Towards a GPS High Accuracy Service (GPS HAS) Based on GDGPS

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Outline

- Motivation and objective
- Galileo HAS vs GPS HAS using GDGPS
  - GPS HAS advantages and challenges
- GDGPS capabilities relevant for GPS HAS
  - GNSS networks
  - GDGPS Operation Centers (GOCs)
  - Redundancy and robustness
  - GNSS POD accuracy, recent stats of UREs, orbit and clock errors
  - Current real-time PPP performance
- Concluding remarks

Motivation and Objective

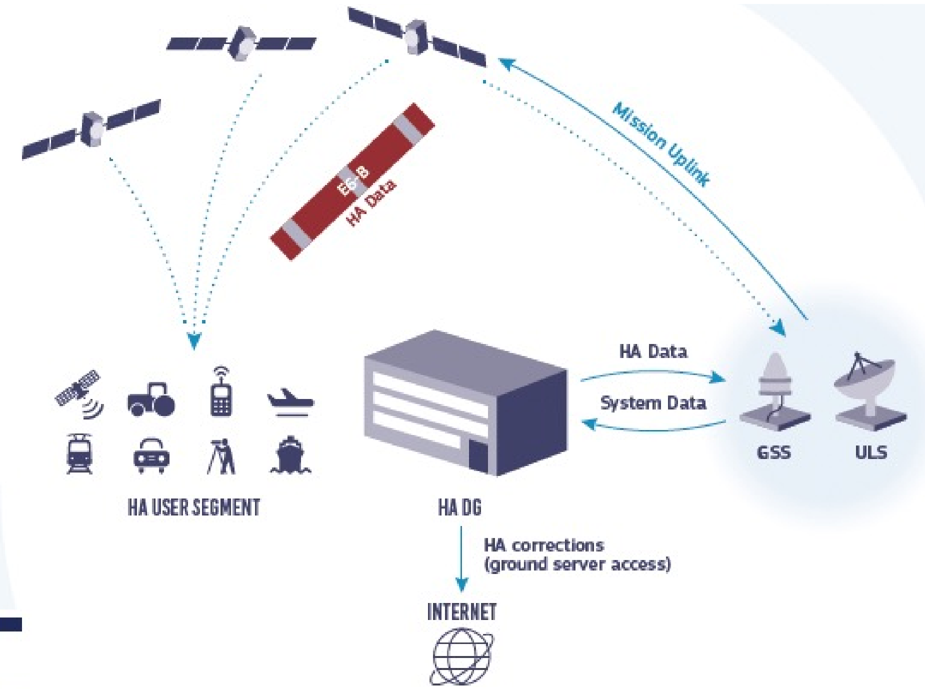
- **Motivation:** find an owner within the Government community to support and sustain GPS HAS capabilities using GDGPS as per PNT Subcommittee

- **Objective:** show the current technical capability that JPL brings to enhance GPS performance by adding High Accuracy Service (HAS) using GDGPS

Galileo High Accuracy Service (HAS)

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

- main elements involved in the broadcasting of HAS data.



HAS	SERVICE LEVEL 1	SERVICE LEVEL 2
COVERAGE	Global	European Coverage Area (ECA)
TYPE OF CORRECTIONS	PPP - orbit, clock, biases (code and phase)	PPP - orbit, clock, biases (code and phase) incl. atmospheric corrections
FORMAT OF CORRECTIONS	Open format similar to Compact-SSR (CSSR)	Open format similar to Compact-SSR (CSSR)
DISSEMINATION OF CORRECTIONS	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)
SUPPORTED CONSTELLATIONS	Galileo, GPS	Galileo, GPS
SUPPORTED FREQUENCIES	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C
HORIZONTAL ACCURACY 95%	<20cm	<20cm
VERTICAL ACCURACY 95%	<40cm	<40cm
CONVERGENCE TIME	<300 s	<100 s
AVAILABILITY	99%	99%
USER HELPDESK	24/7	24/7

Service Level 1 (SL1):

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

Galileo HAS vs GPS HAS Using GDGPS

	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

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

↑

Fernandez-Hernandez et al., 2022

Potential GPS HAS with GDGPS vs GAL HAS

Potential GPS HAS Features

- **Global network** of GDGPS monitoring-stations available (100+ stations globally)
- **Three independent** GDGPS Operations Centers (GOCs). They are:
  - geographically separated,
  - redundant power supplies, and various ancillary devices,
  - computational redundancy, spares, and backup capabilities bring resiliency
- GDGPS is **technologically fully capable** of providing global high-accuracy corrections for a potential GPS HAS. A history of innovation and reliable service.
- 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

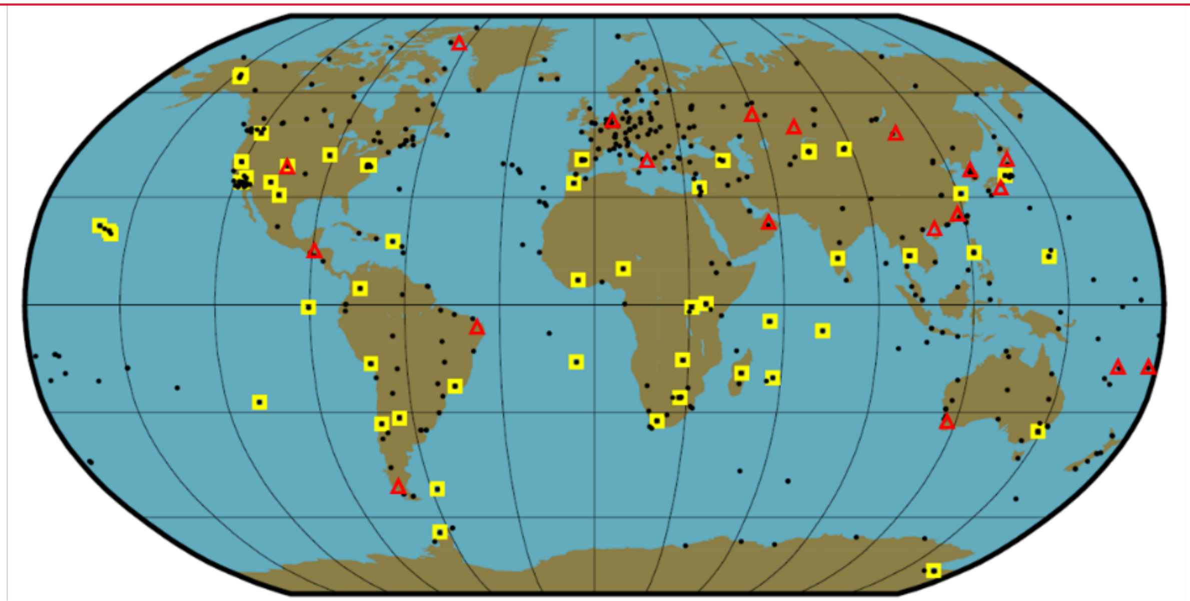
Differences with Galileo HAS

- **Ground-based distribution of solution**, over internet and other land lines (vs 20 uplink stations for GAL HAS)
- **No Signal-in-Space** (SIS) planned for GPS
- **PPP convergence times** not systematically established yet

Network of GDGPS-Processed GNSS Receivers

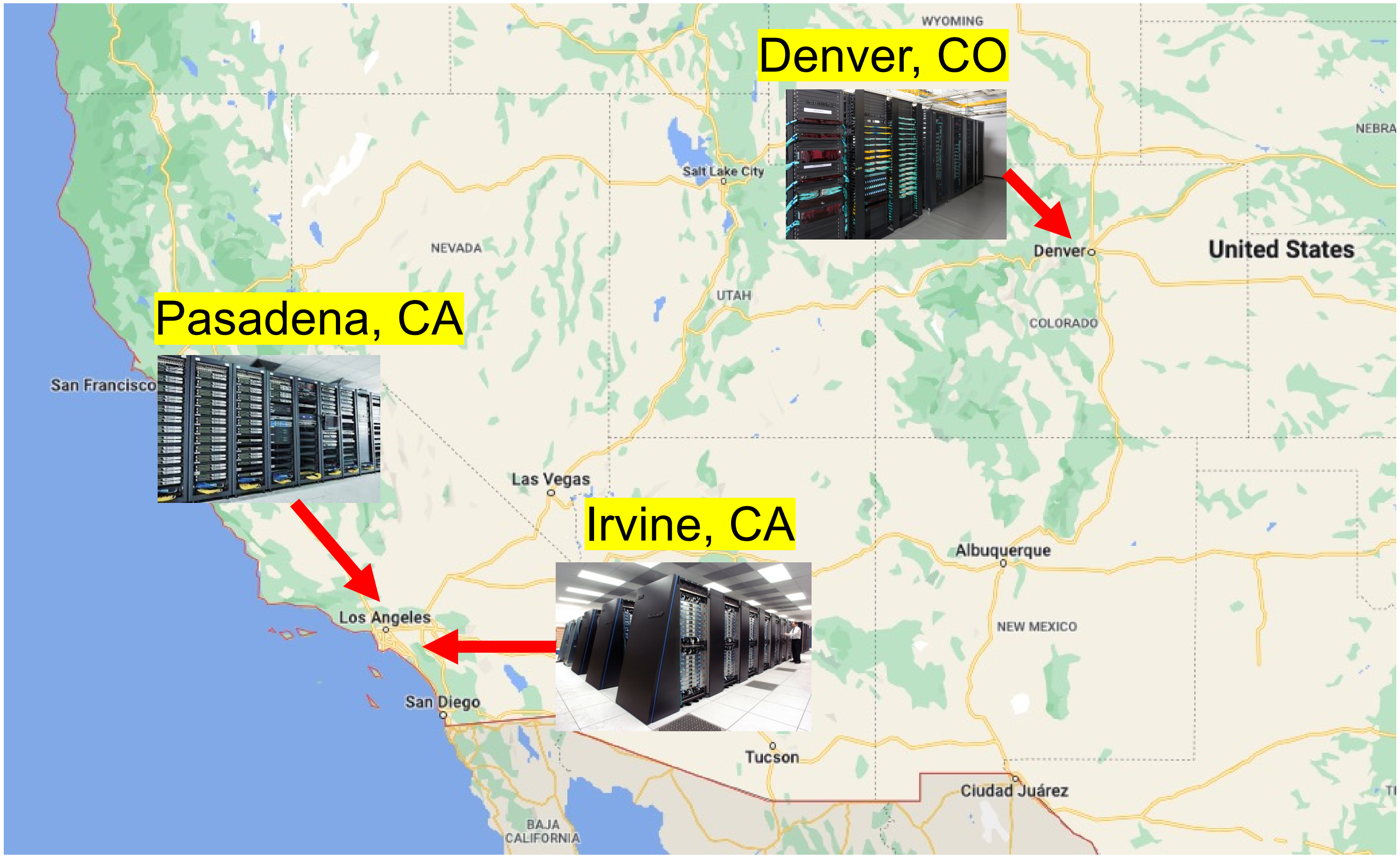
- GDGPS uses and supports NASA-owned JPL-operated GNSS receivers (GGN)
- Network also augmented by a smaller set of GDGPS-operated sites
- Publicly available IGS streaming data supplementing the global network

The available global tracking network undergoes continual review and upgrading.



- Publicly-available International GNSS Service data (100+ sites)
- NASA Global GNSS Network (60 sites), funded by Space Geodesy Program
- GDGPS owned and operated sites (19 sites fielded, ~12 operating at any one time)

Maintaining GDGPS Operations Centers (GOCs)



- Operational data processing is carried out in **three** independent GDGPS Operations Centers (GOCs) with **separate ISPs**.
- **Geographic separation** provides resiliency to single points of failure considering outages or natural hazards.

Resilience: Redundancy and Robustness

Operational GNSS Filters

GPS	DN	gps1dn	datd1dn	pod fast
		gps2dn		pod fast
	OC	gnss7oc	datd1oc	pod fast
		gnss8oc		pod fast
GPS+GLO	DN	gnss1dn	datd1dn + datd2dn	pod fast
		gnss2dn		pod fast
	OC	gnss10oc	datd1oc + datd2oc	pod fast
		gnss11oc		pod fast
GPS+BDS+QZS	DN	gnss3dn	datd1dn + datd2dn	pod fast
		gnss4dn		pod fast
	OC	gnss12oc	datd1oc + datd2oc	pod fast
		gnss13oc		pod fast
GPS+GAL	DN	pod1dn	datd2dn + (datd2dn + datd1oc)(SSR)	pod fast
		pod2dn	datd2dn	pod fast
	OC	gnss14oc	datd2oc + (datd2oc + datd1dn)(SSR)	pod fast
		gnss15oc	datd2oc	pod fast
Operational GNSS-SSR				
GPS+BDS+GAL	OC	dev10oc	datd2oc + datd1la	pod fast
		gnss2oc	(dev/backup for dev10oc)	pod fast
	LA	pp1la	datd2la + datd1oc	pod fast
	DN	pp4dn	(will replace pp1la for ops)	pod fast
Biases				
GPS,BDS,GAL	LA	gnss2la	ftp1la	link
		bias1la	-	(new style to appear)
	OC	bias1oc	ftp1oc	(redundant instance to appear)
PPP / Monitoring				
GPS	LA	dev1la	dev(W1W2+C1C2)	pod fast
GPS+GLO+GAL+BDS+QZS	LA	dev2la	PPP(5con decoupled + in-situ comparison)	pod
GPS	OC	pp1oc	PPP(decoupled, comparison for SSR)	pod fast

- Network design for robustness: through system redundancy
- GOCs *redundantly* connected with internet using leased network connections
- Geographic separation provide a *resiliency* to single points of failure, whether technical failure, or to natural hazards
- Each GOC hosts 10-20 high-end computers along with firewalls, switches, storage devices, redundant power supplies, with *computational redundancy, spares*, and backup capabilities

GNSS Orbit Determination Accuracy Capabilities of the GDGPS System

GDGPS Published Baseline Requirements

Attribute	GPS	Galileo	BeiDou	GLONASS	QZSS	NAVIC
Orbit Errors (3D RMS)	< 0.15 m	< 0.15 m	MEO < 0.3 m IGSO < 5 m GEO < 3 m	< 0.2 m	< 2 m	< 10 m
Clock Error (RMS)	< 0.1 m	< 0.1 m	MEO < 0.20 m IGSO < 1.5 m GEO < 0.5 m	< 0.15 m	< 0.5 m	< 3 m
User Range Error (RMS)	< 0.08 m	< 0.08 m	MEO < 0.3 m IGSO < 1 m GEO < 0.5 m	< 0.12 m	< 0.3 m	< 1 m

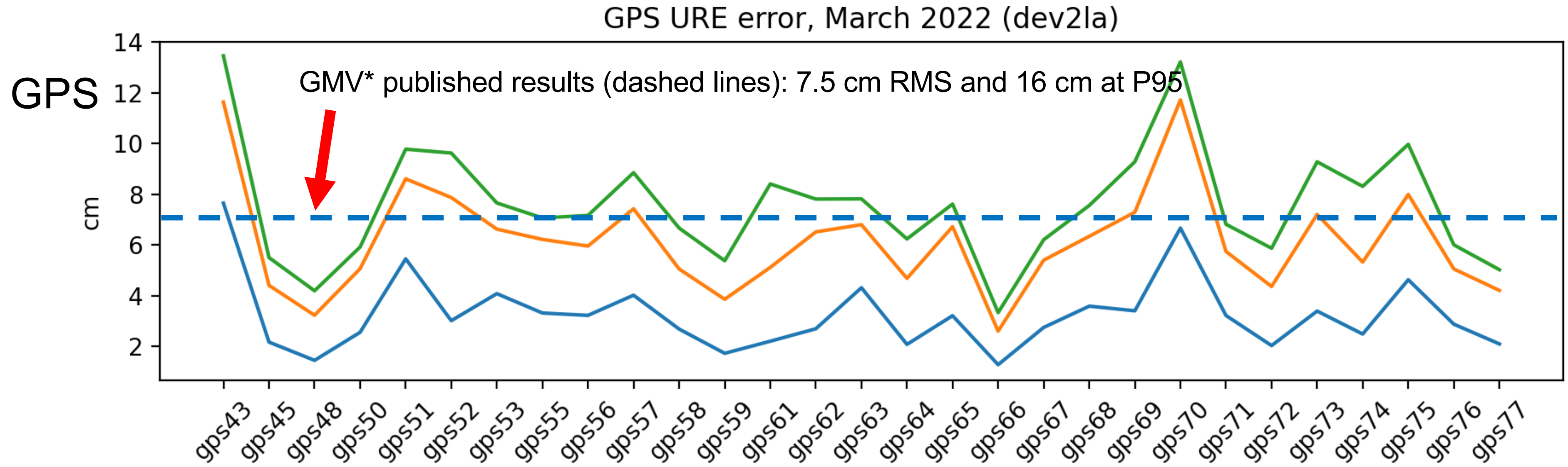
GAL: Multiple solutions are available, currently both I/NAV (E1+E5b) and F/NAV (E1+E5a) signals

BDS: Multiple solutions are available, currently using B1I, B2I, B3A and B2a signals

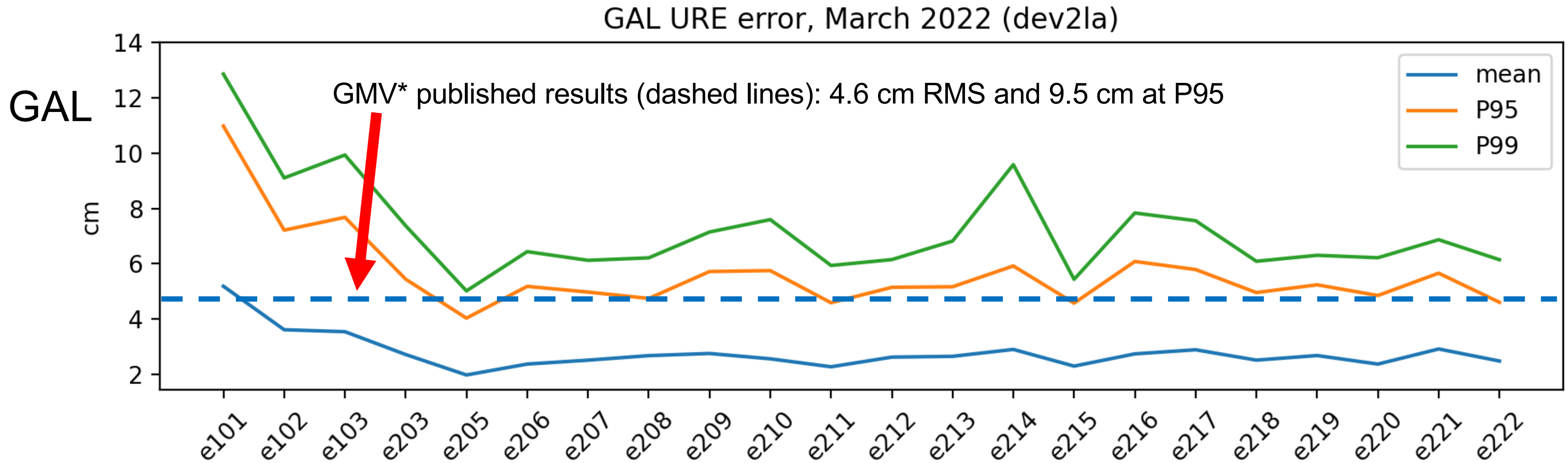
GLO: Satellite-specific clock bias removed due to frequency-specific range biases

Actual GDGPS performance outperforms baseline requirements and will be discussed later

GPS and GAL UREs Using GDGPS Compared to Post-Processed Products



GDGPS-derived **GPS** UREs and P95 errors compares favorably to GMV published values of Phase 1

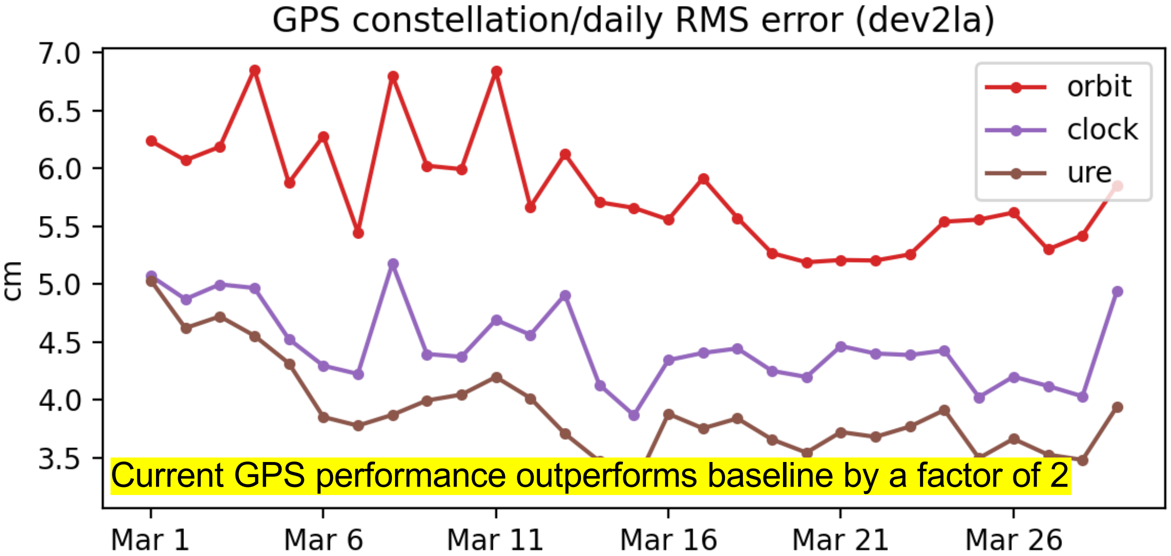


GDGPS-derived **GAL** UREs and P95 errors compares favorably to GMV published values of Phase 1

**Fernandez-Hernandez et al., 2022*

Real-Time Orbits, Clock and UREs for March 2022

GPS

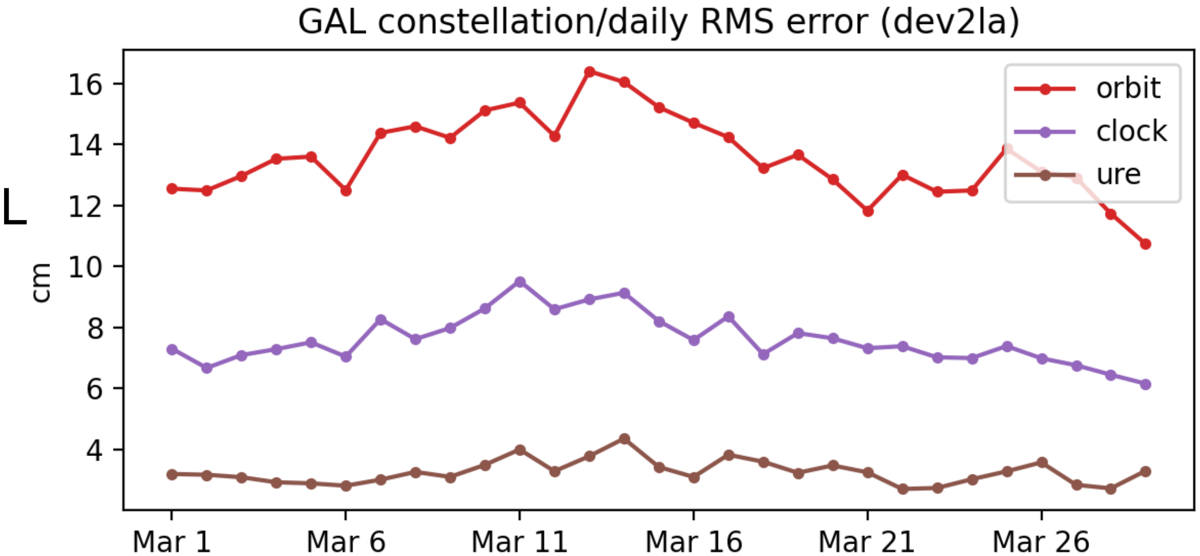


Current GPS performance outperforms baseline by a factor of 2

GDGPS Baseline Requirements

Attribute	GPS	Galileo
Orbit Errors (3D RMS)	< 0.15 m	< 0.15 m
Clock Error (RMS)	< 0.1 m	< 0.1 m
User Range Error (RMS)	< 0.08 m	< 0.08 m

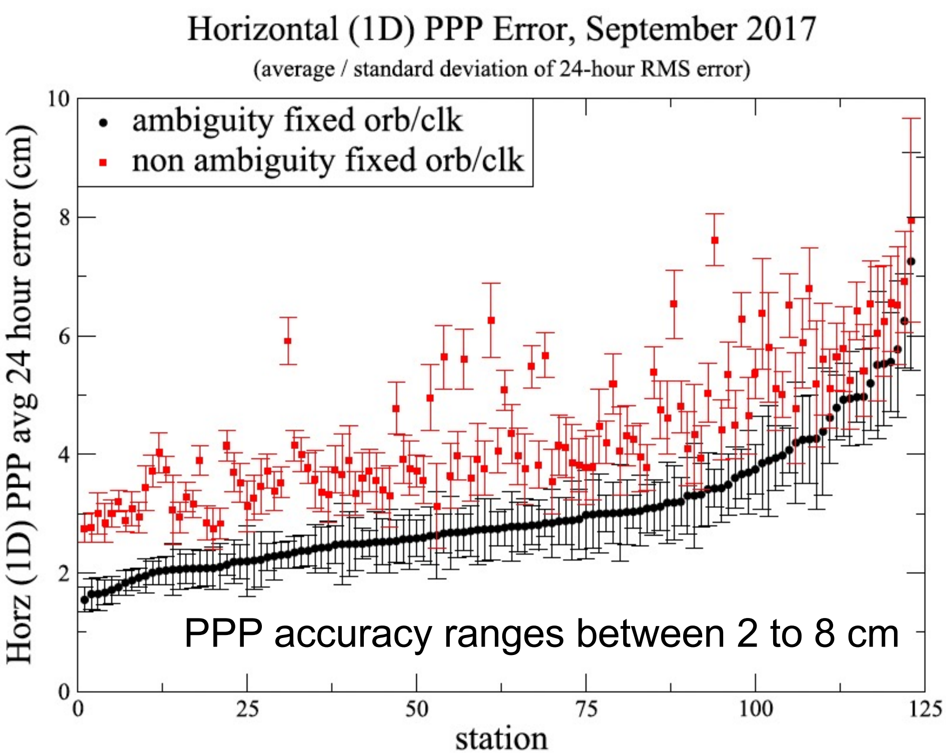
GAL

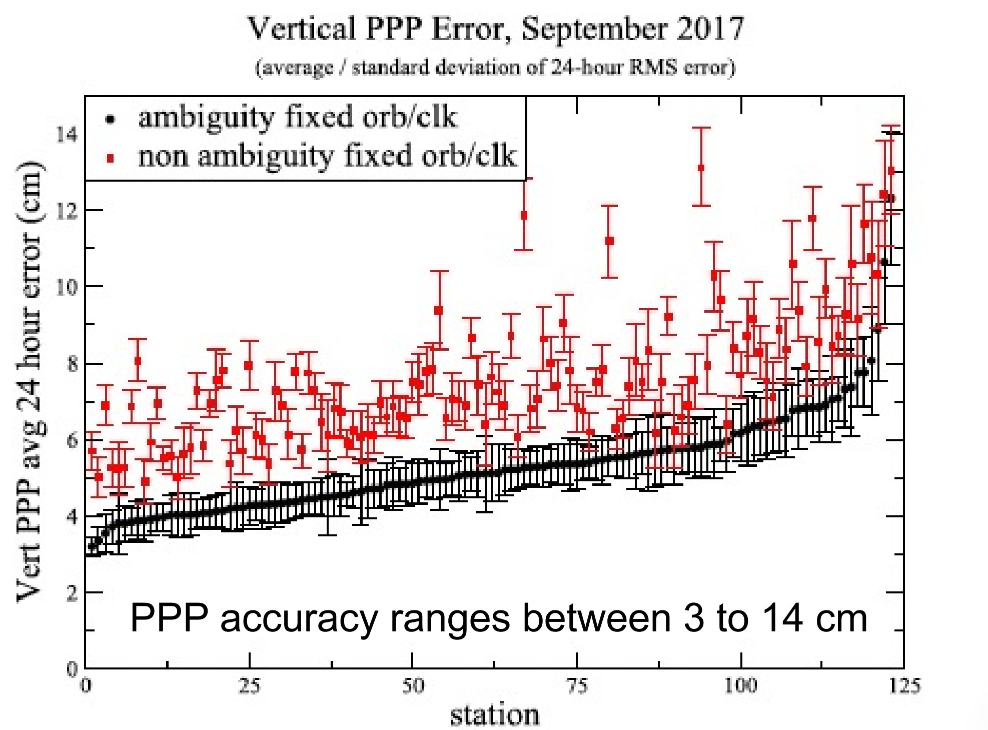


Current GAL performance appears within the baseline requirement

- Low cadence orbit filter at every 60 sec
- High cadence clock filter at every second
- Compared to high precision GipsyX rapid product

Representative Real-Time PPP Accuracy Using RTGx



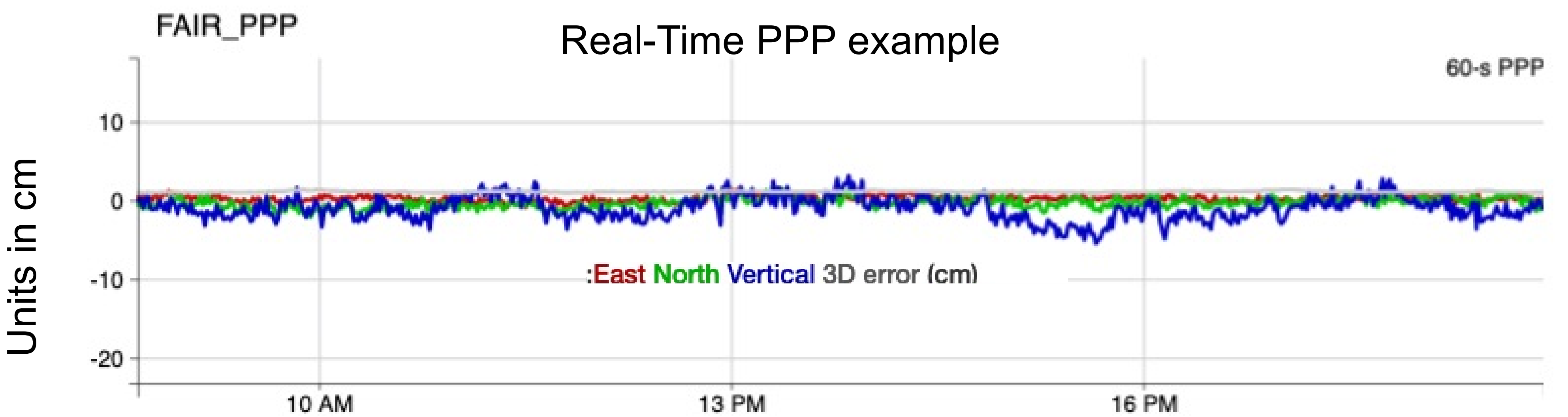


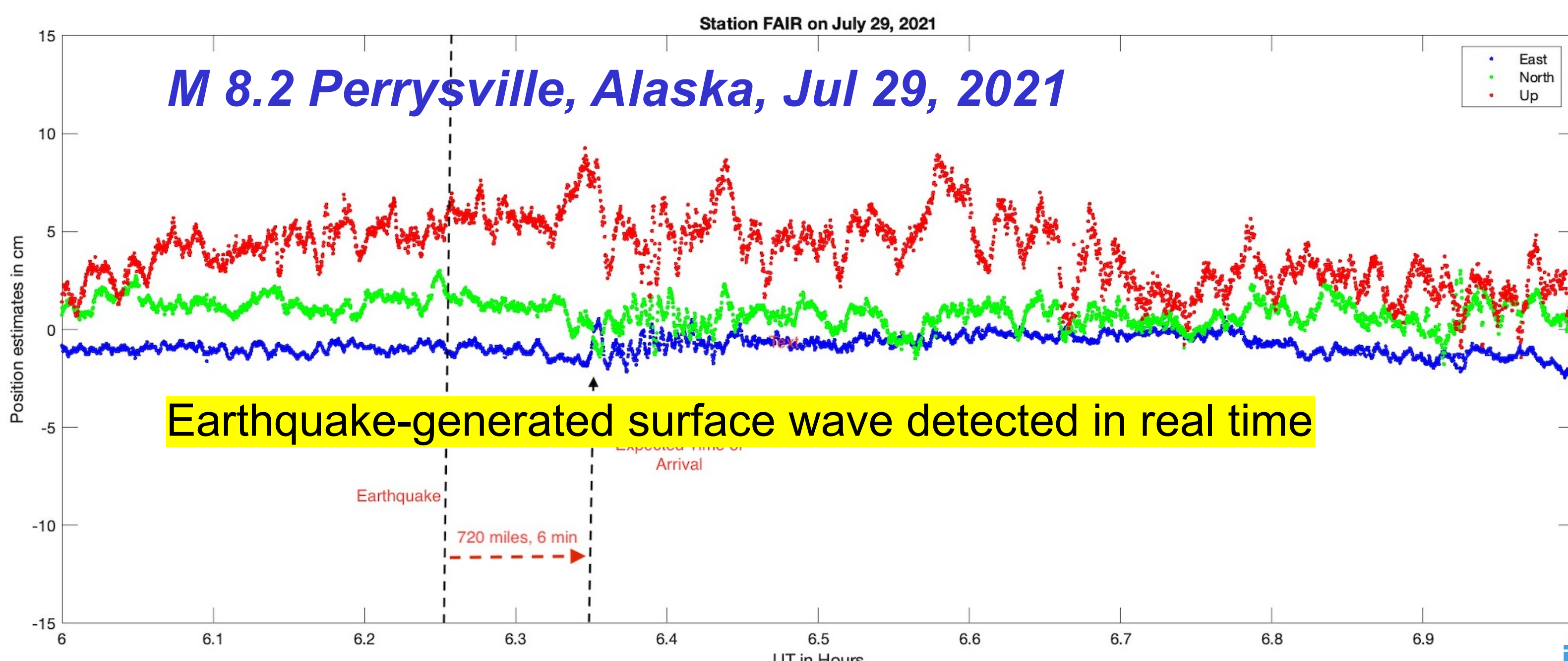
Bertiger et al., 2020

- Real-time positioning accuracy of real-time kinematic 5-min point-positioning of 125 GDGPS tracking sites with RTGx during September 2017

- Real-Time PPP accuracy for GAL HAS Phase 2 is 20 cm (95%) horizontal and 40 (95%) vertical.

RTGx PPP Solution Using GDGPS Clocks and Orbits on May 1, 2022





Conclusions

- A potential GPS HAS using GDGPS has unique and multiple advantages:
  - Global network of GDGPS-processed stations available (100+ stations)
  - Network is designed for resiliency and robustness using redundancies at all levels
  - Current real-time accuracy is shown to be in par or higher than Phase 2 GAL HAS performance anticipated by 2024

- Significant challenges for GPS HAS remain including no signal-in-space planned, no access to uplink stations for GPS
  - Distribution only possible via Internet

- GDGPS is technologically fully capable of providing high-accuracy corrections to GPS and Galileo if requested to support GPS HAS

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