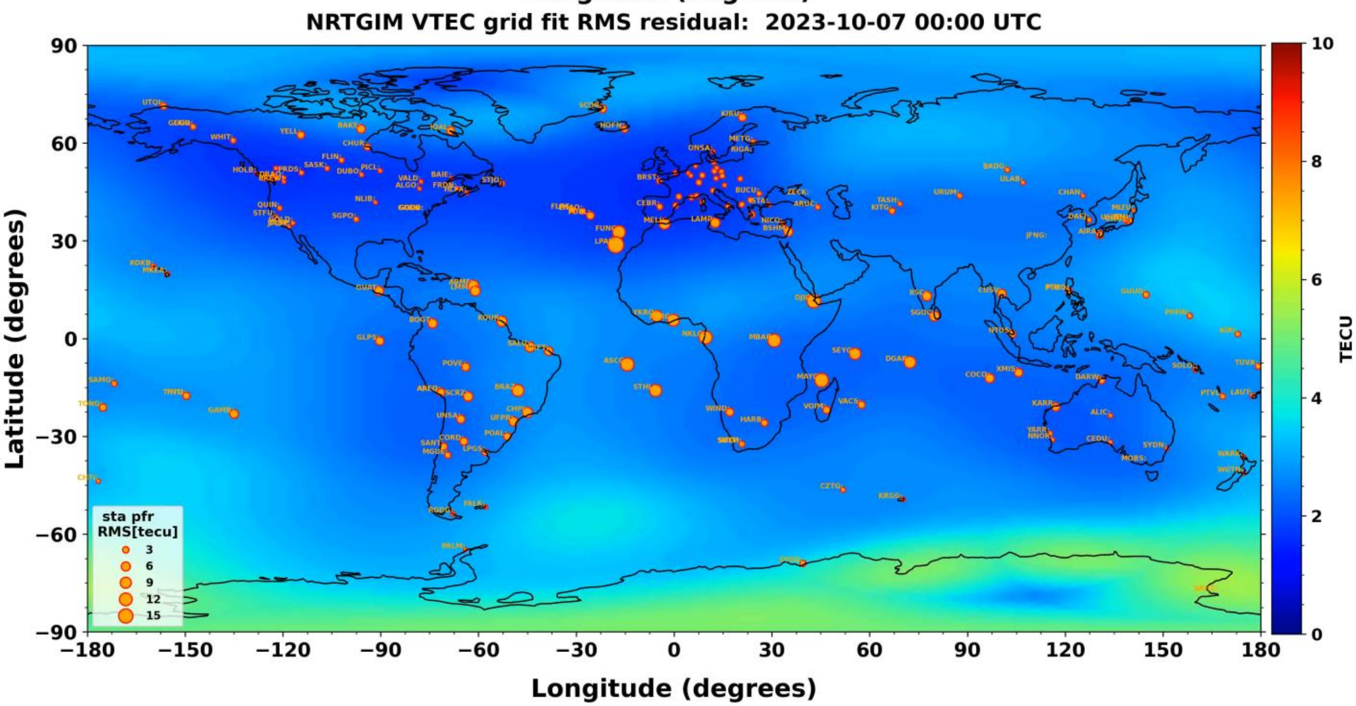


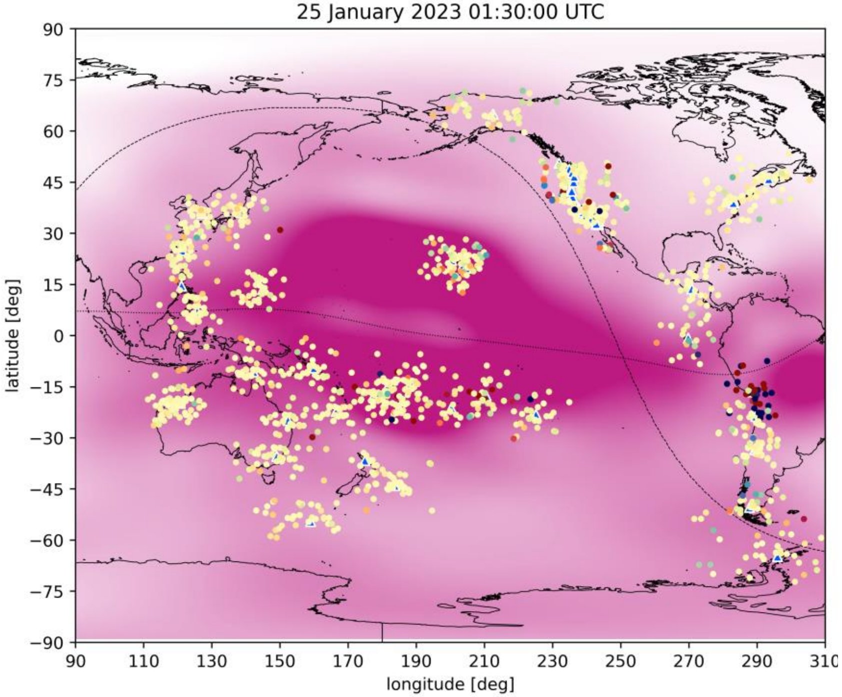


- Near-Real-Time monitoring of ionospheric disturbances including geomagnetic and solar disturbances
- GDGPS features additional science capabilities

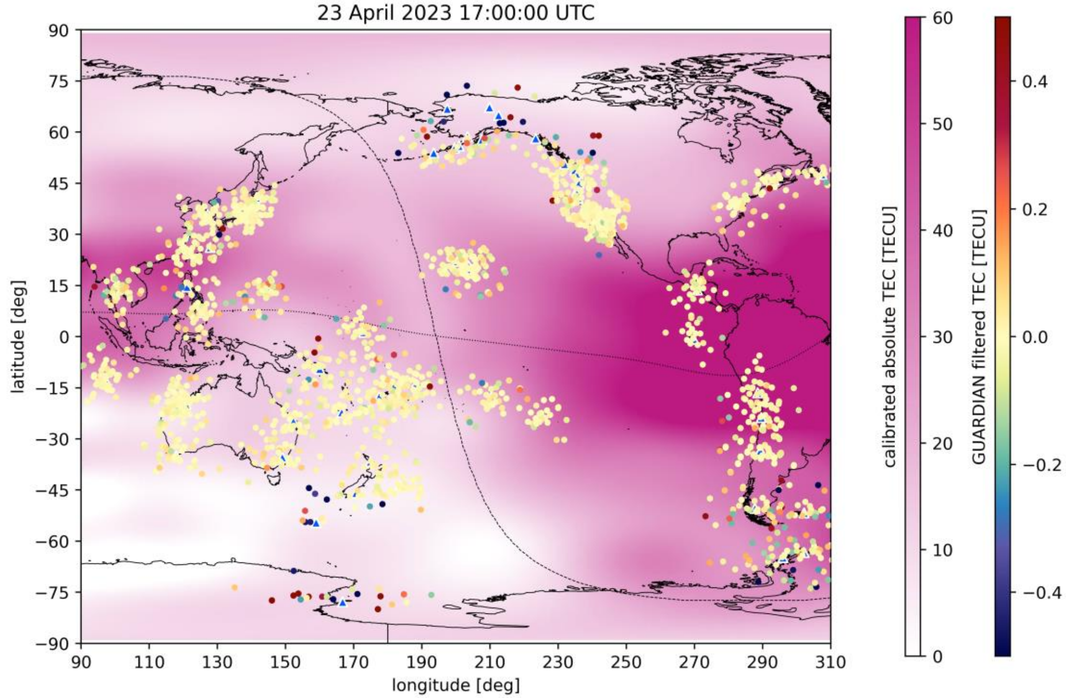
GDGPS Monitoring Ionospheric Perturbations Using Combined NRT and Real-Time GDGPS Data

Space Weather Activity

Low Solar Activity (Kp 0.0)



High Solar Activity (Kp 5.7 to 8.4)



Real-time monitoring of ionospheric disturbances using a combination of high-resolution multi-shell GIM mapping and real-time GDGPS-based TEC measurements

Conclusions

- A potential GPS HAS using GDGPS has unique and multiple advantages:
  - Global network of GDGPS-processed stations available (100+ stations)
  - Network designed for resiliency, robustness using multiple redundancies
  - GDGPS is fully capable of providing GPS & Galileo HAS for PPP-AR
- GDGPS provides global real-time monitoring capability of ionospheric disturbances
  - Could provide early warning of ionospheric disturbances for regional networks such as WAAS impacted by severe space weather

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