Precise Point Positioning PPP

Lantmäteriet, SWEPOS

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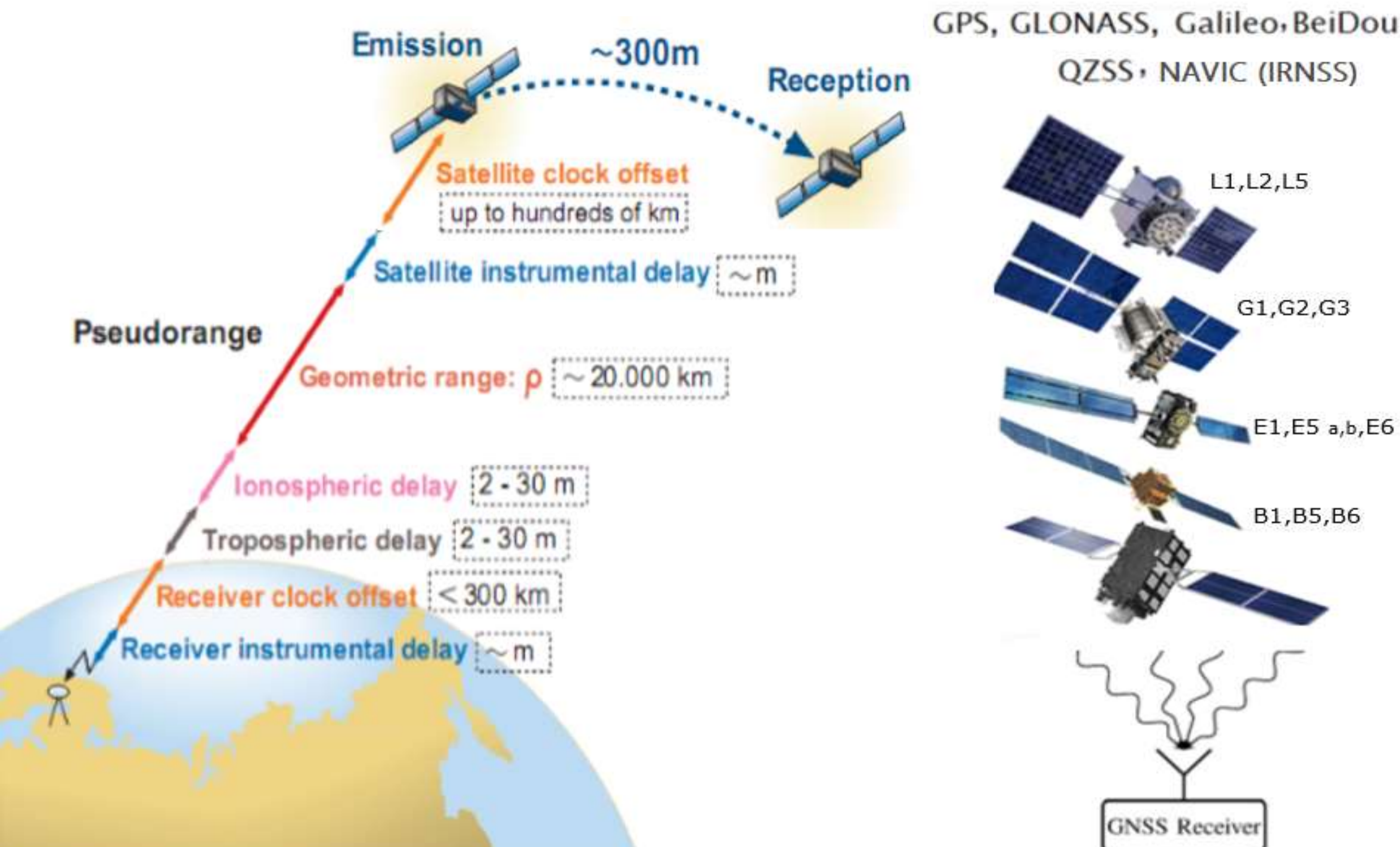
Outlines

- Introduction.
- OSR and SSR approaches.
- PPP Principle and computations.
- Advanced PPP techniques.
- PPP Services.

Introduction
GNSS error sources

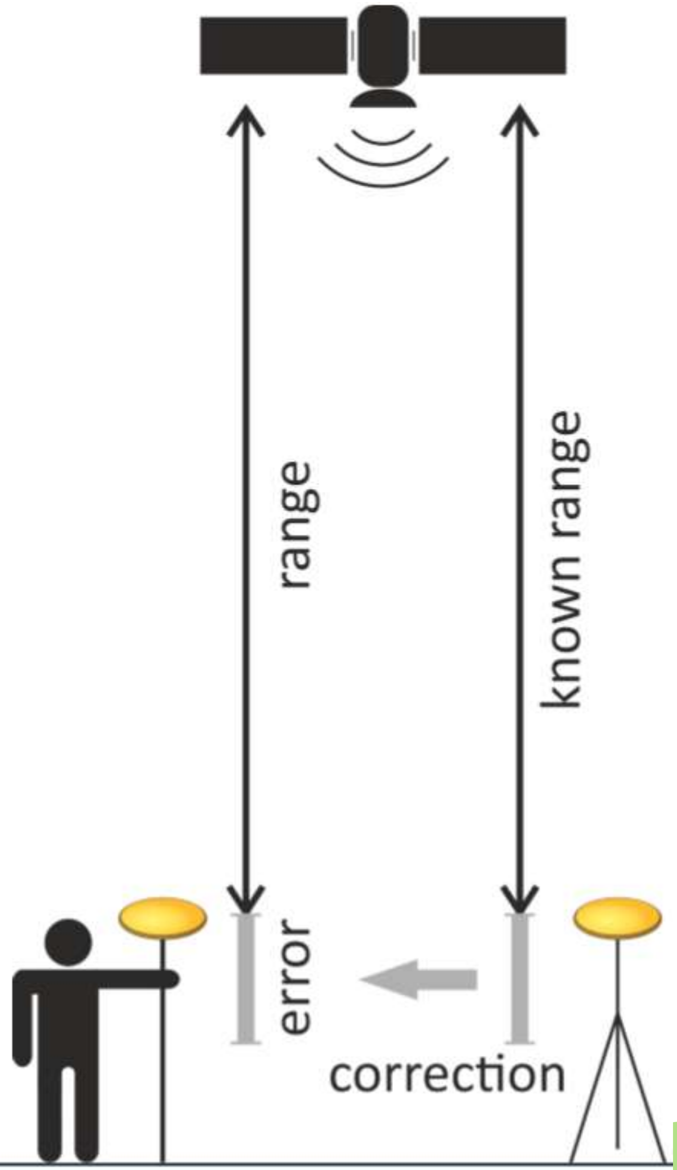
GNSS error sources



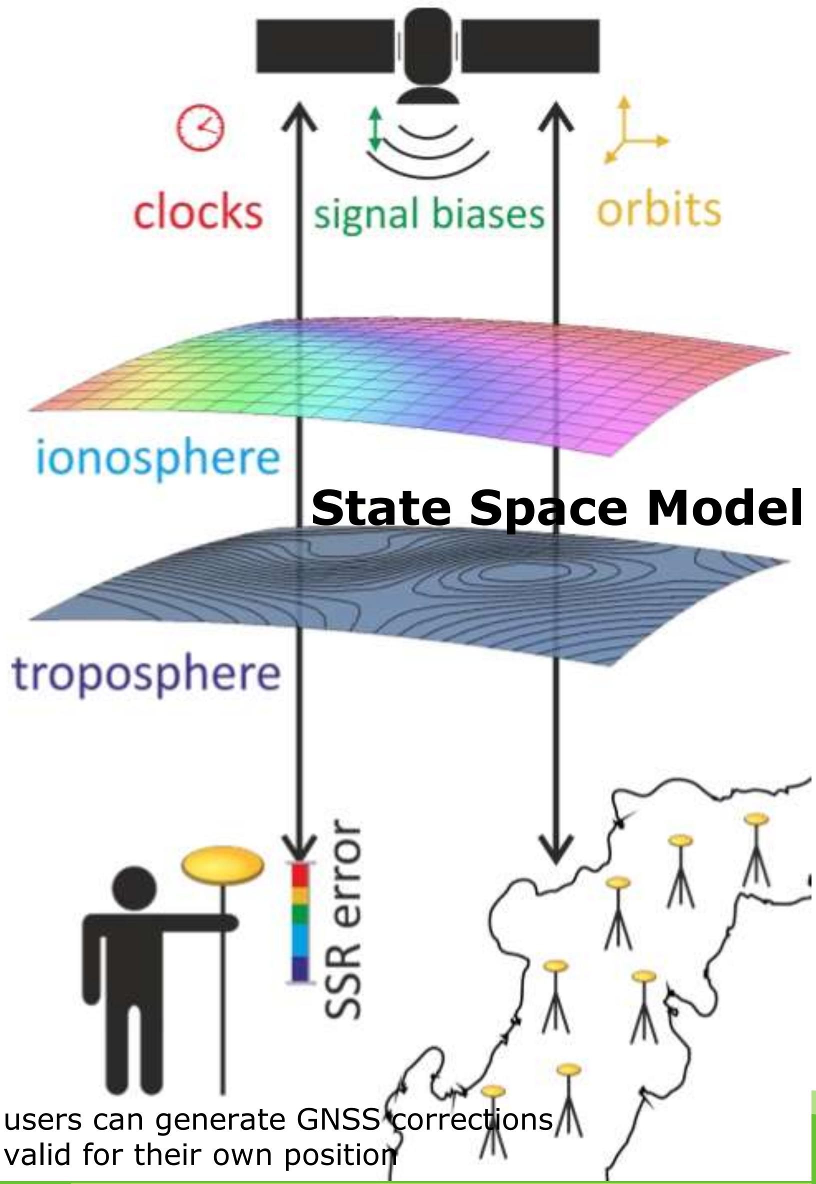
How can we handle these errors in our receivers to satisfy our requirements?

Observation Space Representation (OSR)
&
State Space Representation (SSR)

SSR and OSR - Principle



Observations-based techniqe

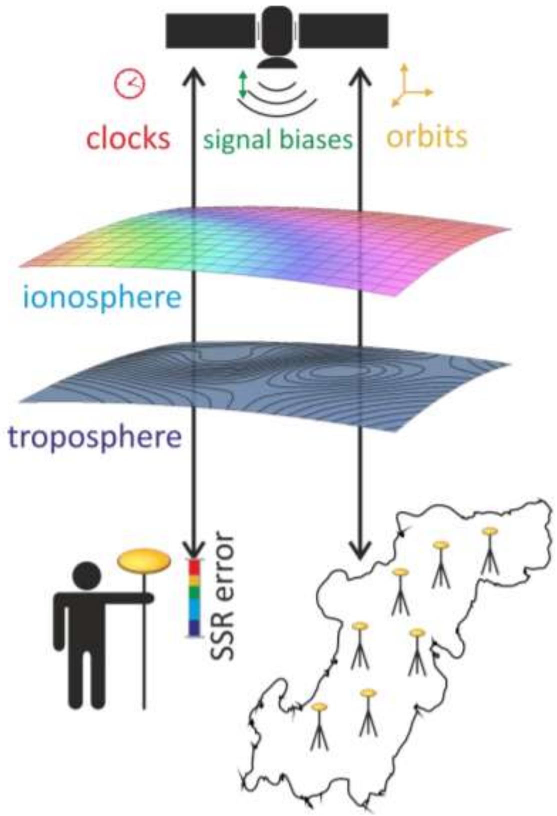


users can generate GNSS corrections
valid for their own position

(State of error components)-based technique

State Space Model (SSM)

- state parameter of state space model (SSM)
  - satellite **clock** synchronization error
  - satellite signal **delays** (phase and code)
  - satellite **orbit** error (kinematic orbits)
  - **ionospheric** signal propagation changes (multiple stage model)
  - **tropospheric** signal delays (multiple stage model)
  - carrier phase **ambiguities**
  - receiver **clock** synchronization error
  - receiver signal **delays** (phase and code)
  - receiver **coordinates**



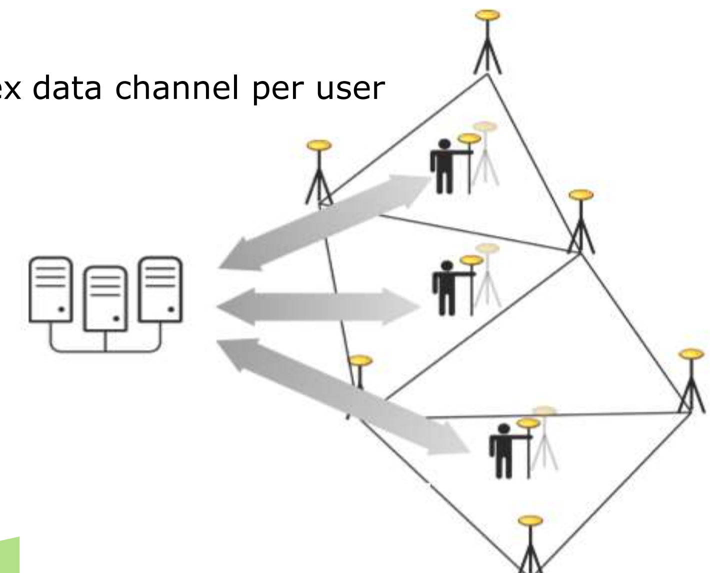
SSR Standardization by the RTCM

Since 2007 the SSR working group of the RTCM SC-104 is developing a standard message format for SSR messages.

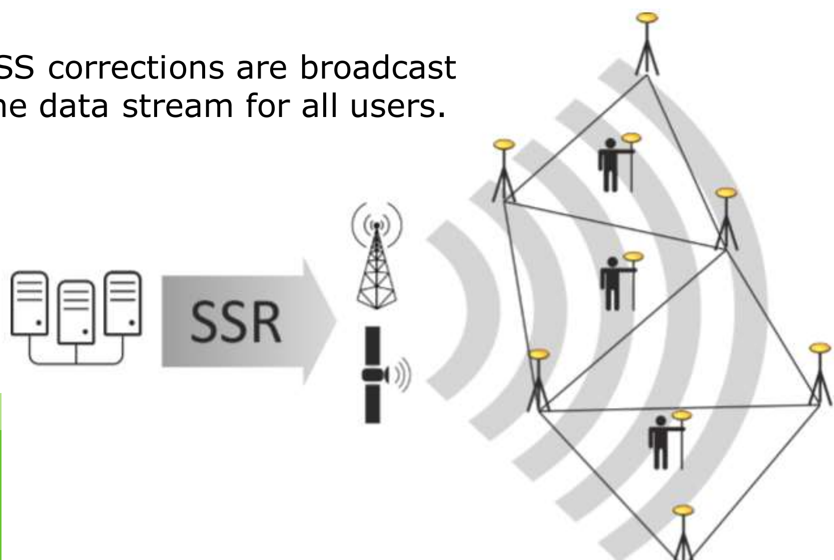
Parameter Nature	RTCM message
GPS orbits/clocks	1060
Glonass orbits/clocks	1066
Galileo orbits/clocks	1243
GPS code biases	1059
Glonass code biases	1065
Galileo code biases	1242
GPS phase biases (L1, L2)	1265
GPS phase biases (L5)	1265
Ionosphere VTEC	1264

OSR vs SSR – Communication Link

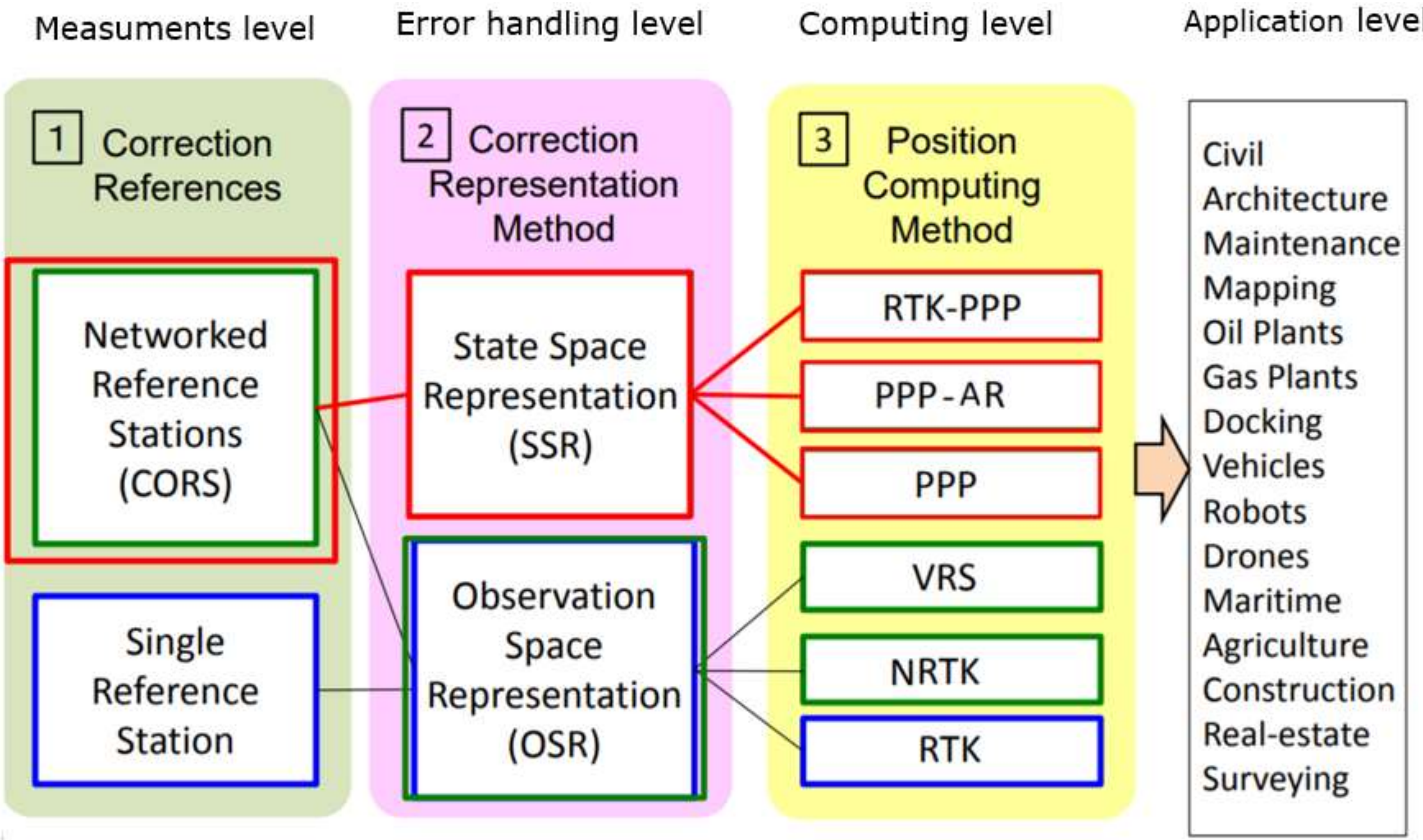
Duplex data channel per user



the GNSS corrections are broadcast with one data stream for all users.



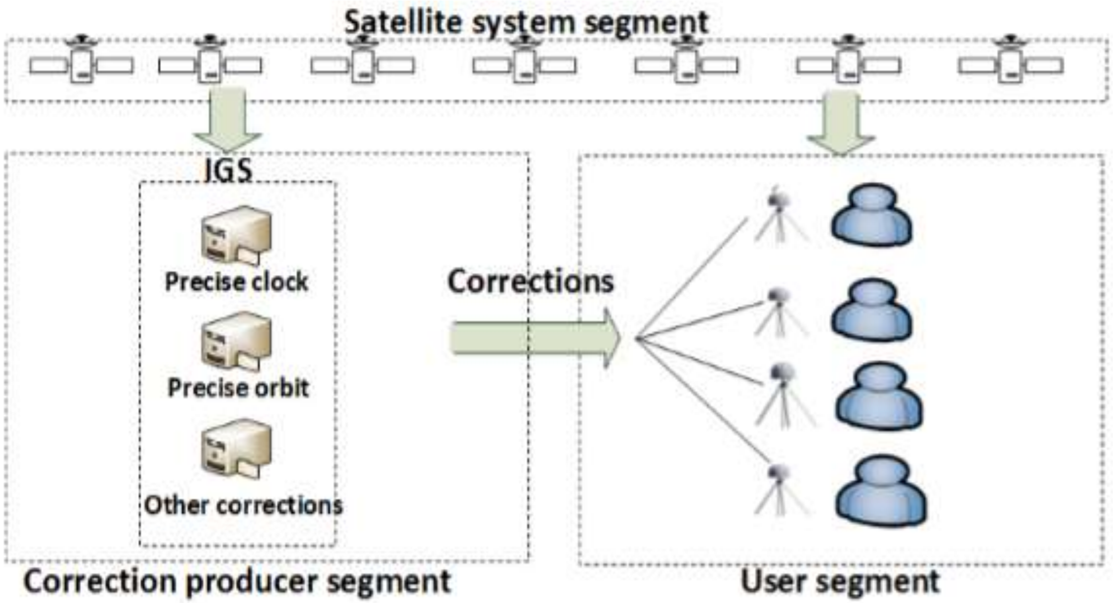
Classification of the modern satellite positioning methods



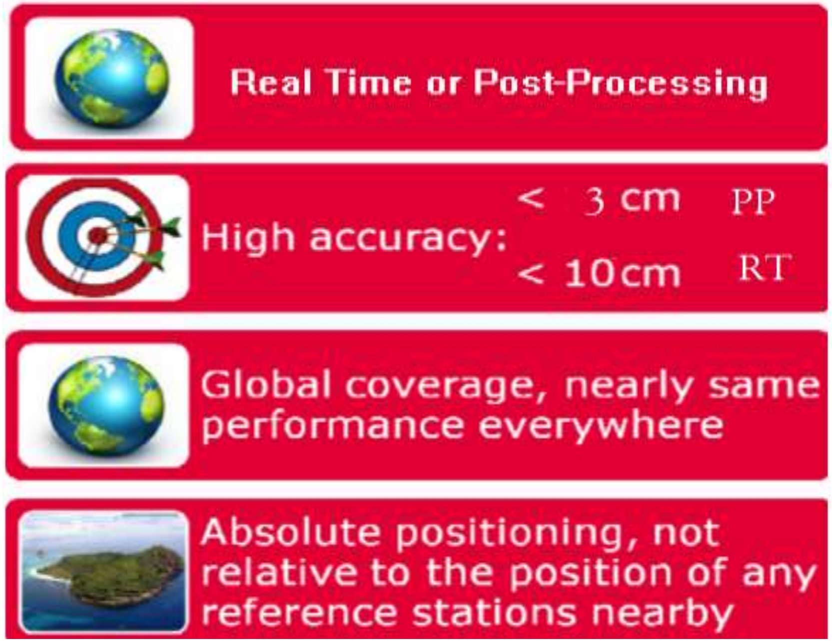
PPP Principle and computations

WHAT IS PPP?

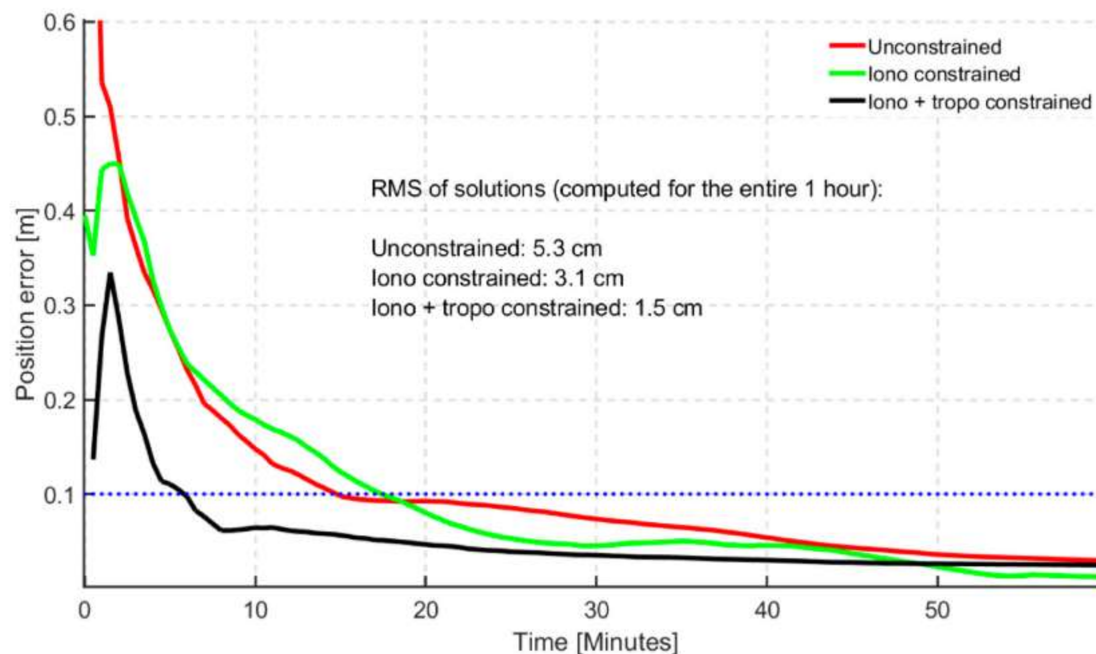
PPP is defined as an advanced high accuracy positioning technique uses the **SSR,** tries to satisfy the needs of the most demanding users, the ones who need centimetre level accuracy.



PPP Performance:



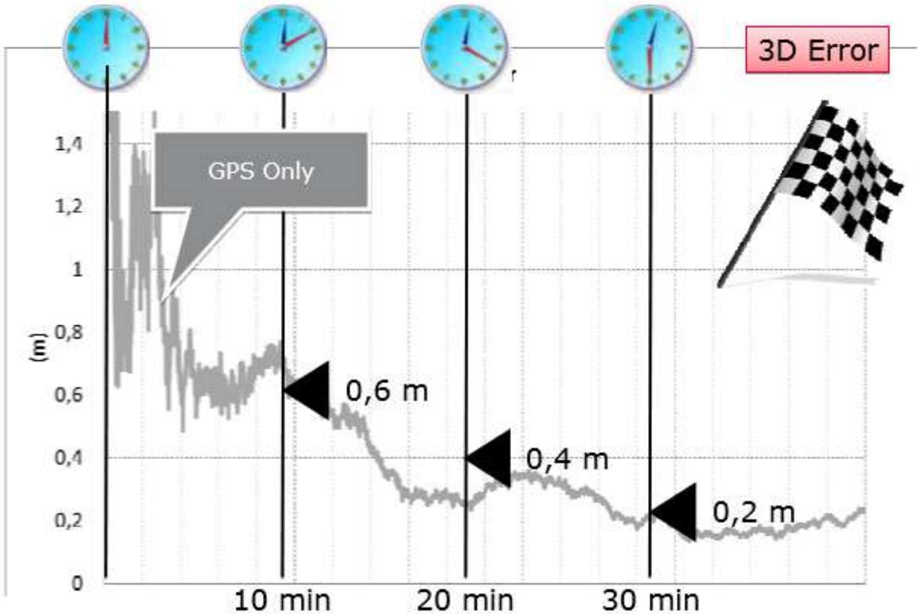
Source:
York University, Canada, 201
Triple-frequency PPP

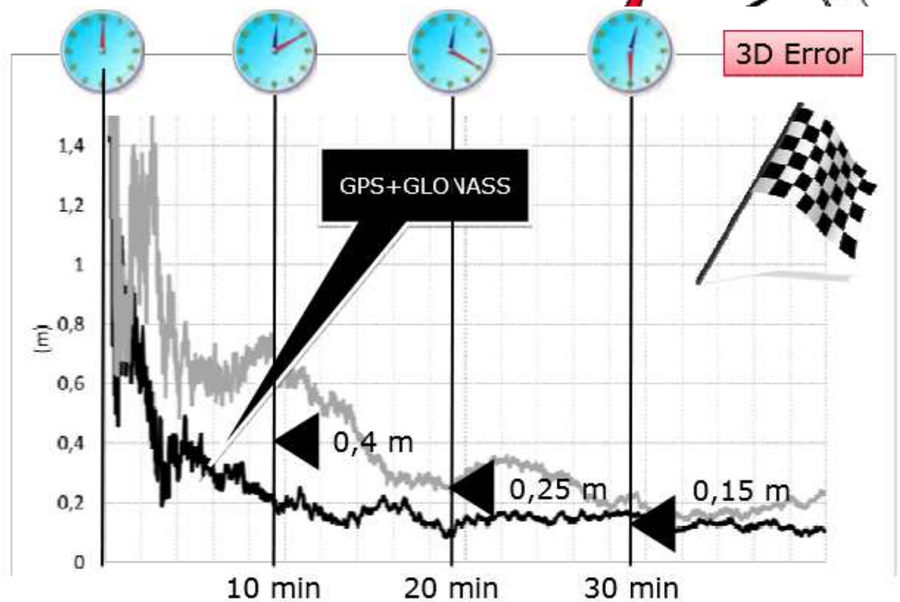


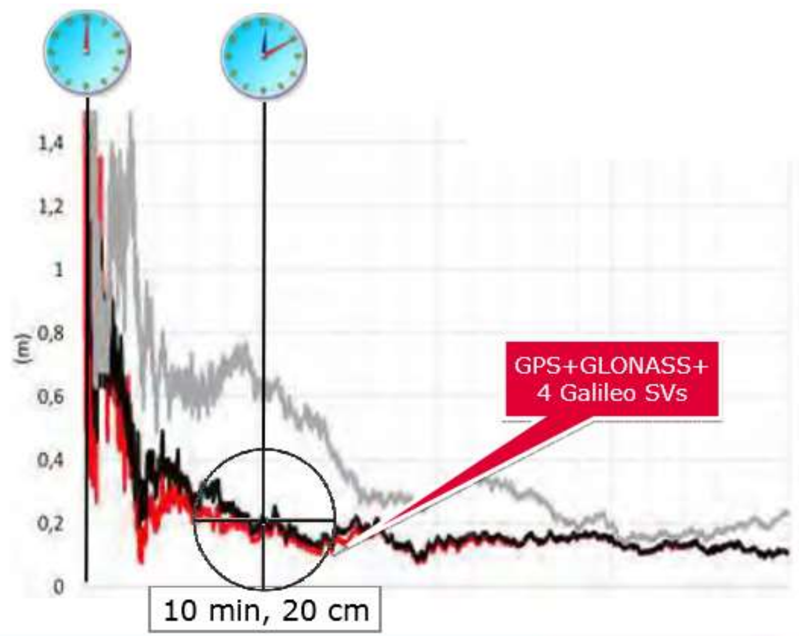
Limitations:

- The main disadvantage of PPP is ***the long convergence time***.

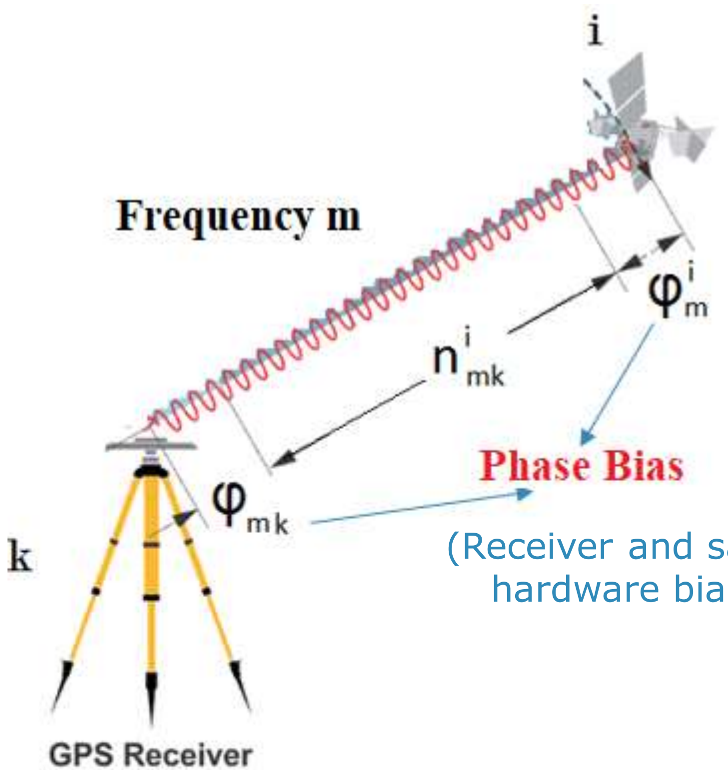
PPP PERFORMANCE: CONVERGENCE





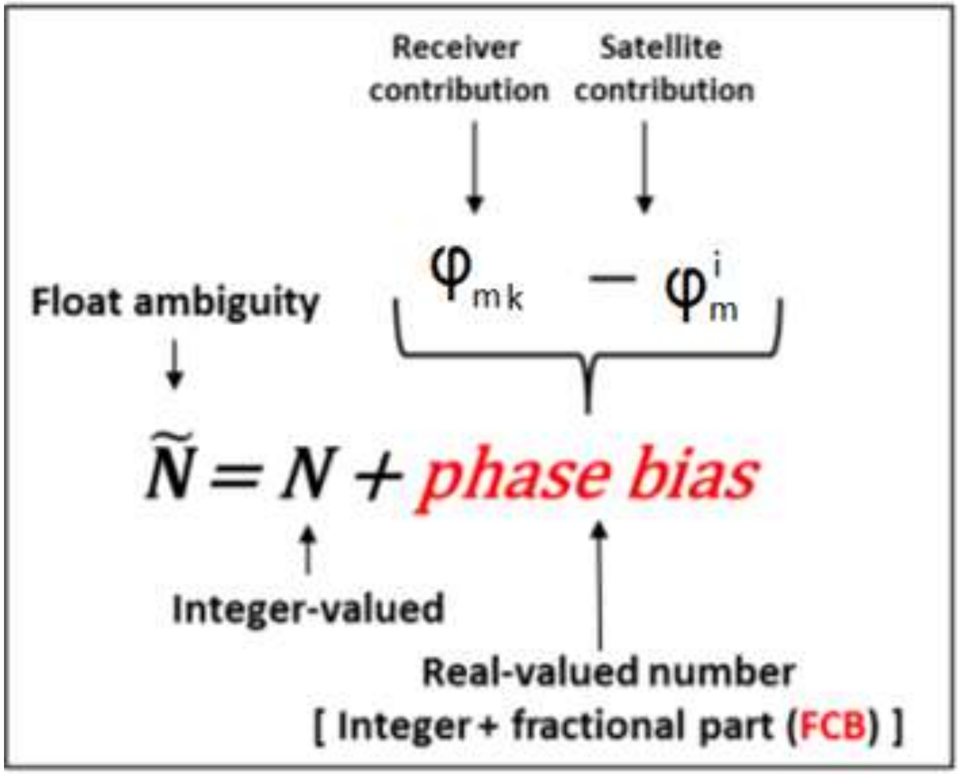


Analysis of convergence time in PPP?



(Receiver and satellite hardware biases)

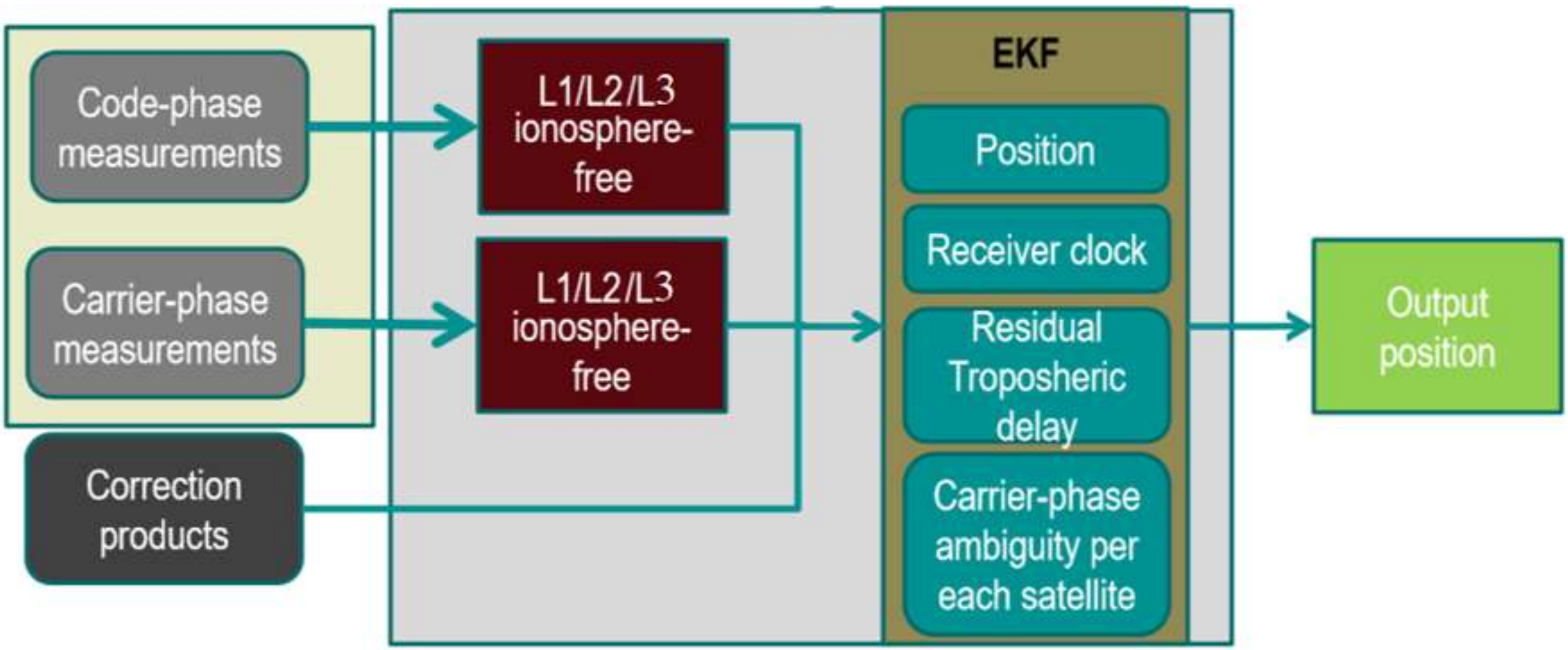
Carrier-Phase ambiguity:



PPP Computations

Error Class	Error Source	Error Magnitude	Mitigation method	Error Uncertainty
Satellite	Clock Offset	<1ms	Filtering	75 ps (GPS)
Satellite	Instrumental Biases	< 0.5 cycle	Estimation	0.01 cycles
Satellite	Precise Ephemeris	10 cm	Filtering	2.5 cm (GPS)
Propagation	Troposphere (Hydrostatic component)	2.3 m	Modelling	5 mm
Propagation	Troposphere (Wet component)	< 0.3 m	Estimation	100%
Propagation	Ionosphere (1st order)	< 30 m	Linear combinations /Modelling	(0-1)mm/1 m
Propagation	Ionosphere (higher order)	< 2 cm	Modelling	1-2 mm
Site Displacement	Solid Earth tide	< 0.4 m	Modelling	1 mm
Site Displacement	Ocean Loading	< 15 mm	Modelling	1 mm
Site Displacement	Pole Tide (second-order effects)	25 mm	Modelling	3-5 mm
Receiver	Phase Center Offset	5-15 cm	Modelling	-
Receiver	Phase Center Variations	< 3 cm	Modelling	1-2 mm
Receiver	Phase windup	10 cm	Modelling	-
Receiver	Incorrect Ambiguity Fix	multiple of cycle	Estimation	-

PPP Reciever general functional diagram



Output Position is affected by

- GNSS Receiver/Antenna - Measurement quality and availability
- Service Provider of Correction Products - Quality and delivery
- Rover PPP Algorithm - Within GNSS Receiver (real time) or Post-Processed

Advanced PPP Techniques

PPP- Ambiguity Resolution (PPP-AR)

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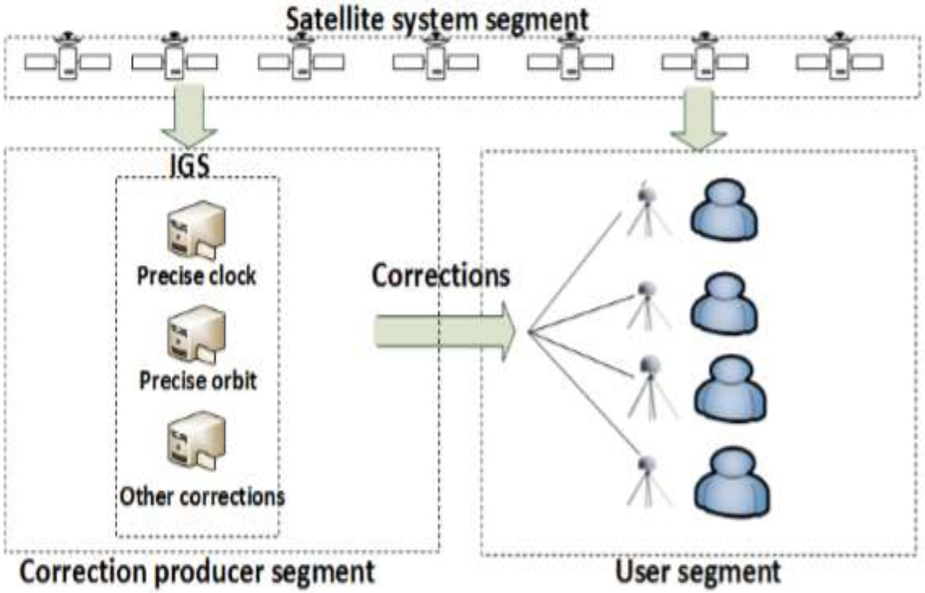
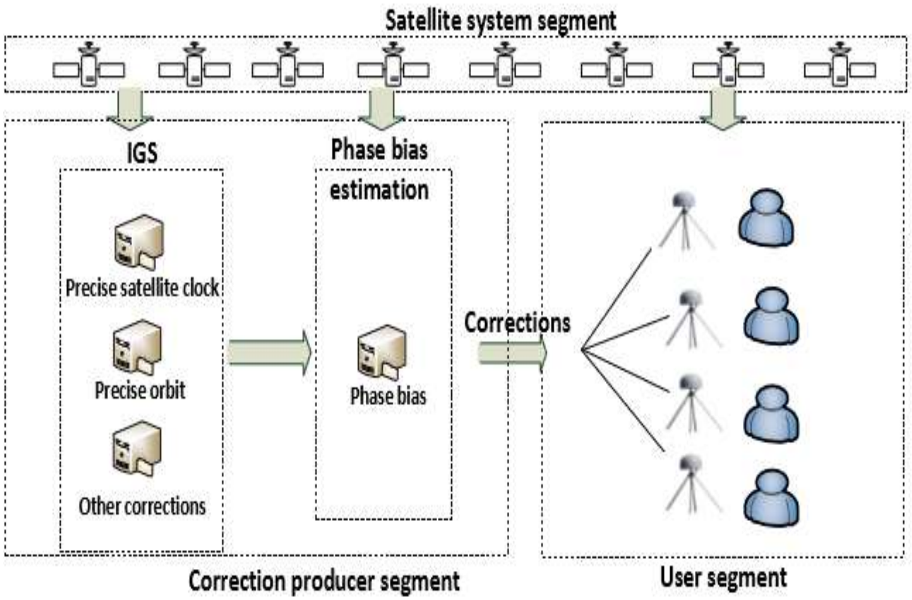
- A key element for PPP AR is the estimation of the Fractional Cycle Biases (FCBs) so as to recover the integer feature of ambiguities.
- The third GPS civil signal L5 is available now (Latest Block IIF), which enables more flexible ambiguity resolution strategies. Triple-frequency PPP AR can be achieved faster with longer wavelength.





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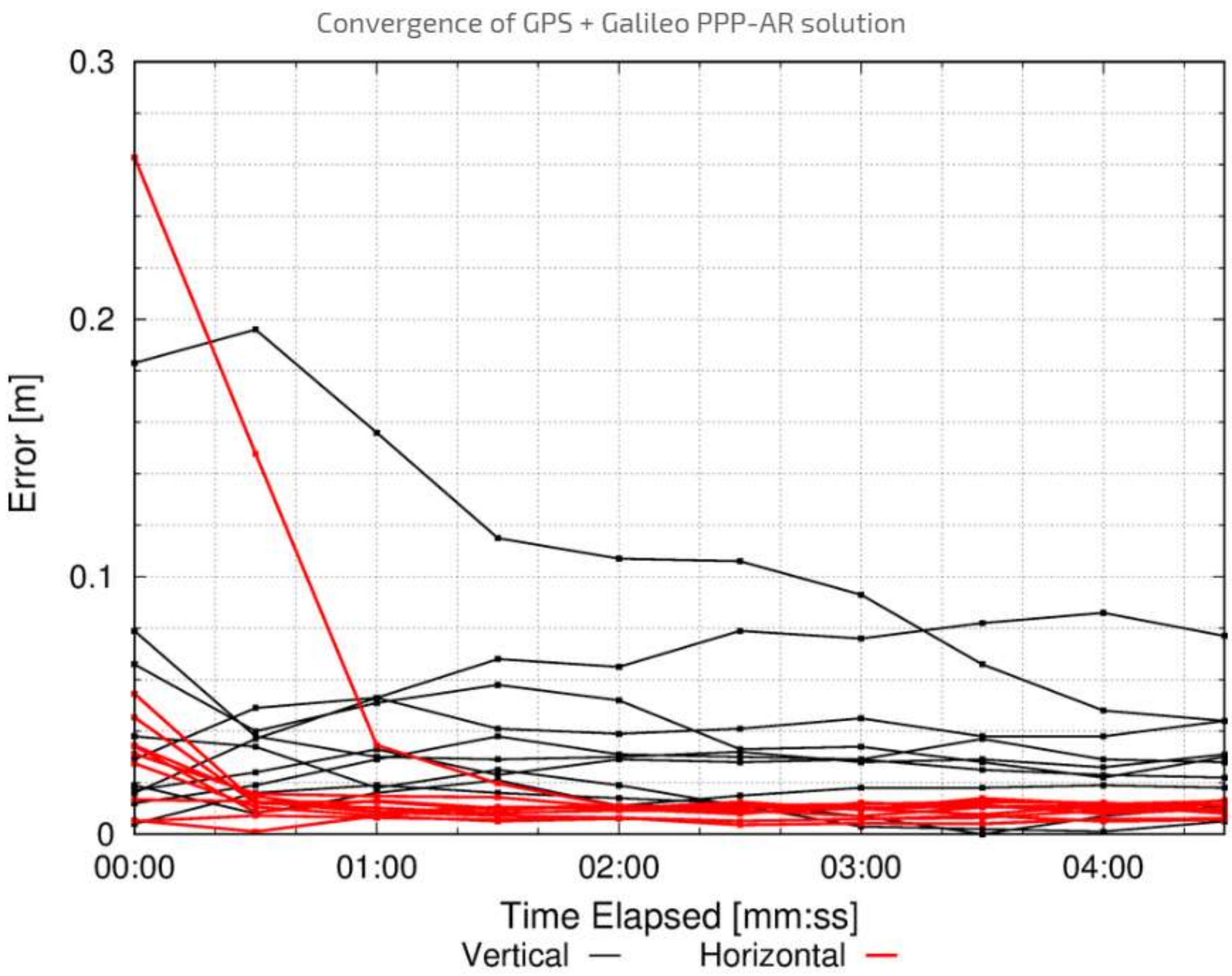
PPP-AR Convergence analysis



CNES Data

Different (independent) sessions

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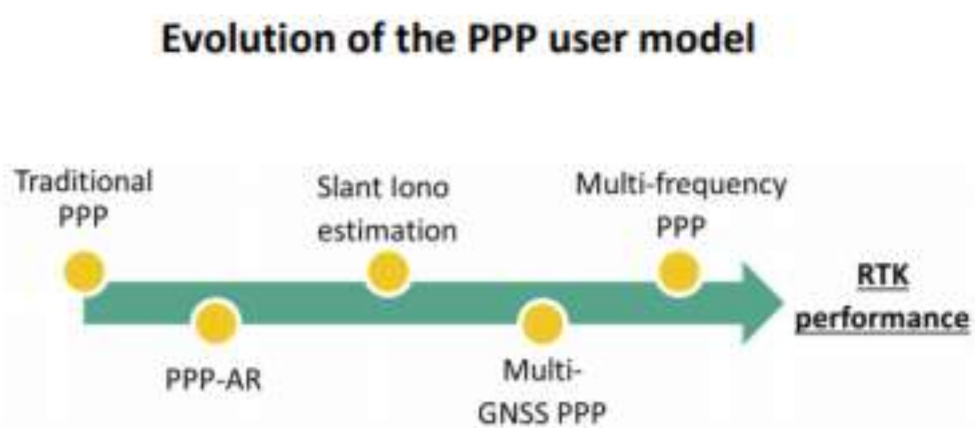
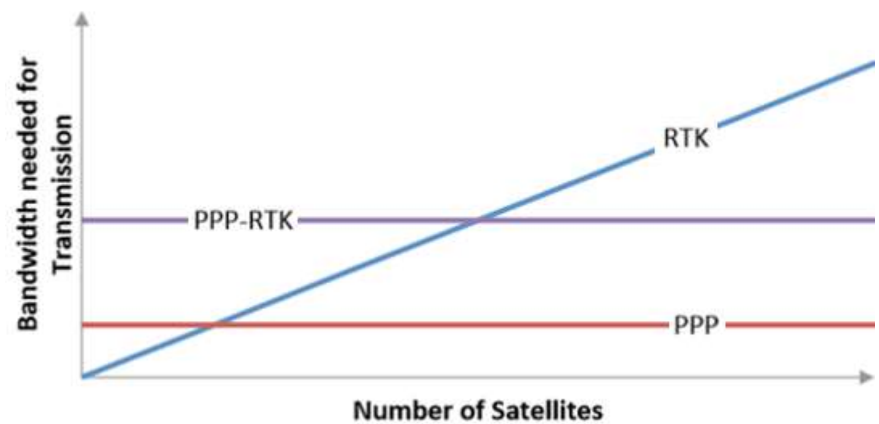
PPP-RTK

- It is a ***combination*** of the original PPP and differential positioning techniques.
- PPP-RTK uses '***State Space Representation***' of GNSS error sources.
- PPP corrections of satellite orbits and clocks are ***independent*** of user location and can be applied worldwide.
- The atmospheric corrections computed from a regional network to **accelerate the filter convergence**, over a local area.





The Future?
RTK, NRTK, PPP, PPP-AR, PPP-RTK

	Technically better term	What does it mean?	What is transmitted?	Initialisation Time	Acuuracy (Horiz)
RTK	DGNSS	Elimination of most errors	Corrections per satellite and per RS	< 20 s	2 cm
NRTK	OSR	Estimation of most errors and estimation of some errors	Corrections per satellite and per VRS	< 20 s	2 cm
PPP	SSR	estimation of errors	-Orbits -Clocks	> 10 min	A few cm
PPP-AR	SSR	estimation of errors	-Orbits -Clocks -Phase biases	< 10	A few cm
PPP-RTK	SSR	estimation of errors	-Orbits -Clocks -Phase biases -Troposphere Ionopshere	< 1 min	A few cm

Key for faster convergence for PPP:

- an accurate ionospheric model to improve performance, or takes advantage of the existence of multiple frequencies from a satellite to create smart combinations of iono-free and wide-lane observables allowing fast convergence.
- High-accuracy Tropospheric Zenith Wet Delay (ZWD) estimation.
- Fixing the ambiguity resolution.

PPP Services

IGS Real-Time Service

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The IGS started an open-access Real Time Service (RTS) in April 2013 (IGS Ultra-rapid orbits IGU)

RTS: contain the satellite orbit and clock corrections, Expressed within the ITRF08 and formatted according to the SSR standard of RTCM (RTCM Version 3.2 (3.3 comming)).

IGS Multi-GNSS Experiments (**MGEX**) network

The IGS RTS network consists of ≈ 220 globally distributed real-time tracking stations maintained by local and regional operators observing 1-second data with latencies of 1-3 seconds.

Sapcorda has indicated that it will provide its own proprietary data format that will be able to deliver the products listed above.

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Commercial PPP Services

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Company	Services
OmniSTAR	GPS L1/L2 **OmniSTAR HP** 10cm H and V Agricultural Machine guidance
	GPS, GLONASS **OmniSTAR G2** 10cm H and V Trees or buildings areas
	GPS L1/L2 **OmniSTAR XP** 15 CM Worldwide
Trimble	GPS, GLONASS, Galileo, BeiDou, QZSS Agriculture **CenterPoint RTX** 2 cm H, 5 cm V < 15 min Worldwide
	GPS, GLONASS, Galileo, BeiDou, QZSS **RangePoint RTX** 30 CM 1-5 min Worldwide
	ViewPoint RTX
Fugro	GPS, GLONASS **Starfix.G2+** ultra-precise 3cm H and 6cm V
	GPS, GLONASS, Galileo and BeiDou **Starfix.G4** 10cm H and V
	Starfix.G2
	Starfix.XP2
	Starfix.HP

Company	Services
NavCom	StarFire
C-Nav	C-NavC2
	C-NavC1
Veripos	Apex 2
	Apex
	Ultra 2
	Ultra
TerraStar	TerraStar-C
	TerraStar-D
Novatel	CORRECT (PPP)
Hemisphere	Atlas

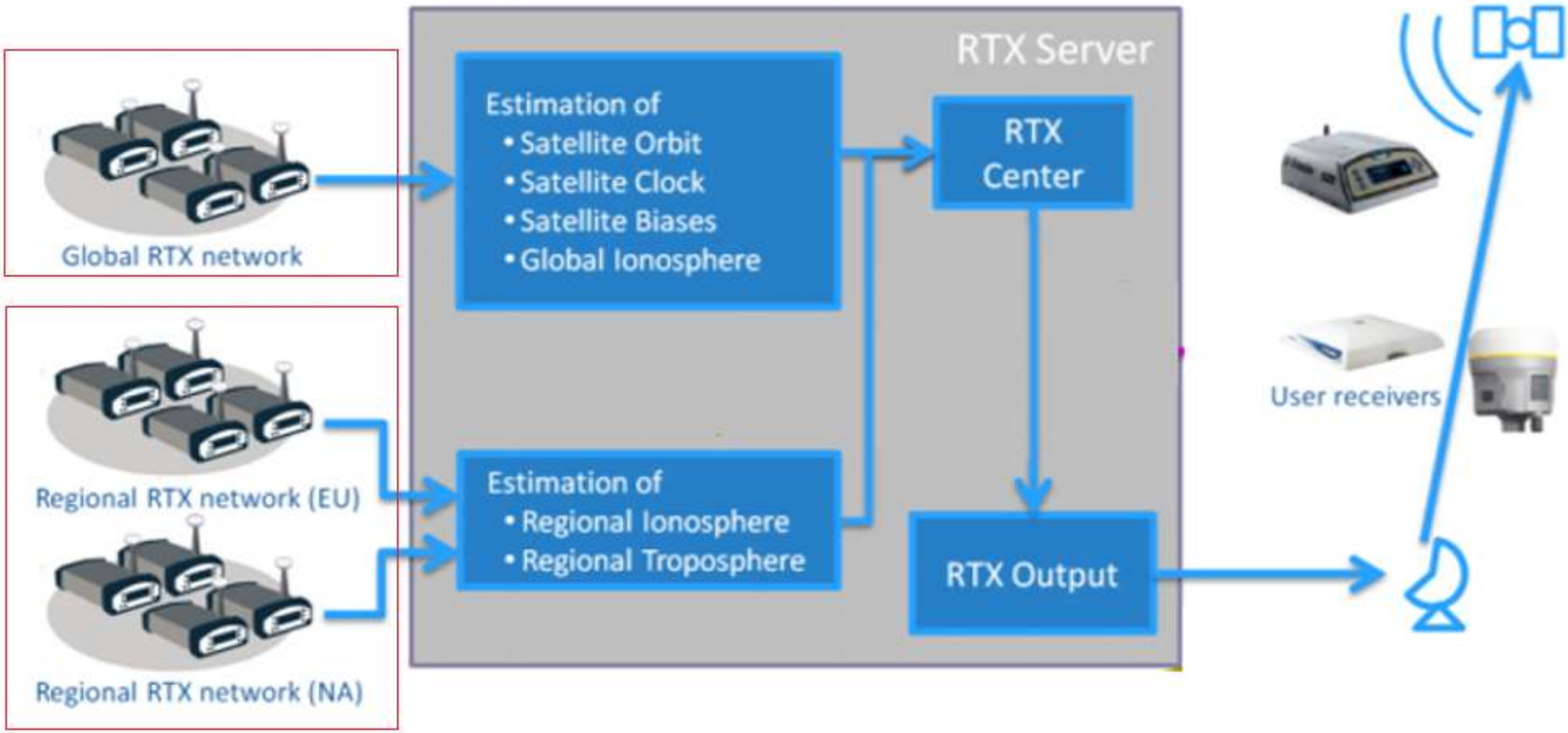
TerraStar X
lane-level accuracy
for autonomous automotive

NovAtel septentrio TOPCON

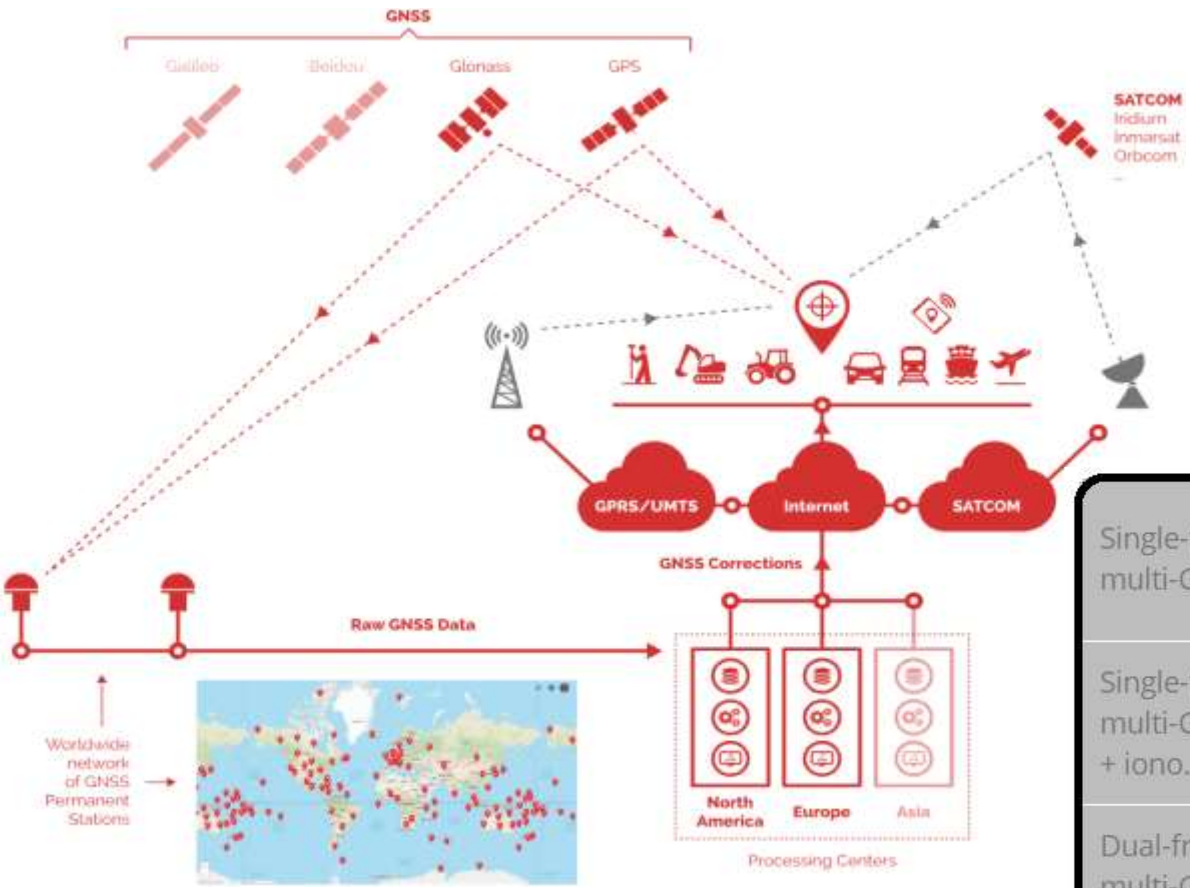
TERRASTAR

Performance	TerraStar-L	TerraStar-C	TerraStar-C PRO
Horizontal Accuracy[3]	40 cm (RMS) 50 cm (95%)	4 cm (RMS) 5 cm (95%)	2.5 cm (RMS) 3 cm (95%)
Vertical Accuracy[3]	60 cm (RMS)	6.5 cm (RMS)	5 cm (RMS)
Convergence Time[4]	< 5 min	30-45 min	< 18 min
Supported GNSS	GPS/GLO	GPS/GLO	GPS/GLO/GAL/BDS

Trimble® CenterPoint® RTX Correction Service



GÉOFLEX service (PPP-CNES technology)



Single-frequency PPP multi-GNSS	**RT-PPP-L1** Accuracy of 80 cm Convergence of 30 minutes
Single-frequency PPP multi-GNSS + iono. SBAS	**RT-PPP-L1 "Fast and Precise"** Accuracy of 50 cm Convergence of 1 minute
Dual-frequency PPP multi-GNSS with float ambiguities	**RT-PPP-L1/L2** Accuracy of 10 cm Convergence of 30 minutes
Dual-frequency PPP multi-GNSS with fix ambiguities	**PPP-IAR** Accuracy of 4 cm Convergence of 30 minutes
Tri-frequency PPP multi-GNSS with fix ambiguities	**PPP-RTK** Accuracy of 2-4 cm Convergence of 5 minutes

2 redundant calculation centers

Spaceopal launches its PPP service NAVCAST

German Aerospace Centre (DLR e.V.)

spaceopal
a DLR GfR and Telespazio company

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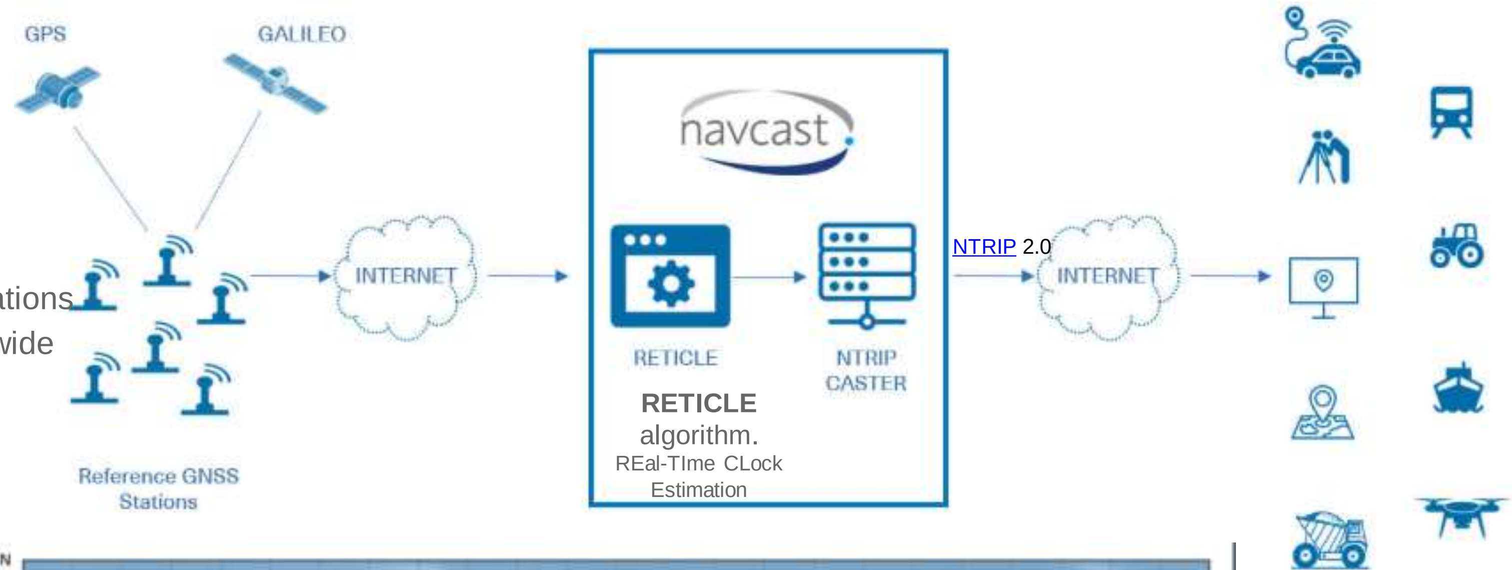
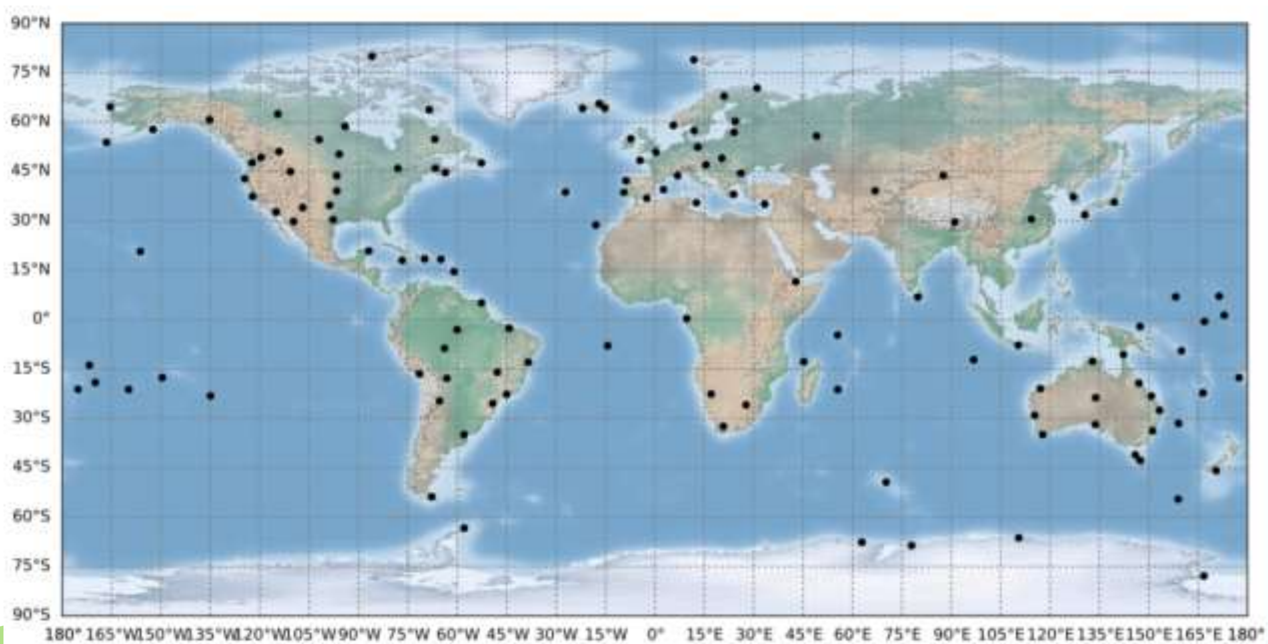
100 stations world-wide





NAVCAST

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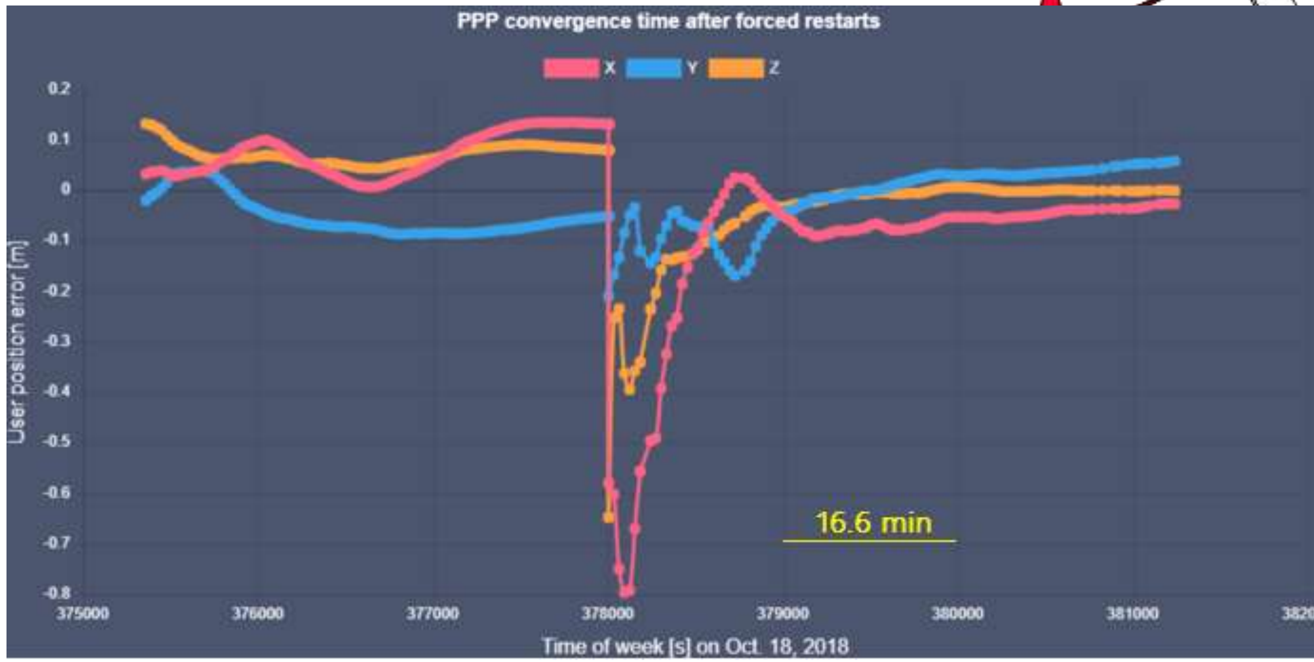
NAVCAST Performance



The PPP engine (dual frequency, ionosphere free observations) estimates the local troposphere delays and fixes the carrier phase integer ambiguities.

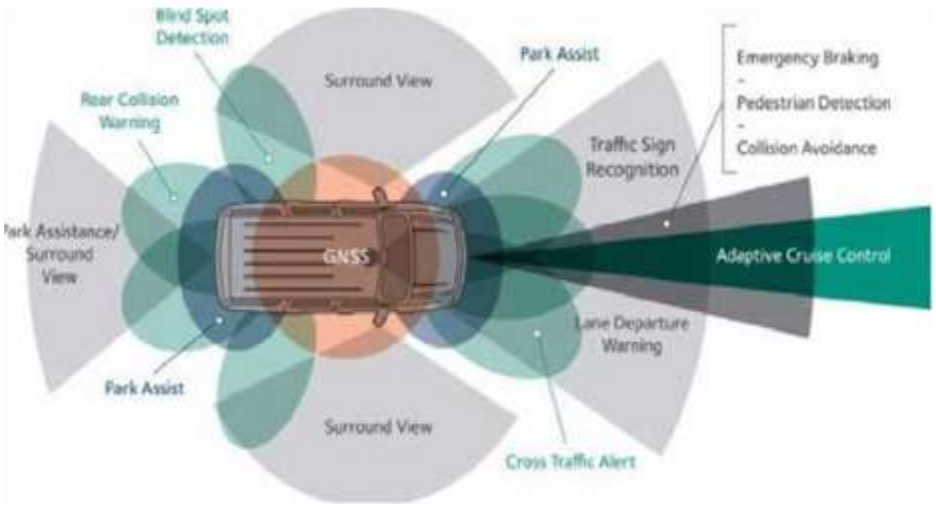
ROAG – (Spain)

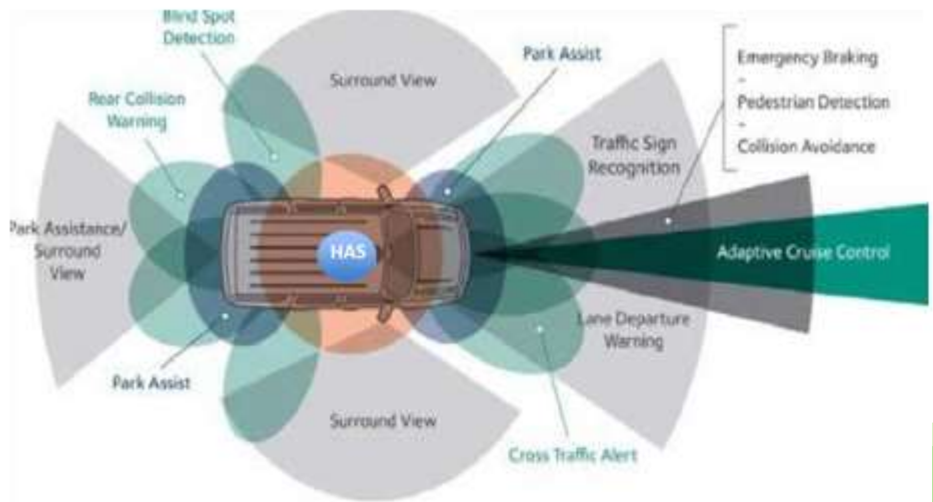
Galileo High accuracy Service (HAS)

- High accuracy (PPP) corrections provided in the Galileo E6-B signal component:
  - Satellite orbits
  - Satellite clock corrections
  - Code biases for multi-frequency
  - Signal/correction quality information
  - Phase biases
  - Ionosphere in EU
- Corrections will for Galileo (E1, E5a, E5b, E6, E5 TBC) and GPS (L1, L2, others TBC), and in the future potentially for other GNSS.
- Global coverage when fully operational. Partial coverage before.

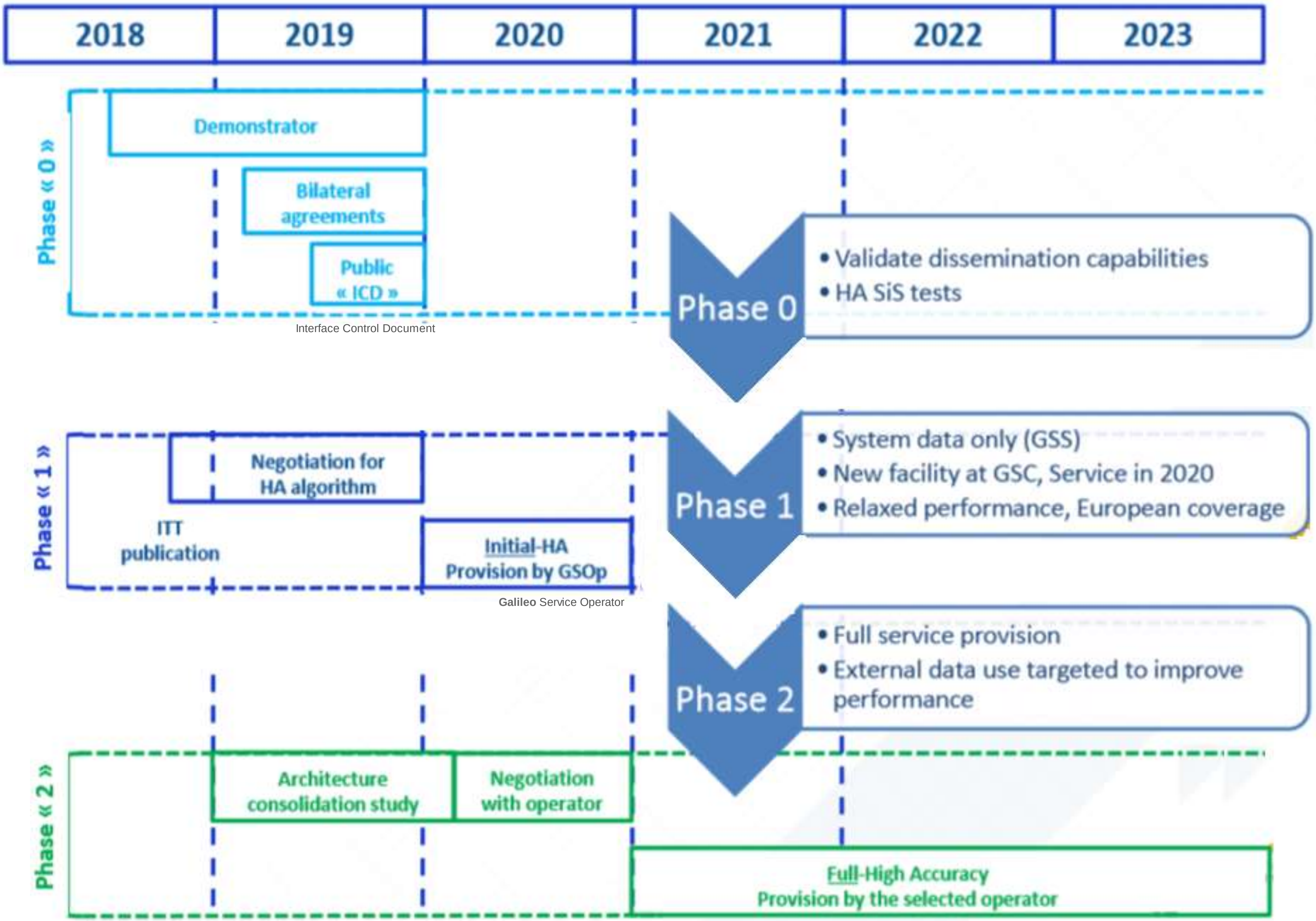
EU always included

Motivation





HIGH ACCURACY ROADMAP – UNDER CONSOLIDATION

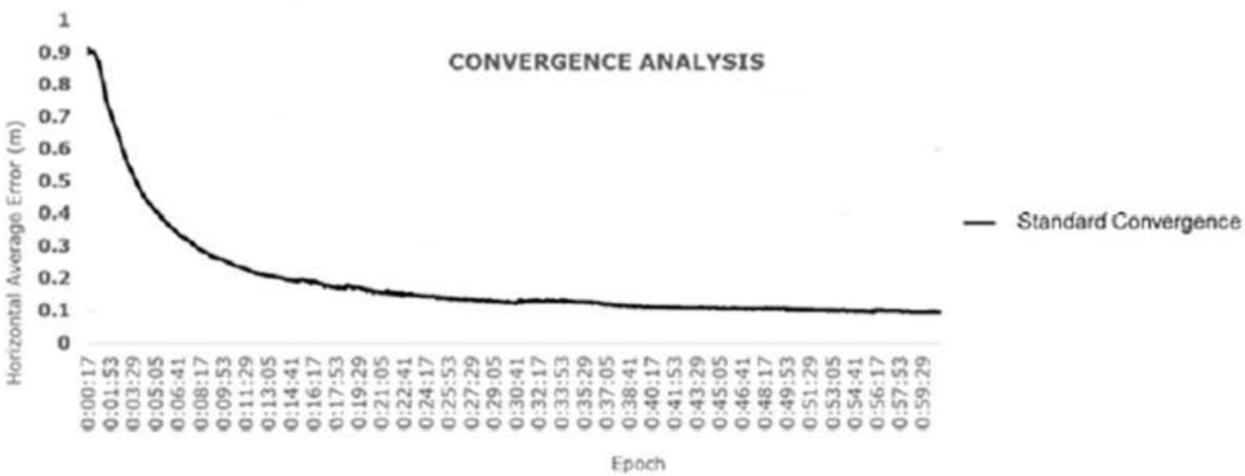


GALILEO HAS – Status Overview

- The Galileo Programme will include a ***free and open HAS*** based on the transmission of PPP corrections globally through the E6b signal
- The EC expects it will accelerate its adoption and lead to innovation in new applications such as ***autonomous driving and mobile devices***: the first truly global, standalone HA service.
- It is based on open standards (***RTCM CSSR*** as basis).
- Global target accuracy < ***20 centimeter*** (Depend also on Receiver type, algorithm and environment).
- Support HAS via ***terrestrial network*** is also under consideration.

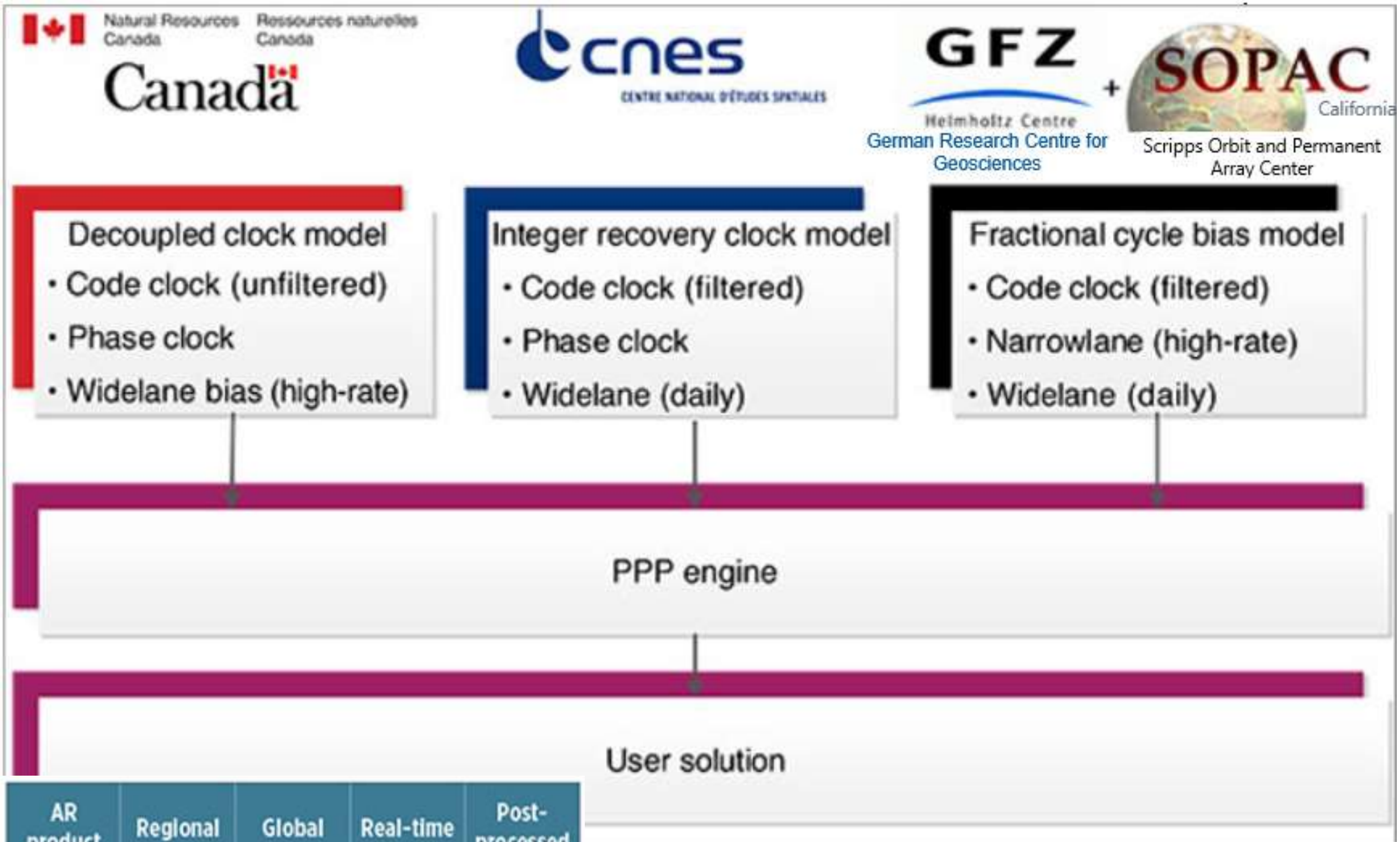
GALILEO HAS – Exp. Performance

- PPP Convergence time is still the problem



CSSR: compact SSR

Public providers of PPP-AR products



AR product	Regional	Global	Real-time	Post-processed
IRC		✓	✓	
FCB	✓		✓	
DC		✓		✓

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Questions?