24th GPS/GNSS Symposium 2019

PPP Correction Service - Current and Future

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- PPP Technology Review
- Commercial PPP Services
- PPP Service Performance
- Galileo HAS
- MADOCA-PPP
- Faster Convergence for PPP

PPP (Precise Point Positioning)

- **Historical View**
  - **Firstly introduced in 1990s** to analyze data of large GPS station N/W [1]
  - **Conventionally PP** with IGS precise ephemerides since 1990s
  - Several **RT-PPP services have launched via GEO satellite links** since 2000s
  - Recently improving accuracy with **multi-constellation GNSS and PPP-AR**
  - **Convergence time is still an issue** for some applications even in 2019

[1] J. F. Zumberge et al., Precise point positioning for the efficient and robust analysis of GPS data from large networks, Journal of Geophysical Research, 1997

	RTK	PPP
Base Station	Required	Not required
Area Coverage	Local (< 30 km)	Global (worldwide)
Accuracy (HRMS)	1 ~ 4 cm	2 ~ 5 cm
Convergence Time	< 60 s	15 ~ 45 min

PPP Applications

Broad (Existing and Potential) Applications of PPP ...

Automated Farming

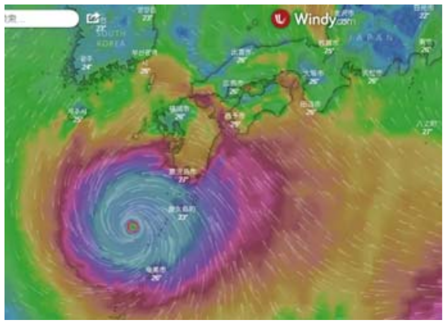
Offshore Construction/ Mining

Drone/UAV

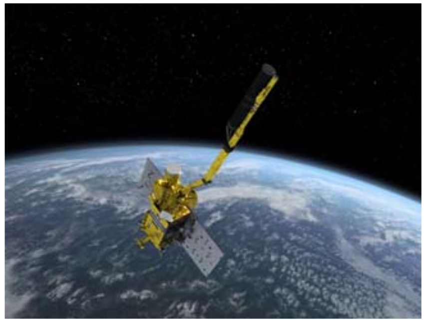
ADAS/ Autonomous Driving

Tsunami Warning

Precise Time Transfer

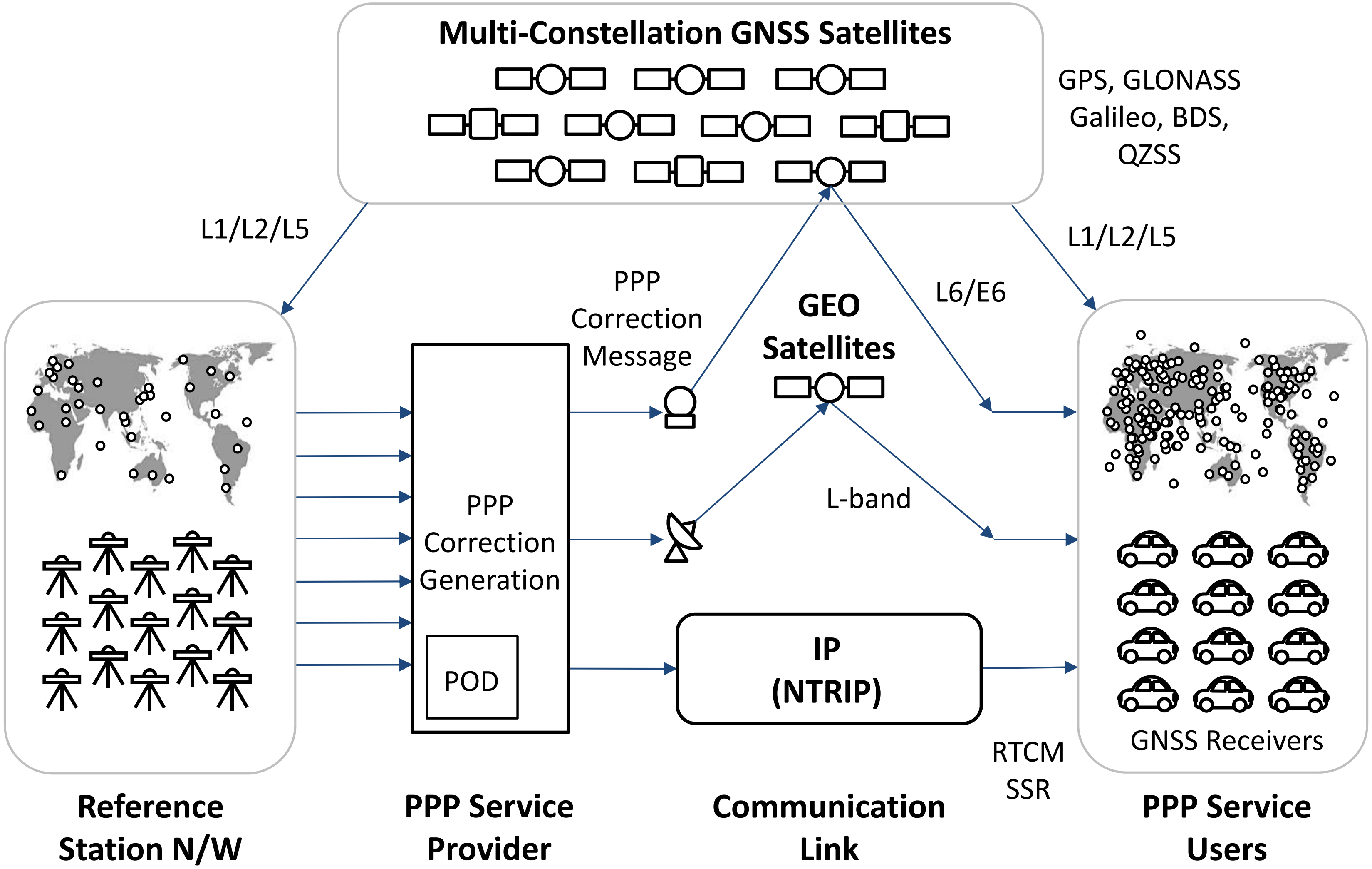


Weather Forecast (GNSS Meteorology)



Satellite POD

PPP Service Architecture



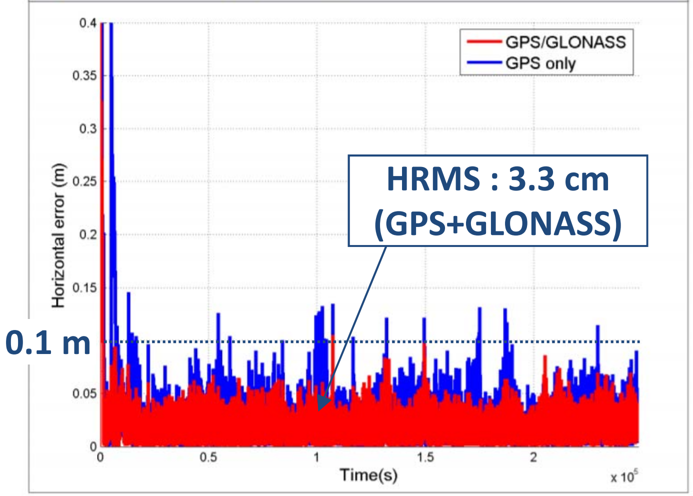
Commercial PPP Services

Service	Provider	Target GNSS	# of Ref. Stations	Comm. Link	Receivers	Accuracy
StarFire™ [1]	NAVCOM A John Deere Company (US)	GPS, GLO	> 40	3 GEO (L-band), IP	NavCom	< 5 cm
Seastar™ [2]	FUGRO (NED)	GPS, GLO, GAL, BDS (G4)	~ 80	6 GEO (L-band), IP (NTRIP)	Fugro	10 cm H 15 cm V (95%)
Apex/Ultra [3] TerraStar® [4]	veripos (UK)	GPS, GLO, GAL, BDS, QZS (Apex^5)	~ 80	7 GEO (L-band)	VERIPOS, NovAtel [7], Septentrio [8], TOPCON [9], Hemisphere [10]	< 5 cm H < 12 cm V (95%)
CenterPoint RTX [5]	Trimble (US)	GPS, GLO, GAL, BDS, QZS	~ 100	6 GEO (L-band), IP (NTRIP)	Trimble, Qualcomm (?)	2 cm H 5 cm V (RMS)
magicGNSS [6]	gmv (Spain)	GPS, GLO, GAL, BDS, QZS	~ 80	IP (NTRIP)	(RTCM SSR)	5 cm H 8 cm V (RMS)

[1] https://www.navcomtech.com, [2] https://www.fugro.com, [3] https://veripos.com, [4] https://www.terrastar.net, [5] https://positioningservices.trimble.com, [6] https://magicgnss.gmv.com, [7] https://www.notavel.com, [8] https://www.septentrio.com, [9] https://www.topconpositioning.com, [10] https://www.hemispheregnss.com

PPP Service Performance in 2015

Figure 10 Accuracy (Canada) – GPS vs GPS+GLONASS



(3 days)

Table 5: Error Statistics at the Canada Station

PPP Correction Source	Horizontal RMS Error (cm)	Vertical RMS Error (cm)
TerraStar-C (GPS/GLONASS)	3.3	4.9
TerraStar-C (GPS only)	4.4	6.5

Figure 8 Convergence time (Canada) – GPS vs GPS+GLONASS

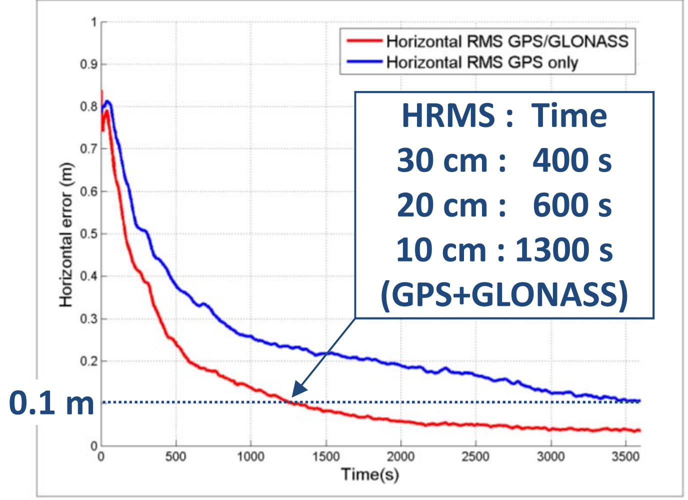
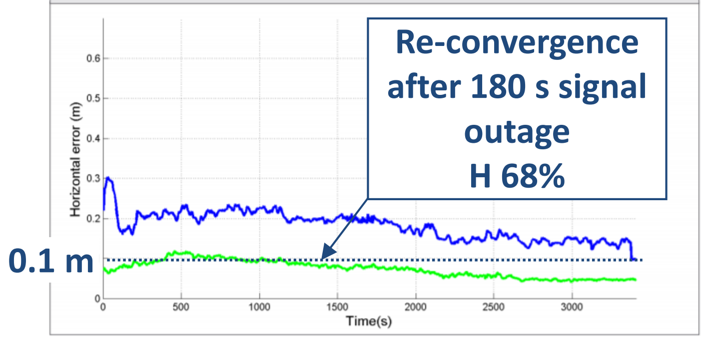


Figure 6 Re-convergence after 180 second signal outage



NovAtel White Paper, Precise Positioning with NovAtel CORRECT Including Performance Analysis, April 2015
(https://www.novatel.com/assets/Documents/Papers/NovAtel-CORRECT-PPP.pdf)

PPP for Next-Gen Vehicle Positioning

Qualcomm

Snapdragon Automotive 4G/5G Platform:
supporting
GPS, GLONASS, Galileo, BDS and QZSS (L1, L2, L5)

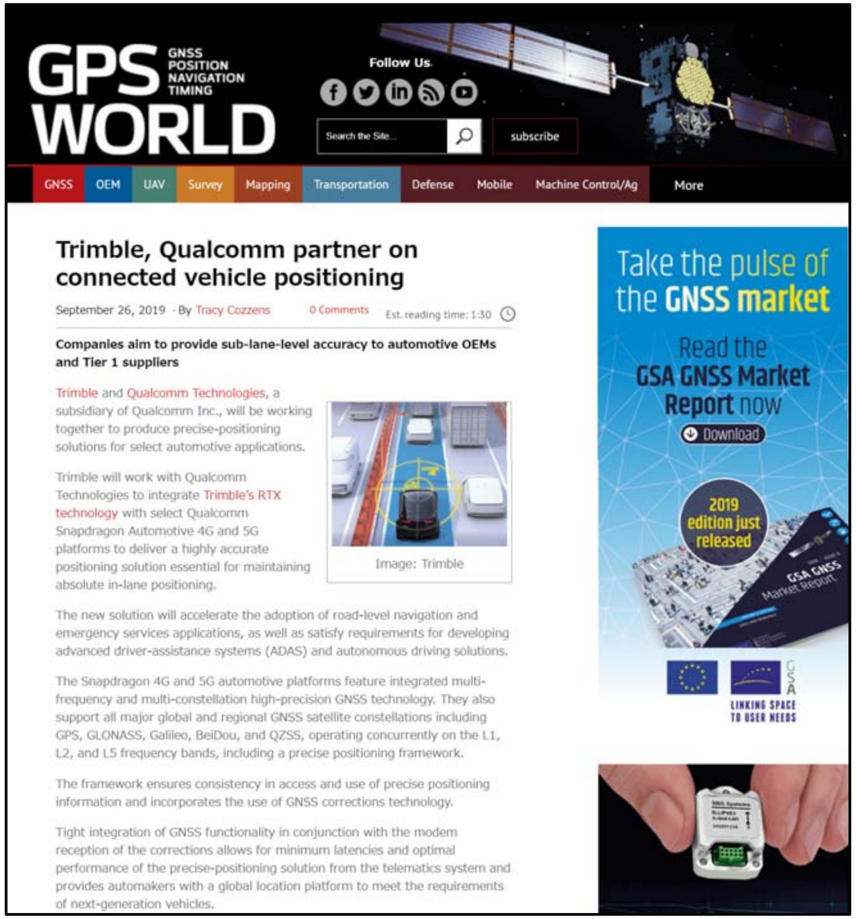
+

Trimble

RTX Auto:
ASIL and ASPICE compliant RTX precise positioning software library

⇩

Absolute In-lane positioning for ADAS/autonomous-driving


GPS WORLD GNSS POSITION NAVIGATION TIMING

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Trimble, Qualcomm partner on connected vehicle positioning

September 26, 2019 · By Tracy Cozzens 0 Comments Est. reading time: 1:30

Companies aim to provide sub-lane-level accuracy to automotive OEMs and Tier 1 suppliers

Trimble and Qualcomm Technologies, a subsidiary of Qualcomm Inc., will be working together to produce precise-positioning solutions for select automotive applications.

Trimble will work with Qualcomm Technologies to integrate Trimble's RTX technology with select Qualcomm Snapdragon Automotive 4G and 5G platforms to deliver a highly accurate positioning solution essential for maintaining absolute in-lane positioning.

Image: Trimble

The new solution will accelerate the adoption of road-level navigation and emergency services applications, as well as satisfy requirements for developing advanced driver-assistance systems (ADAS) and autonomous driving solutions.

The Snapdragon 4G and 5G automotive platforms feature integrated multi-frequency and multi-constellation high-precision GNSS technology. They also support all major global and regional GNSS satellite constellations including GPS, GLONASS, Galileo, BeiDou, and QZSS, operating concurrently on the L1, L2, and L5 frequency bands, including a precise positioning framework.

The framework ensures consistency in access and use of precise positioning information and incorporates the use of GNSS corrections technology.

Tight integration of GNSS functionality in conjunction with the modem reception of the corrections allows for minimum latencies and optimal performance of the precise-positioning solution from the telematics system and provides automakers with a global location platform to meet the requirements of next-generation vehicles.

GPS World, Trimble, Qualcomm partner on connected vehicle positioning, September 26, 2019 (https://www.gpsworld.com)

Galileo HAS (1/2)

- **Galileo CS (commercial service) HA (high accuracy)**
  - HA originally provided as **one of CS with fee**
  - "positioning error of **less than one decimeter** in nominal conditions of use"
  - AALECS (authentic and accurate location experimentation with the CS) conducted since 2016 by a consortium including **GMV** and **Veripos**
  - Initial commercial operating phase was **planed from 2018**

	E6B	E6C
Component	Data	Pilot
Carrier Frequency	1278.75 MHz	1278.75 MHz
Spreading Modulation	BPSK(5)	BPSK(5)
Chip Rate	5.115 Mcps	5.115 Mcps
Primary Code Length	5115 chips	5115 chips
Primary Code Duration	1 ms	1 ms
Secondary Code Length	N/A	100 chips
Secondary Code Duration	N/A	100ms
Symbol Rate	1000 sps	N/A
Data Rate	492 bps	N/A
Data Encoding	As per SIS ICD	N/A
Data interleaving (col. x row)	123 x 8	N/A
Spreading code encryption capability	Yes	Yes
Power sharing	50%	50%
Received Minimum Power (E6B + E6C)	-155 dBW	

TABLE 1. Galileo E6-B/C signal characteristics

E6B: 1278.75 MHz

Sync Symbols	Data Symbols				Total
16	984				1000 symbols
	Page type	**CS data**	CRC	Tail	492 bits
	16	**448**	24	6	

TABLE 2 Galileo CS E6B per-second data structure

Correction Data Bandwidth: 448 bps/ satellite

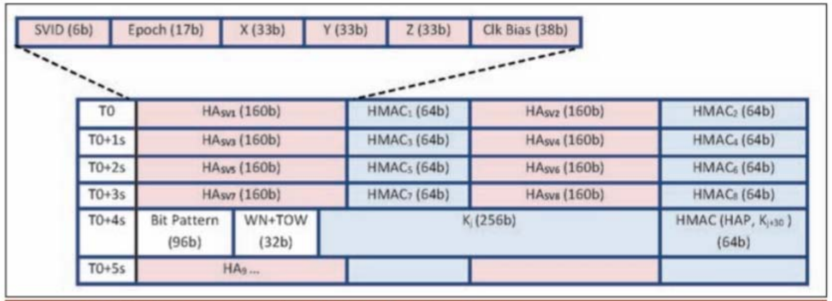


FIGURE 6 EPOC high accuracy and authentication data format

HA: PPP with GPS/GAL

I. F. Hernandez et al., Galileo's Commercial Service Testing GNSS High Accuracy and Authentication, Inside GNSS, 2015

Galileo HAS (2/2)

- **Redefined Galileo HAS**
  - Open consultation launched for **free Galileo HAS** in 2017
  - EU redefined **Galileo HAS as a free service** in March 2018
  - Accuracy requirement relaxed as "**less than two decimeters**" (<= 20 cm)
  - "Initial signal supply until at least 2020"
  - However, formal HAS SIS-ICD has not yet be published in October 2019

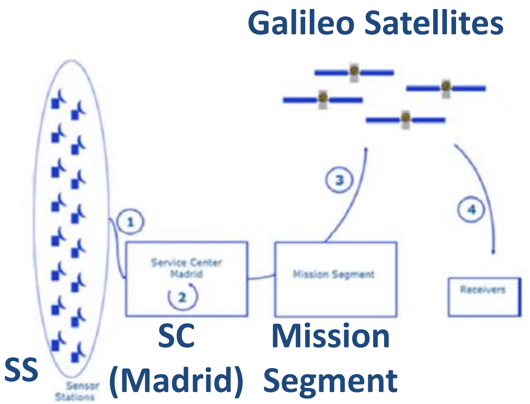
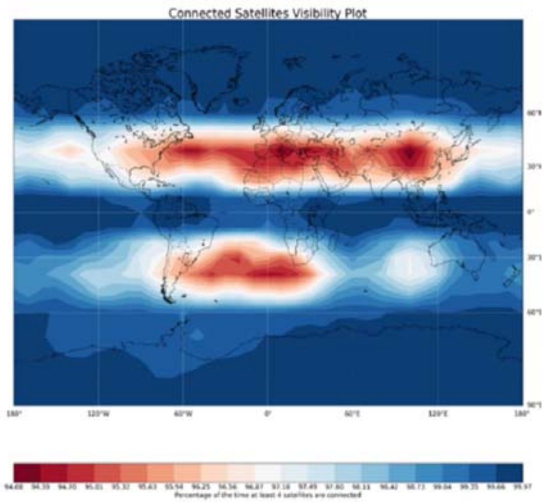


Figure 4 - HAS initial architecture based solely on Galileo infrastructure.



	20 uplinks	16 uplinks
Avg. BW worst user	2704 bps	2118 bps
Avg. BW best user	3452 bps	2864 bps

Table 2 – HAS estimated bandwidth

HAS Uplink Bandwidth:
2704 ~ 3452 bps
(20 uplink stations)

I. F. Hernandez et al., Galileo High Accuracy: A Program and Policy Perspective, Conference 69th International Astronautical Congress - IAC 2018, Bremen

MADOCA-PPP (1/4)

Brief History of MADOCA

- **June 2011 - March 2013**: Development for **QZSS LEX-PPP experiment**
  - Initial development as **JAXA R & D**
  - Implement multi-GNSS precise orbit and clock determination S/W, named as "**MADOCA**" later
  - **PP** (FY2011) and **RT** (FY2012) features supporting **GPS, GLO, GAL, QZS**
- **Feb 2014 - Dec 2015**: Adding advanced PPP Features
  - Extensions supporting **BDS**, **FCB generation for PPP-AR**
  - R & D for advanced PPP functions (**PPP-AR, local-correction, INS/PPP**)
  - Improve performance by refining orbit dynamics model
- **Sep 2014**: Start broadcast via **QZS-1 LEX and NTRIP by JAXA** [1]
- **Aug 2016 -** : Continuous improvement of MADOCA accuracy and stability
- **Dec 2017**: Start broadcast via **QZS-2, 3, 4 L6E by GPAS** [2][3]

[1] https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html
[2] https://www.gpas.co.jp/service.php
[3] Global Positioning Augmentation Service Corporation, Quasi-Zenith Satellite System Correction Data on Centimeter Level Augmentation Service for Experiment Data Format Specification (1st edition), November 2017

MADOCA-PPP (2/4)

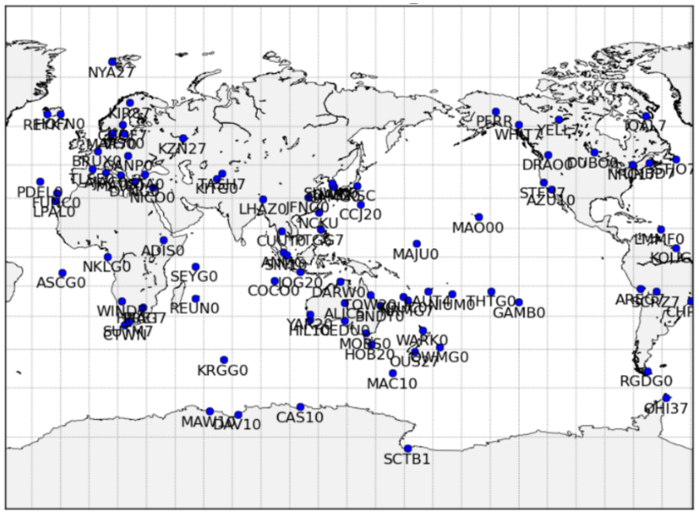
JAXA MADOCA Products (NTRIP)

PPP Correction Messages (RTCM 3 SSR)

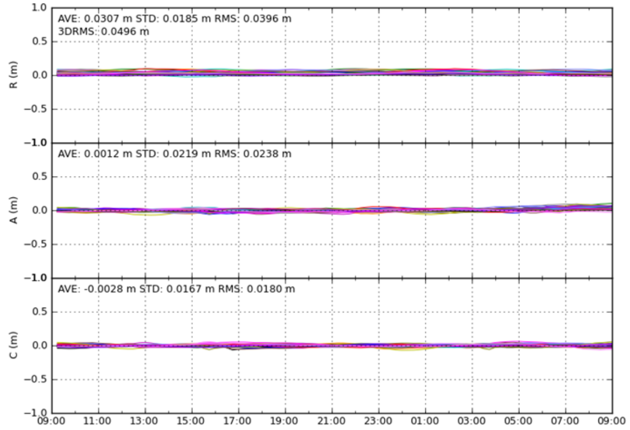
Product	Interval		RTCM Message Type		
	Estimate	Provide	GPS	GLO	QZS
Orbit correction	30	1	1057	1063	1246
Clock correction	1	1	1058	1064	1247
HR-Clock correction	1	1	1062	1068	1251
URA	1	1	1061	1067	1250

(PPP-AR, GAL and BDS are not yet supported)

Reference Station N/W (~ 80 stations)

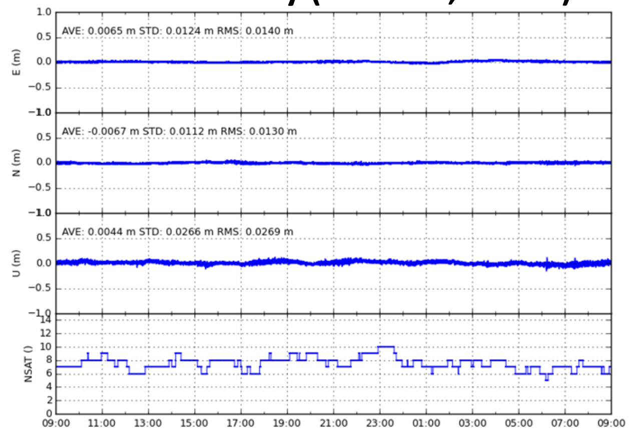


Orbit Accuracy (GPS, MDC1)



RMSE
3D: 4.96 cm
R: 3.96 cm
A: 2.38 cm
C: 1.80 cm

PPP Accuracy (Tsukuba, MDC1)



RMSE
E: 1.40 cm
N: 1.30 cm
U: 2.69 cm
(HRMS: 1.91 cm)

(2019/10/15 9:00 - 10/16 9:00 GPST)

https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html

MADOCA-PPP (3/4)

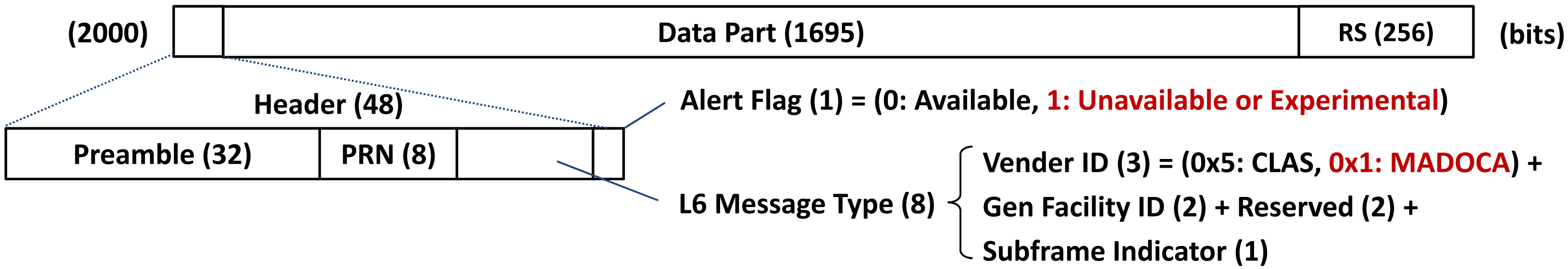
QZSS L6 Signal Specifications

Satellite	QZS-1 (Block I)		QZS-2, 3, 4 (Block II)	
Carrier Frequency	1278.75 MHz		1278.75 MHz	
Code Modulation	BPSK(5)		BPSK(5)	
Min Received Power	- 155.7 dBW		- 156.82 dBW	
Component	Data	Pilot	Data	Data
Chip Rate	2.5575 Mcps	2.5575 Mcps	2.5575 Mcps	2.5575 Mcps
Code Length	4 ms	410 ms	4 ms	4 ms
Data Rate	2 kbps	-	2 kbps	2 kbps
Data Modulation	CSK (8 bit/sym)	-	CSK (8 bit/sym)	CSK (8 bit/sym)
Frame Rate	1 frame/s	-	1 frame/s	1 frame/s
FEC	RS(255,223)	-	RS(255,223)	RS(255,223)
Message	L6D	-	L6D	L6E
Contents	CLAS	-	CLAS	MADOCA
Status	Available (2018/11/1~)	-	Available (2018/11/1~)	Experimental (2019/10)

[1] IS-QZSS-L6-001, Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service, November 5, 2018

MADOCA-PPP (4/4)

QZSS L6 Frame Structure



QZSS L6 Message Contents

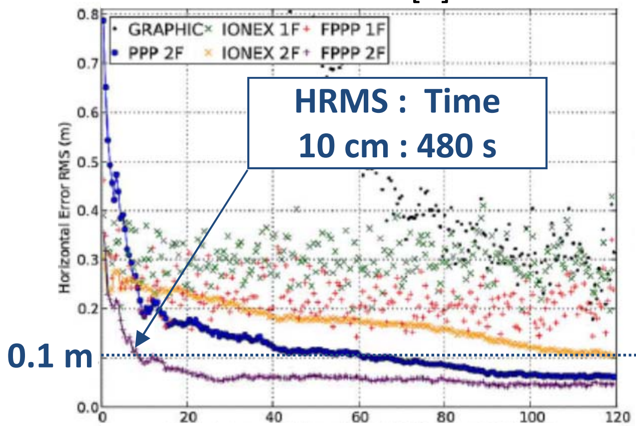
	CLAS	MADOCA
Positioning Mode	PPP-RTK	PPP
Service Area	Japanese Island	All areas covered by QZSS
Accuracy	H: < 6 cm, V: < 12 cm (static, 95%) H: <12 cm, V: < 24 cm (kinematic, 95%)	Not Specified
TTFF	< 60 s (95%)	Not Specified
Target GNSS/ Signal *	GPS (L1C/A, L2P(Y), L2C, L5), GAL (E1, E5a), QZS (L1C/A, L2C, L5)	GPS (L1C/A, L2P(Y)), GLO (L1C/A, L2P), QZS-1
Corrections	Satellite Mask, Orbit, Clock, Code Bias, Phase Bias, URA, STEC, Gridded Corr.	Orbit, High-Rate Clock, Code Bias, URA
Format	Compact SSR (CSSR) on RTCM 3 Proprietary (MT 4073)	RTCM 3 SSR + Draft SSR (w/o preamble, length, CRC)

* in October 2019

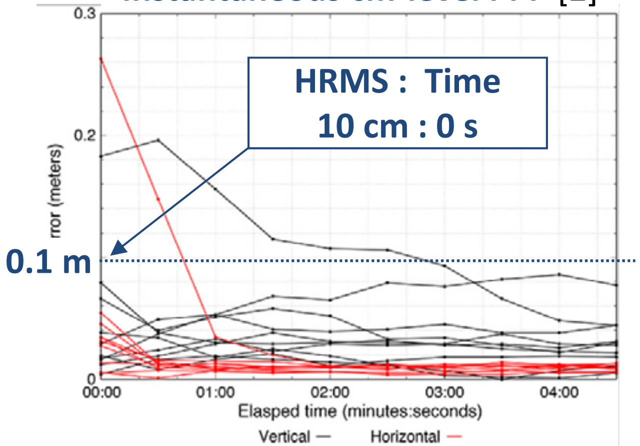
Faster Convergence for PPP

- **PPP-RTK**
  - **PPP-AR with local STEC and tropos** corrections
  - **Much bandwidth** required to support broad coverage larger than nation-wide
  - **Dens CORS N/W** required for local corrections
- **Fast-PPP** [1]
  - **PPP-AR with global VTEC** corrections
  - **Multi-layer model** for global VTEC
- **Instantaneous cm-level PPP** [2]
  - **No local or global TEC** corrections
  - **Cascading PPP-AR with triple or quad frequencies** (L1-L2-L5, E1-E5a-E5b-E6)

Fast-PPP [1]



Instantaneous cm-level PPP [2]



[1] A. R. Garcia et al., A worldwide ionospheric model for fast precise point positioning, IEEE Transaction on Geoscience and Remote Sensing, 2015

[2] D. Laurichesse and S. Banville, Innovation: Instantaneous centimeter-level multi-frequency precie point positioning, GPS World, 2018

Summary

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