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| iALA Guideline |

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GNSS satellite-based Precise Point Positioning(PPP) MARITIME SERVICE

Edition x.x

Document date

Revisions to this IALA document are to be noted in the table prior to the issue of a revised document.

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# Introduction

Global Navigation Satellite Systems (GNSS) have become the primary means of obtaining Position, Navigation and Timing (PNT) information at sea. Most ships are equipped with GNSS receivers (SOLAS carriage requirement [1]).

Within the realm of GNSS satellite-based Precise Point Positioning Maritime Services, the Precise Point Positioning (PPP) is defined as a method for global absolute positioning that typically combines multi-frequency GNSS phase measurements with provided corrections to the individual error contributions at the user receiver, or error states, such as signal-in-space terms (satellite orbit, clock and signal biases) and atmospheric corrections (ionosphere and troposphere). PPP data products are generated based on the measurements of a global or regional network of GNSS monitoring stations. Local effects have to be compensated at the user side when the PPP service provider does not offer data for regional or local corrections. If single frequency phase measurements are used, additional precise ionosphere models have to be considered. Once the PPP corrections are calculated, they are delivered to the end users via satellite, Internet or any other dissemination means. These corrections are used by the receivers, resulting in decimetre-level or centimetre-level positioning without the need for communication with close range GNSS reference stations.

PPP can achieve high accurate positioning, but it strongly depends on accurate and uninterrupted satellite orbit and clock error estimations, the number of tracked satellites and the time of continuous phase measurements. The main error sources for PPP are mitigated by Dual-Frequency Operation, External Error Correction Data, Modelling or PPP Filter Algorithms. A typical PPP solution requires a period of time to converge to dm or cm accuracy in order to resolve any local biases such as the atmospheric conditions, multipath environment and satellite geometry. The actual accuracy achieved and the convergence time required is dependent on the quality of the corrections and how they are applied in the receiver.

Currently, there are two types of consolidated PPP implementations. One is to obtain post-processed solutions and the other is to have real-time solutions. Post-processed PPP solutions have been in use for many years and generally achieve better results than real-time solutions. Conventional PPP enjoys the great advantage of scalability; however, it has the great challenge of a slower convergence time than that of RTK (Real-Time Kinematic), typically devoted to estimate the state of the individual error contributions, which is not necessary for RTK. A core feature of PPP is the estimation of the carrier phase measurement ambiguities. In order to solve the ambiguities as an integer number, the PPP algorithm needs the satellite carrier phase biases, in addition to the abovementioned PPP corrections (orbit, clock, code biases). Ambiguity resolution techniques allow a higher accuracy and a faster convergence. If the service provides both accurate ionospheric and tropospheric corrections, allowing the full correction of the atmospheric errors, it is defined as PPP-RTK, which can be a post-processed PPP solution providing almost-instantaneous convergence and cm-level accuracy. The main difference between the two implementations is that, post-processed solutions apply correction after measuring using the corrections provided by the service provider, while real-time solutions require precise orbit information and clock corrections to be sent in real-time to the GNSS receiver location.

A communication channel is continuously needed to broadcast correction parameters. Satellite-based Precision Point Positioning (PPP) services broadcast PPP navigation messages on the public service signals of GNSS satellites. It is an important technology for satellite navigation systems to achieve wide-area high-precision positioning through satellite navigation signals due to its wide signal coverage, uniform accuracy distribution, and small number of ground reference monitoring stations. Especially in the use cases of PPP fields, such as autonomous ship automatic berthing, channel mapping, dredging, cargo loading and unloading, etc., decametre or centimetre level positioning accuracy is very necessary.

## Scope of the document

The guideline provides the description of all the elements of GNSS satellite-based PPP service (including PPP and PPP-RTK)relevant to the maritime administrations or authorities (direct reception of GNSS satellite-based PPP service Signal in Space (SiS) onboard the vessels). This includes some scenarios and the scheme for maritime application.

## Structure of the document

Section 1 is the introduction to this Guideline, including the scope of the document.

Section 2 establishes the IMO Resolution A.1046(27) and A.915(22) operational requirements as the reference for the implementation of GNSS satellite-based PPP maritime service.

Section 3 describes the main elements of a basic GNSS satellite-based PPP service architecture and the existing systems.

Section 4 proposes a list of service parameters to characterize GNSS satellite-based PPP service for maritime use, including their definition.

Section 5 describes the GNSS satellite-based PPP service compatible equipment and maritime application scheme.

And Section 6 describes scenarios of the GNSS satellite-based PPP service in maritime service.

# IMO Resolution A 1046(27) and a.915(22) Reference Requirements

The IMO Resolution A.1046(27) established the requirements that a radionavigation system needs to be recognized by IMO as a component of the Worldwide RadionNavigation System (WWRNS), and the IMO Resolution A.915(22) operational requirements published in 2001 are considered to be the appropriate reference requirements for the implementation of GNSS after GPS and GLONASS.

## IMO Resolution A 1046(27) Requirements

Till 2024, IMO has recognized six GNSS systems (GPS, GLONASS, BDS, Galileo, IRNSS, QZSS) as the WWRNS elements in ocean waters. As one potential capability of the recognized GNSS elements by IMO WWRNS such as BDS, Galileo, QZSS and so on, GNSS satellite-based PPP service should be in compliance with the responsibilities of Governments or organizations and the operational requirements. Meanwhile, with the capability of better than decimeter precise positioning of GNSS satellite-based PPP service, the recognized WWRNS can achieve the levels of performance required in IMO Resolution A.1046(27) for coastal areas and harbour approaches.

The IMO Resolution A.1046(27) establishes the operational requirements that a radionavigation system shall fulfil, which are summarized in the table below:

Table 2 1: IMO Resolution A.1046(27) operational Requirements

|  |  |  |
| --- | --- | --- |
|  | Ocean waters | Harbour entrance, harbour approach and coastal waters |
| Accuracy  (95%) | 100 m | 10 m |
| System Integrity  (Time to alarm) | As soon as practicable by Maritime Safety Information | Within 10s |
| Signal Availability | 99.8% | 99.8% |
| Continuity | N/A | 99.97%(over 15 min) |

Moreover, IMO Resolution A.1046(27) requires that governments or organizations owning and operating the recognized radionavigation systems should comply with the following points:

• The government or organization providing and operating the system has stated formally that the system is operational and available for use by merchant shipping.

• The continued provision of the service is assured.

• The system is able to provide position information within the declared coverage area with a performance not less than that established in the present resolution.

• Adequate arrangements have been made for publication of the characteristics and parameters of the system and of its status.

• Adequate arrangements have been made to protect the safety of navigation should it be necessary to

introduce changes in the characteristics or parameters of the system that could adversely affect the

performance of shipborne receiver equipment.

## IMO Resolution a.915(22) Requirements

The IMO Resolution A.915(22) established general requirements, operational requirements, institutional requirements and transitional requirements for the WWRNS GNSS elements after 2001, the requirements can be summarized below:

• A future GNSS should primarily serve the operational user requirements for general navigation. This includes navigation in harbor entrances and approaches, and other waters in which navigation is restricted.

• A future GNSS should have the operational and institutional capability to meet additional area-specific requirements through local augmentation, if this capability is not otherwise provided. Augmentation provisions should be harmonized worldwide to avoid the necessity of carrying more than one shipborne receiver or other devices.

• A regional satellite navigation system that is fully operational may be recognized as a component of the WWRNS.

Therefore, the administration may consider if the above requirements should be fulfilled and documented by the GNSS satellite-based PPP service provider. This may possibly be achieved by using the appropriate IALA recommended methods.

The list of service parameters required for a complete characterization of a GNSS satellite-based PPP service are derived from the list in IMO Resolution A.915(22) and IALA Guideline 1127.

Table 4‑1: IMO Resolution A.915(22) service requirements

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | System level parameters | | | | | Service level parameters | | | |
|  | Accuracy | | Integrity | | | Availability  % per 30 days | Continuity  % over 3hours | Coverage | Fix interval2  (seconds) |
|  | Horizontal  (metres) | Vertical  (metres) | Alert limit (metres) | Time to alarm2(seconds) | Integrity risk (per 3 hours) |
| **Operations** | Relative accuracy | |  |  |  |  |  |  |  |
| tugs and pushers | 1 |  | 2.5 | 10 | 10^-5 | 99.8 | 99.97 | Local | 1 |
| icebreakers | 1 |  | 2.5 | 10 | 10^-5 | 99.8 | 99.97 | Local | 1 |
|  | Absolute accuracy | |  |  |  |  |  |  |  |
| automatic docking | 0.1 |  | 0.25 | 10 | 10^-5 | 99.8 | 99.97 | Local | 1 |
| Hydrography | 1-2 | 0.1 | 2.5-5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| **Marine engineering, construction, maintenance and management** |  |  |  |  |  |  |  |  |  |
| dredging | 0.1 | 0.1 | 0.25 | 10 | 10^-5 | 99.8 | N/A | Local | 1 |
| cable and pipeline laying | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| construction works | 0.1 | 0.1 | 0.25 | 10 | 10^-5 | 99.8 | N/A | Local | 1 |
| Aids to navigation management | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| Port operations | Absolute accuracy | |  |  |  |  |  |  |  |
| local VTS | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Local | 1 |
| container/cargo management | 1 | 1 | 2.5 | 10 | 10^-5 | 99.8 | N/A | Local | 1 |
| law enforcement | 1 | 1 | 2.5 | 10 | 10^-5 | 99.8 | N/A | Local | 1 |
| cargo handling | 0.1 | 0.1 | 0.25 | 1 | 10^-5 | 99.8 | N/A | Local | 1 |
| Casualty analysis | Predictable accuracy | |  |  |  |  |  |  |  |
| port approach and  restricted waters | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| Offshore exploration and  exploitation | Absolute accuracy | |  |  |  |  |  |  |  |
| exploration | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| appraisal drilling | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| field development | 1 | N/A | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| support to production | 1 | N/A^2 | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |
| post-production | 1 | N/A^2 | 2.5 | 10 | 10^-5 | 99.8 | N/A | Regional | 1 |

# GNSS satellite-based PPP service

The main elements of a basic GNSS satellite-based PPP service architecture is usually as following:

* **Space segment**: Includes the satellites with payloads aimed to transmit the corrections to the GNSS core constellations.
* **Ground segment**: Includes all the ground elements which provide the PPP navigation messages.
* master control station (MCS)
* uplink stations (ULS)
* monitoring stations (MS)
* **User segment**: Includes the user equipment needed to receive and use the GNSS high accuracy PPP service information.

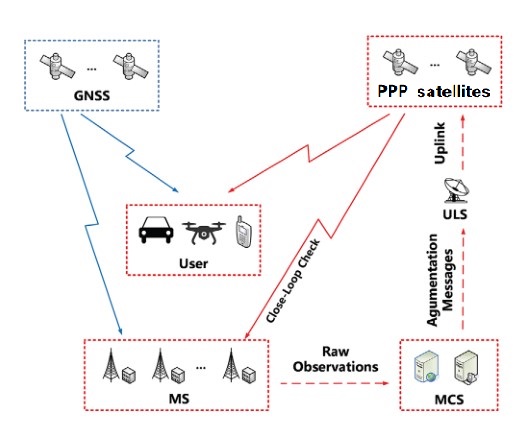


Figure 3‑1: Basic GNSS satellite-based PPP service architecture

## Existing and planned GNSS satellite-based PPP systems

The current institutional service providers of PPP/PPP-RTK are Japan (QZSS), China (BDS), EU (Galileo), Australia/New Zealand (SouthPAN), Russia (GLONASS) and Korea (KPS). At the time of writing this report, only Japan, China and EU provide an operational service: QZSS CLAS [3], BDS PPP [4], and Galileo HAS [5], respectively. Australia/New Zealand is also offering an early open service of PPP via SouthPAN on L5. Russia is offering a ground-based experimental service and developing their satellite-based service . Finally, Korea is developing an open service of PPP-RTK via KPS. All providers offer PPP.The existing and Planned GNSS satellite-based PPP service and their status are shown in Table 3‑1 below:

Table 3‑1: The existing and planned GNSS satellite-based PPP systems

| Country/Region | GNSS satellite-based PPP system | Organisation in charge | Coverage area | Broadcast Signals | Status | GNSS Augmented | CHARGE/FREE |
| --- | --- | --- | --- | --- | --- | --- | --- |
| China | BDS PPP B2b | China Satellite Navigation Office | Asian-Pacific Area | PPP-B2b | Operational | GPS  BDS  GALILEO  GLONASS | free |
| Europe | Galileo HAS | EUSPA | SL1：GLOBAL  SL2：EUROPEAN AREA | E6-b | Operational | GPS  Galileo | free |
| Japan | CLAS  QZSS MADOCA-PPP | cabinet Office of Japanese Government |  | L6-d  L6-e | Operational | QZSS  BDS  GPS  GALILEO  GLONASS |  |
| Australia and New Zealand | PPP via SouthPAN (PVS) | Geoscience Australia and Toitū Te Whenua Land Information New Zealand | Australian and New Zealand | L5 (now)  L5-b(future) | Operational (Initial Operating Capability) OS-PVS-IOC  In-development (Final Operating Capability) OS-PVS-FOC | GPS  Galileo | free |
| KOREA | KPS POINT | Ministry of Oceans and Fisheries, and Ministry of Science and ICT | Republic of Korea | L6 | Ground-based  Satellite-based(future) | GPS  Galileo  KPS | free |
| Russia | GLONASS PPP | ROSCOSMOS, State Space Corporation, Russian Federation | Russian Federation  Global(furutre) | L3SVO | Ground-based expertise  Satellite-based (future) | GLONASS  GPS  Galileo  BDS |  |

## Correction parameters

PPP Messages are synchronized with their own system time reference through a preamble or synchronization pattern transmitted regularly, as is the case for most GNSS signals. The satellite corrections are linked to the corrected broadcast messages through the broadcast IODs and satellite ID. Error detection and/or correction codes are added in all messages.

Regarding satellite corrections, all corrections are provided for satellite broadcast orbits and clocks. Code biases are provided for between multiple signals, where GPS L1C/A is one of them in all cases. Other corrected signals include L5/E5a, E5b/B2, L2C/L2OF and E6. Phase biases are provided by QZSS and will be provided by Galileo and GLONASS. Note that biases are closed related to satellite antenna phase centers. Usually PPP/PPP-RTK service providers will align their satellite clock products with the satellite center of mass (Ref. CoM) or the satellite antenna phase centers (Ref. APC). Which reference point, CoM or APC, to be used will lead to different code/phase bias corrections, and they are totally incompatible. Therefore, the observations used for code/phase bias estimation are corrected by the APC corrections, in order to reconcile the signal bias to a uniform and frequency-independent reference point for both the server side and the user side. This has been a common practice in bias estimation processes using geometry-related observations (e.g., for ionosphere-free phase bias) for long time, but it was not clear until recently for bias estimation processes using geometry-free observations (e.g., for MW phase bias and differential code bias) . The APC issue should be considered when accounting for the interoperability of PPP bias products.

Regarding atmospheric corrections, ionosphere corrections are already provided by QZSS through STEC (Slant Total Electron Content) and will be provided by Galileo through VTEC (Vertical Total Electron Content) as part of the so-called Service Level 2 in Europe. Other PPP providers have not shared yet any plans to provide ionospheric corrections. QZSS CLAS is the only system providing tropospheric corrections over the Japan area, as part of CLAS. KPS will provide the atmospheric correction for PPP-RTK.

Additional data also provided by some operators includes a confidence level on the corrections, such as URA (User Range Accuracy) or equivalent, integrity, and authentication. URA is provided by QZSS and BDS and confidence values for corrections will be also provided by Galileo (HAS Phase 2). Authentication is not yet provided but foreseen by QZSS, Galileo and GLONASS.

For the supported GNSS for correction, most services support GPS, and their own navigation system, QZSS for QZSS CLAS and QZSS MADOCA-PPP, Galileo for Galileo HAS, BDS for BDS PPP, GLONASS for GLONASS PPP, KPS for KPS POINT. QZSS CLAS also support Galileo, QZSS MADOCA-PPP also support Galileo and GLONASS, and PVS (PPP via SouthPAN) supports GPS and Galileo. For supported navigation message, LNAV is supported for all GPS and QZSS correction providers, I/NAV is supported for Galileo except for PVS. CNAV1 is supported for BDS by BDS PPP.The PPP messages are transmitted at a rate between 2,800 bps (GLONASS PPP) to 448 bps (Galileo HAS) per satellite. Both have been proven sufficient to provide corrections with a high-enough update rate for their intended service.

Correction parameters messages for Satellite-Based PPP are broadcast through GNSS satellites, mainly include satellite orbit correction, clock correction, biases(code and phase) and user range accuracy. shown in Table 3‑2 below.

Table 3‑2: Correction parameters for Satellite-Based PPP

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Correction parameters | BDS PPP | Galileo HAS | QZSS MADOCA-PPP | | | PPP via SouthPAN | KPS POINT | GLONASS |
| Time | BDT | GST | QZSST | | CLAS | SNT | KPST | UTC+3h |
| Reference frame | BeiDou Coordinate System (BDCS) | Galileo Terrestrial Reference Frame (GTRF) | ITRF | |  | ITRF2014 | Korean Terrestrial Reference Frame (KTRF) | ITRF2014 |
| Satellite mask | Y | Y | Y |  | | Y | Y | Y |
| Satellite orbit correction | Y | Y | Y |  | | Y | Y | Y |
| Clock correction | Y | Y | Y |  | | Y | Y | Y |
| Code Biases | Y | Y | Y |  | | N | Y | Y(future) |
| Phase Biases | - | YN/A | Y |  | | N | Y | Y(fufure) |
| User Range Accuracy | Y | Y | Y |  | | Y | Y | Y |
| Atmospheric corrections | n/a | Service Leve 2 | n/a |  | | N | Y | Y(future) |
| Broadcasting Frequencies | B2b | E6 | L6 |  | | L5 | L6 | L3SVO |

## Augmented navigation message

PPP/PPP-RTK Messages are synchronized with their own system time reference through a preamble or synchronization pattern transmitted regularly, as is the case for most GNSS signals. The satellite corrections are linked to the corrected broadcast messages through the broadcast IODs and satellite ID. Error detection and/or correction codes are added in all messages, including a checksum by CRC, encoding by LDPC, Reed-Solomon or convolutional codes.

Figure 3-2 shows the frequency of PPP/PPP-RTK signals. The signal carrier frequencies used for the PPP/PPP-RTK signals coincide with those used for GNSS: 1278.75 MHz (Galileo E6, QZSS L6, KPS L6), 1207.14 (BDS B2b, SouthPAN E5b), or 1202.025 MHz (GLONASS L3). Signal power ranges across the typical GNSS power levels, from -160dBW to -153dBW on earth. All signals are RHCP.

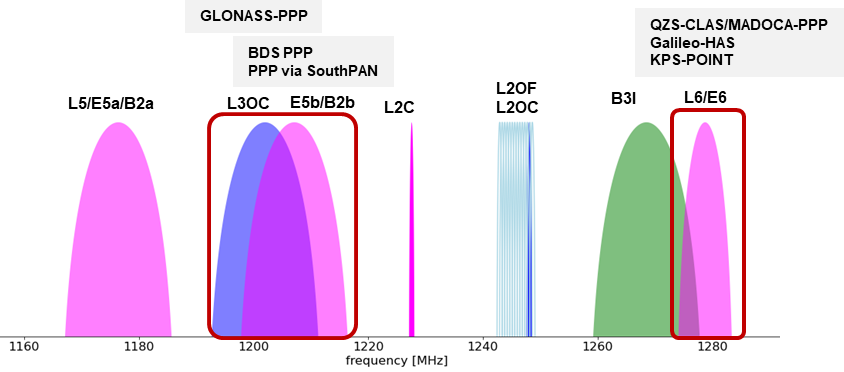


Figure 3-2 – Power spectrums vs frequency of the main PPP/PPP-RTK signals

Concerning signal modulation, all signals are DS-SS (Direct Sequence-Spread Spectrum) using BPSK code modulations: BPSK(5) for L6/E6 (QZSS, Galileo) and L3 (GLONASS); and BPSK(10) for E5b-B2b (BDS, SouthPAN). They use shift register (Gold, Kasami) or memory codes, at least in those publicly defined. The correction message is multiplexed with the code in a binary phase-modulated way for all cases but QZSS, which uses Code Shift Keying (CSK) to transform 250 sps into the 2000 bps abovementioned.

BDS PPP-B2b augmented navigation message

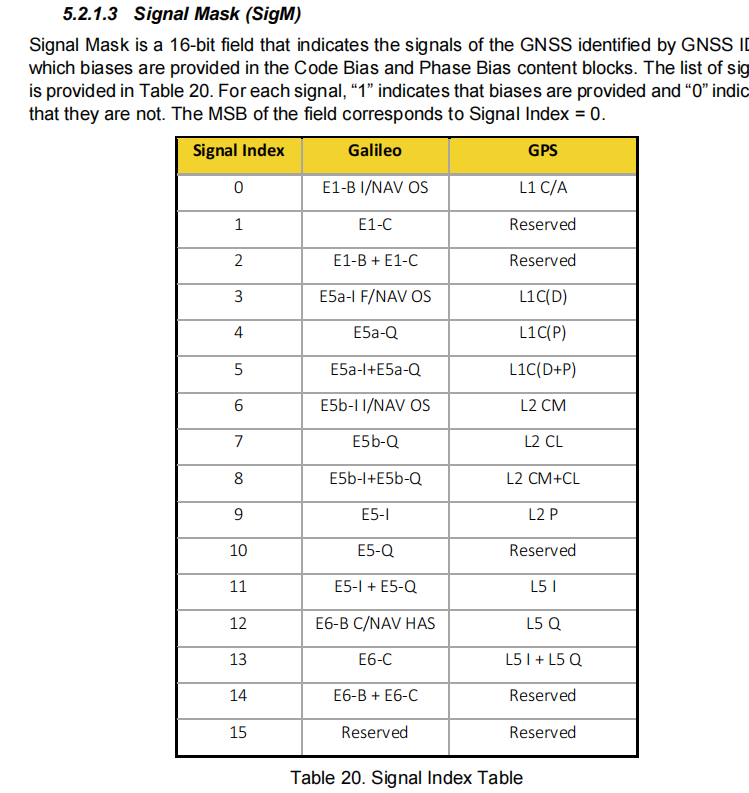
The BDS PPP-B2b signal is designed to provide PPP service for GNSS and their combinations. For each satellite navigation system, the reference broadcast navigation messages corresponding to various corrections are:

1) BDS: PPP-B2b information is used to correct the CNAV1 navigation messagesofB1C signal.

2) GPS: PPP-B2b information is used to correct the LNAV navigation messages.

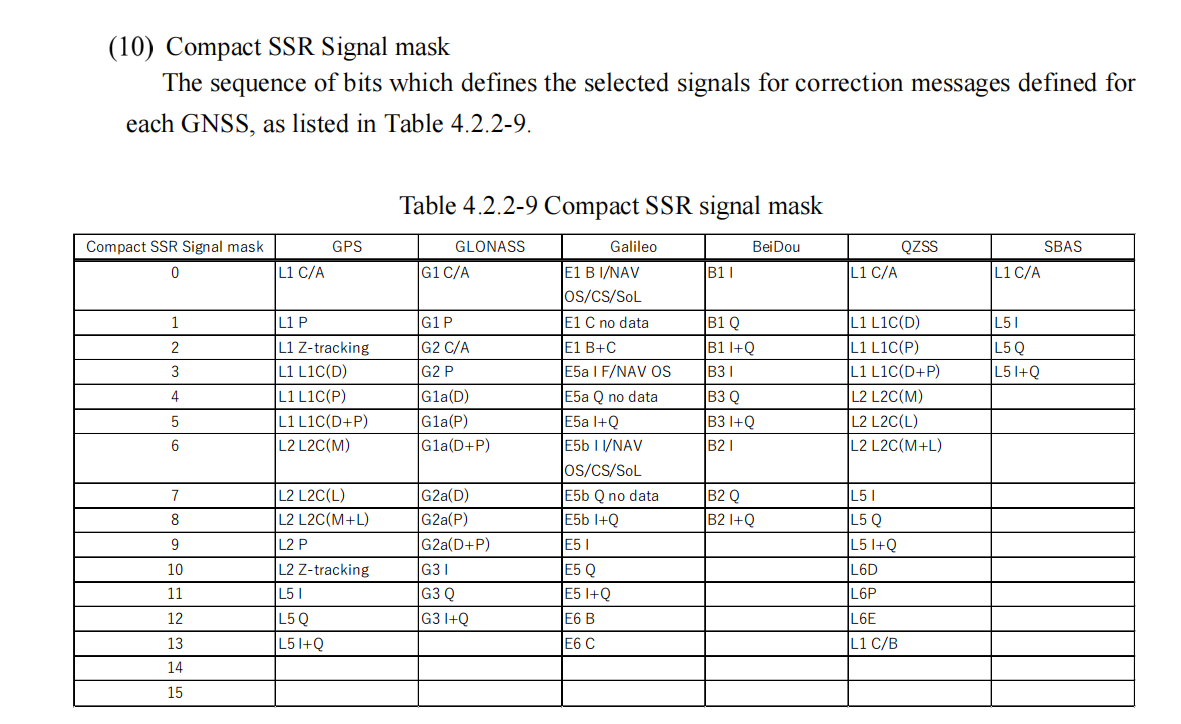
3) Galileo: PPP-B2b information is used to correct the I/NAV navigation messages.

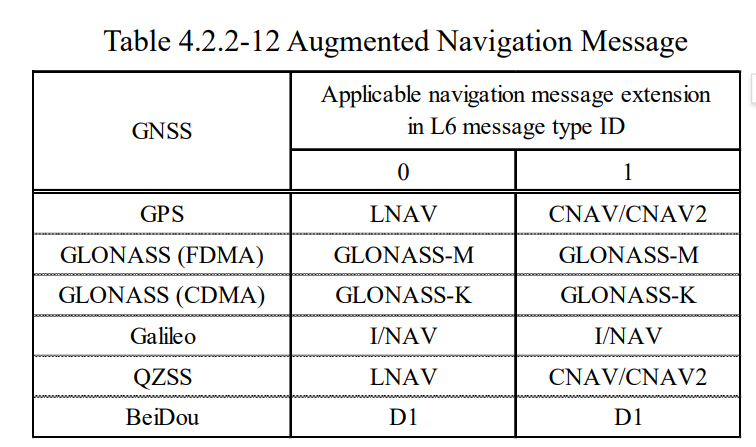
4) GLONASS: PPP-B2b information is used to correct the L1OCd navigation messages



QZSS: augmented navigation message

[Reference: Quasi-Zenith Satellite System Interface Specification Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning (IS-QZSS-MDC-002)- (November 2023) Cabinet office]





South-PAN: augmented navigation message

[Geoscience Australia, Land Information New Zealand, “Service Definition Document for Open Services (Revision 02),” December 2022. Available: <https://www.ga.gov.au/__data/assets/pdf_file/0011/123320/SBAS-STN-0001_02_SDD-OS.pdf.>]

KPS

## Service Coverage

Regarding coverage, most services are provided regionally: QZSS CLAS for Japan and MADOCA-PPP for the Asia-Oceania region, PPP via SouthPAN in Exclusive Economic Zone of Australia/New Zealand and BDS in China and its surroundings. Only Galileo HAS is provided globally, although with a temporary limitation excluding the Asia-Pacific region from the official service area during the initial service phase (Phase 1). There are plans for a global service also from GLONASS PPP.

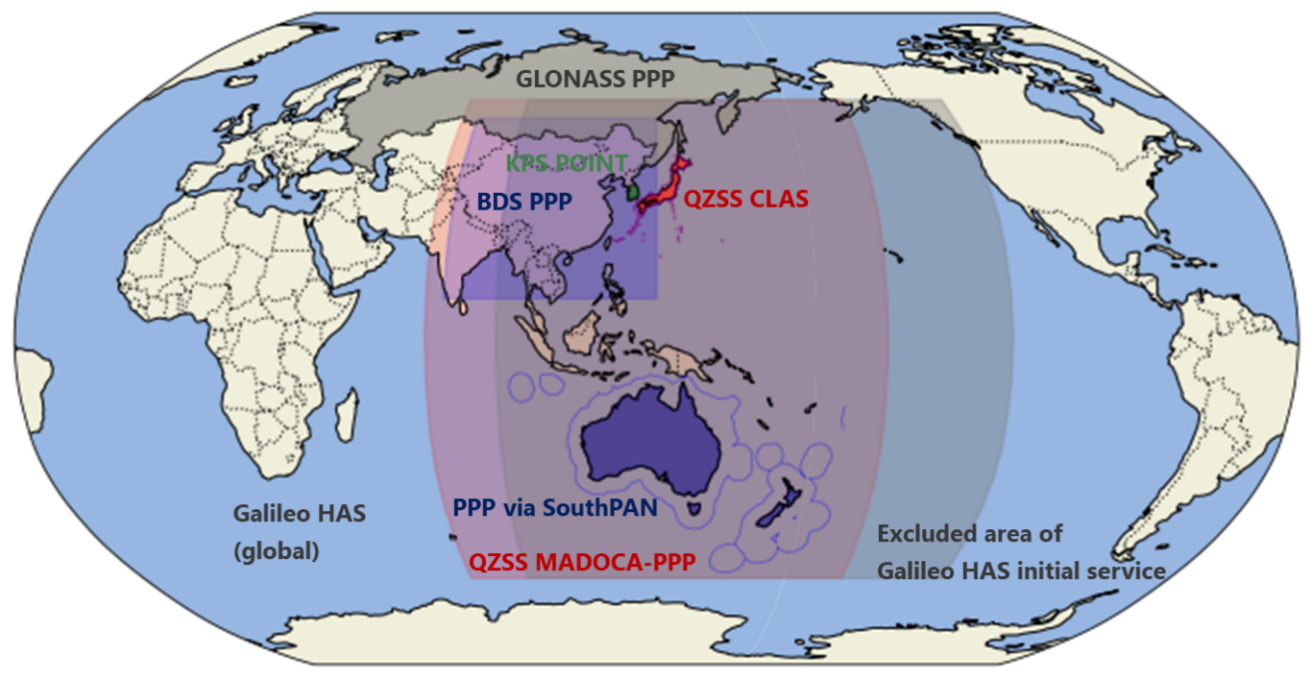


Figure 3‑2: Service Area of GNSS satellite-based PPP

# GNSS satellite-based PPP service Performance Parameters

This section proposes a list of service parameters to characterize GNSS satellite-based PPP service for maritime use.

Positioning accuracy and convergence time. Positioning accuracy is expressed as the horizontal and vertical accuracy [m], both at the 95%. It relates to convergence time as convergence time is defined as the time required to permanently[[1]](#footnote-1) reach the specified positioning accuracy, including the time to receive the correction data. These two magnitudes are depicted in Figure 2.

The paragraphs below detail how these parameters can be understood and measured.

* Signal Availability
* Service Availability
* Service Continuity
* Horizontal Accuracy 95%
* Integrity
  + Time to Alarm
  + ~~Horizontal Alert limit~~
  + ~~Vertical Alert limit~~
  + Integrity risk
* Position Update Rate
* Service Coverage Area

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | BDS PPP | Galileo HAS | QZSS MADOCA-PPP | CLAS | PPP via SouthPAN | KPS POINT | GLONASS PPP |
| Real-time Horizontal Accuracy | 30cm (using BDS only)  20cm (BDS+GPS) | 20cm | 30cm | 12cm horizontal, 24cm vertical (kinematic)  6cm horizontal, 12cm vertical (static) | 37.5 cm | 10cm | 20cm horizontal |
| Real-time  Vertical Accuracy | 60cm  (using BDS only)  40cm (BDS+GPS) | 40cm | 50cm  (static) |  | 52.5 cm | 20cm | 30cm vertical |
| Convergence time | 30 mins  (using BDS only)  20 mins (BDS+GPS) | 300 sec(L1)  100 sec(L2) | 30mins | 60 sec (Including time to receive correction data) | OS-PVS-IOC =< 80 minutes (average 45-55 minutes)  OS-PVS-FOC =< 40 minutes | TBD | 1200 sec |



# GNSS satellite-based PPP MARITIME Service Provision Scheme

A scheme for providing the users with the appropriate GNSS satellite-based PPP maritime service should be established, including the provision of maritime safety related information to the end users.

This section describes an example of this scheme, with relevant stakeholders involved, including the interfaces between them and the provision of GNSS satellite-based PPP service related Maritime Safety Information (MSI) to the end users. The picture below presents schematically this High level Service provision model:



Figure 5‑1: GNSS Satellite-based PPP Maritime Service Provision Scheme

# User Segment Approach

[Including specific scenarios for maritime usage]

Considering the method under free or charging

## MASS

Maritime Autonomous Surface Ships (MASS) is defined by IMO as being: *A ship which, to a varying degree, can operate independently of human interaction.* The MASS should be able to navigate to minimise risk of grounding, collision and environmental impact and to communicate its limitations and navigational intentions to other vessels. Navigational systems should identify all navigation hazards, fixed or mobile, and measure and interpret environmental data. The navigational systems should be designed and constructed to:

(a) Enable their operation in all Reasonably Foreseeable Operating Conditions;

(b) Operate in a predictable manner with a level of integrity commensurate with operational and safety requirements;

(c) Meet requirements for watertight, weathertight and fire integrity;

(d) Minimise the risk of initiating fire and explosion;

(e) Enable the maintenance and repair in accordance with the maintenance philosophy.

(f) allow for automated docking.

Satellited-based PPP provide high accuracy of operation of MASS for navigation in harbour entrances, harbour approaches without assistance of the ground broadcasting system. Once the PPP service converges, it can provide stable and continuous high-precision location service at centimetre level. This will be critical in enabling MASS to navigate safely and manoeuvre as required by international regulations.

## OFFSHORE OPERATIONS

PPP can support offshore drilling and construction through provision of an accurate and reliable method of maintaining precise locations, which is essential for the safety and efficiency of these operations.

Critical for Complex Offshore Activities. Offshore operations like pipe-laying, drilling, and maintenance require high levels of accuracy to ensure proper alignment and avoid costly errors. PPP provides centimeter-level precision, which is essential when exact positioning is critical.

Support for Dynamic Positioning Systems. Many offshore vessels and platforms use dynamic positioning (DP) systems to maintain their location without the need for anchors. PPP enhances these systems by supplying highly accurate geospatial data, allowing vessels to remain in a fixed position even when affected by currents, waves, or wind. This stability is especially important during complex and high-stakes activities such as drilling or construction in challenging sea conditions.

Minimizing the Risk of Drifting. For vessels like survey ships, floating production systems, or support vessels, precise station-keeping is necessary to avoid drifting, which could lead to accidents or disruptions in operations. PPP ensures that vessels remain within defined positional limits, reducing the risk of collisions, environmental damage, or costly downtime due to repositioning.

Increased Operational Efficiency and Safety. By providing precise and continuous positioning data, PPP helps reduce the margin for error in offshore operations. This improved accuracy enhances both operational efficiency and safety, preventing incidents that could compromise the integrity of critical infrastructure or endanger personnel. In unpredictable and often harsh ocean environments, this level of precision is indispensable.

## PORT AND HARBOUR OPERATIONS

Port and harbour operations require accuracy of position to enhance safety and efficiency in critical activities, such as:

Safe and Efficient Docking for Large Vessels. Large ships, such as container vessels and cruise liners, require precise navigation when entering or leaving ports, especially in crowded harbours or during challenging weather conditions. PPP provides highly accurate positioning, allowing these vessels to dock safely and efficiently, minimizing the risk of collisions or grounding, even in narrow or congested areas.

Accurate Dredging Operations. Maintaining safe depths in ports and harbours is essential for accommodating large vessels. PPP ensures precise positioning during dredging operations, which is critical for removing sediment and maintaining the necessary depths for vessel passage. Accurate dredging also optimizes costs by ensuring only the necessary areas are dredged and to the required depth.

Precision in Harbour Infrastructure Construction. Building breakwaters, piers, and other harbour structures requires a high degree of accuracy to ensure structural stability and alignment. PPP supports precise construction by providing accurate location data for construction teams, ensuring that these structures are built to the correct specifications and in the right positions.

Enhanced Automation in Port Machinery. Modern ports increasingly rely on automated systems such as cranes and transport vehicles to handle containers and other cargo. PPP enhances the precision of these automated systems by ensuring accurate positioning of cranes and machinery, enabling efficient loading and unloading of goods. This not only streamlines port operations but also reduces human error and improves overall safety.

Weather-Independent Operations. PPP remains reliable even in challenging weather conditions, providing continuous and accurate data. This allows for uninterrupted port operations regardless of reduced visibility or adverse environmental factors, further ensuring the safety and efficiency of vessel movements and cargo handling.

## SURVEY OPERATIONs

Accurate Seabed Mapping for Navigation. Hydrographic surveys rely on high-precision positioning to map the seabed, coastal areas, and underwater hazards. PPP ensures that these surveys provide the necessary detail to support safe navigation, identifying potential obstacles or changes in the seabed that could pose risks to vessels. This level of accuracy is crucial for charting safe shipping routes and preventing accidents.

Supporting Port Development. Accurate hydrographic data is vital for the planning and development of ports and harbours. PPP ensures the precise mapping of underwater features and topography, aiding in the design of new infrastructure such as piers, docks, and dredging zones. With PPP, engineers can make informed decisions based on reliable data, ensuring that development projects proceed smoothly and safely.

Critical for Environmental Assessments. Environmental assessments often require precise mapping of coastal and underwater areas to monitor ecosystems, assess the impact of construction, and detect changes in marine environments. PPP enhances the accuracy of hydrographic surveys used for these assessments, providing data that is vital for protecting marine life and coastal habitats, ensuring that development or industrial activities are environmentally sustainable.

Supporting Underwater Installations. Pipelines, cables, and other underwater installations rely on precise mapping and monitoring to ensure their integrity. PPP allows for highly accurate surveys and monitoring systems, enabling precise placement of these critical infrastructures. Additionally, PPP supports maintenance operations by providing exact positional data for inspecting and repairing underwater assets, minimizing the risk of damage and reducing downtime.

Improving Safety and Efficiency in Surveying. Hydrographic surveys conducted with PPP improve both safety and efficiency. By providing real-time, highly accurate positioning data, surveyors can avoid costly errors, complete surveys more quickly, and reduce the likelihood of revisiting sites due to inaccurate data. This is particularly important in complex environments where precision is vital to avoid hazards or disruption to marine operations.

## SEARCH AND RESCUE

In search and rescue operations, PPP provides rescue vessels and aircraft with highly accurate location data, enabling quicker response times and more effective rescue efforts, particularly in bad weather or poor visibility. The system supports real-time tracking of vessels in distress, providing rescuers with accurate, up-to-date information for planning and coordination.

Dredging is the removal of sediments and debris from the bottom of lakes, rivers, harbors, and other water bodies. It is a routine necessity in waterways around the world because sedimentation—the natural process of sand and silt washing downstream—gradually fills channels and harbors. Dredging often is focused on maintaining or increasing the depth of navigation channels, anchorages, or berthing areas to ensure the safe passage of ships. Vessels require a certain amount of water in order to float and not touch bottom. A Dredge Positioning System is often used combined with GNSS Real-time kinematic (RTK) positioning devices to show a superimposed view of the dredge location in real-time over the survey. GNSS satellite-based PPP service can provide real-time high accuracy location without extra augmentation GNSS devices. It precisely identifies the location of the attachment at the end of the excavator boom/stick assembly. And together with the dredge positioning system, displays a survey or map of an as-built color bathometric surface of the area to be dredged. It decreases the potential for damage by increasing situational awareness, keeping the operator alerted when the digging attachment is positioned too close to environmental borders, infrastructure, or any other areas where the digging attachment can cause undesired damage.

# Acronyms

BEIDOU Chinese Global Navigation Satellite System

CHAYKA Russian long range navigation system

CLAS Centimetre Level Augmentation Service

DGNSS Differential GNSS

EGNOS European Geostationary Navigation Overlay Service

Galileo European GNSS

GLONASS Russian Global Navigation Satellite System

GMDSS Global Maritime Distress and Safety System

GNSS Global Navigation Satellite System such as Galileo, GPS, GLONASS or BEIDOU.

GPS U.S. Global Positioning System

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

IEC International Electrotechnical Commission

IGS International GNSS Service

IMO International Maritime Organization

IRNSS Indian Regional Navigation Satellite System

MADOCA-PPP Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning

PNT Position, Navigation, and Time

PPP Precise Point Positioning

QZSS Quasi-Zenith Satellite System

RTK Real Time Kinematic

SBAS Satellite-based Augmentation System

SDCM System of Differential Correction and Monitoring

WWRNS World Wide Radio Navigation Systems

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1. The term *permanently* is added to clarify that if the positioning error reaches the accuracy specification but then it raises above it during the convergence process, the receiver positioning error should not be considered as converged. [↑](#footnote-ref-1)