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EGNOS Performance Along Finnish Coast

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ABSTRACT: The purpose of this article is on one side to inform Maritime community about the ongoing activities adopted for the provision of EGNOS (European Geostationary Navigation Overlay Service) L1 maritime service and IEC standardisation process to produce a new IEC (International Electrotechnical Commission) standard for SBAS maritime receivers and on the other side, to demonstrate the benefits of the SBAS system in Europe, EGNOS (European Geostationary Navigation Overlay Service) in high latitudes to Maritime community.

1 INTRODUCTION

Satellite Based Augmentation Systems (SBAS) are designed to augment global navigation system constellations by broadcasting additional signals from geostationary (GEO) satellites. The basic scheme is to use a set of ground monitoring stations to receive GNSS signals that are processed in order to estimate satellite (position and clock) and ionospheric errors which are also applicable to users within the service definition area. Once these estimations have been computed, they are broadcast in the form of "differential corrections" by means of SBAS geostationary satellite(s). Some integrity data are also broadcast along with these correction messages for the GNSS satellites that are in the view of this network of monitoring stations what increases the confidence that a user can have in the satellite-based positioning solution.

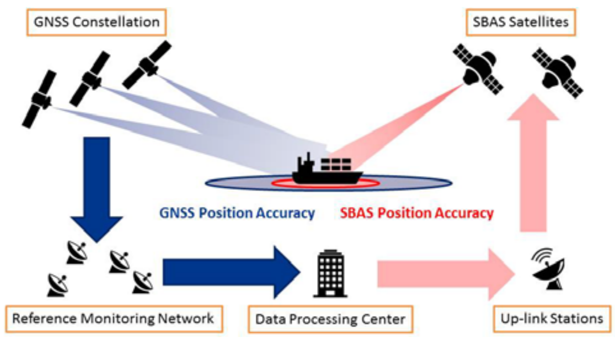

Figure 1.SBAS architecture

EGNOS is the satellite-based positioning service over Europe which provides better accuracy with respect to GPS standalone position. In addition, EGNOS provides Integrity, which can be suitable for safety critical applications in the maritime sector.

2 EGNOS L1 MARITIME SERVICE

The European Commission, EC (EGNOS owner), the GNSS Agency, GSA (EGNOS Services Programme Manager), the European Satellite Services Provider, ESSP (EGNOS service provider) and the European Space Agency, ESA (EGNOS design agency) are working in close collaboration to provide an EGNOS L1 maritime service for "Harbour entrances, Harbour approaches and Coastal waters" and for "Ocean Waters" over Europe.

The EGNOS L1 Maritime service aims at providing pseudo-range corrections, associated ranging integrity and alert information to GPS L1 signals to let shipborne receivers compute an enhanced navigation solution with respect to GPS standalone, meeting operational requirements included in in the IMO Resolution A.1046 (27) for maritime navigation in ocean waters, harbour entrances/approaches and coastal waters over European coastal and inland waters. EGNOS L1 Maritime service is planned by 2023 when the IEC SBAS test standard is expected to be ready. The service will include performance monitoring reporting and provision of Maritime Safety Information (MSI) as well.

EGNOS L1 performance (accuracy, availability, continuity, integrity, time to alarm, coverage) was analysed concluding that EGNOS L1 meet the operational requirements stated in International Maritime Organization (IMO) Resolution A.1046 (27) for "Harbour entrances, Harbour approaches and Coastal waters" and for "Ocean Waters" over Europe. Assessment is ongoing to define the potential servicer area for the EGNOS L1 maritime service, which plans to cover most of European coast and inland waters. Moreover, GNSS campaigns on board vessels (such as the one presented in section 6 of this paper) along European coasts have been carried out to demonstrate the EGNOS benefits in real environmental conditions and potential and common vessels.

The service provision scheme required to guarantee the required service level is under definition, and was presented in the European Maritime Radionavigation Forum (EMRF) to maritime authorities. This service plans to include an EGNOS Maritime Safety Information (MSI) service to mariners and a potential establishment of specific working agreements between the EGNOS Service Provider and any national competent authority.

In addition, vessels should be equipped with type approved receivers for SBAS L1 in order to ensure the required operational performance for maritime community. For that, EC requested CEN / CENELEC to support the development of a test standard regarding SBAS L1 receivers for maritime applications, which will be covered in a new part standard in IEC 61108 series. The IEC standardisation process has started in February 2020, and is expected to be completed by 2023.

3 SBAS STANDARDISATION FRAMEWORK FOR SHIPBORNE RECEIVERS

Currently, IALA G-1152, [2], states that "IMO recognises GNSS as part of World Wide Radio Navigation System (WWRNS) only for ocean areas where required performance levels which can be achieved without using augmentation systems [e.g. IMO Circular SN.1/Circ.329]". Besides, GNSS standalone positioning such as GPS, GALILEO, GLONASS, Beidou and IRNSS are not suitable by themselves for Harbour entrances, harbour approaches and coastal waters.

According to IALA Guidelines for SBAS maritime Service, G-1152 [2], SBAS systems are needed to achieve the performance levels required (i.e. accuracy and integrity) for harbour entrances/approaches and coastal waters in IMO Res. A.1046(27), [9], in which the freedom to manoeuvre is limited. Therefore, SBAS systems are particularly needed where there is no back-up infrastructure (i.e. DGPS/ DGLONASS) or in poorly covered environments.

Supporting this last necessity, it has been published that as of June 30th 2020, all Nationwide Differential GPS System (NDGPS) service has been discontinued in favour of SBAS system in accordance with the Nationwide Differential GPS System (NDGPS) Federal Register Notice USCG-2018-0133, [1]. Apart from the United States of America, Australia and Japan have recently discontinued their radio beacon DGNSS service. The United Kingdom and Ireland have stated that their DGPS service will cease in 2022. DGPS is no longer deemed a necessary augmentation for close harbour approach.

IMO MSC.401(95), [10], and IEC 61108-4 (Shipborne DGPS and DGLONASS maritime radio beacon receiver equipment), [6], allow the use of augmentation signals in shipborne receivers but there is no standard for its implementation. Most of recent maritime GNSS receiver models are SBAS compatible but they could present important differences in their performance since they are not certified according to a specific test standard.

An IEC 61108 standard for SBAS receiver equipment should be published in order to ensure a safe use of Satellite Based Augmentation Systems by all shipborne receivers. IEC 61108 is a collection of IEC standards for "Maritime navigation and radio-communication equipment and systems - Global navigation satellite systems (GNSS)". IEC has published International Standards for the following GNSS systems: 61108-1, [3], for GPS, 61108-2, [4], for GLONASS, 61108-3, [5], for Galileo and 61108-5, [7], for BDS, and launched a new proposal 1108-6, [8], for IRNSS. In addition, IEC has published International Standard 61108-4, [6], for DGPS and DGLONASS, which are ground-based Augmentation systems based on an enhancement to primary GNSS constellations (GPS and GLONASS).

A new IEC 61108 is planned to be developed to include the minimum performances for SBAS L1 maritime GNSS receivers to be fulfilled by the receiver equipment in order to be compliant with the IMO Res. A.1046(27) [9] operational requirements for harbour entrances, harbour approaches and coastal waters, along with the methods of testing and required test results.

At this point, two initiatives are currently working to support this standardisation process:

- First, the GNSS Space Agency (GSA) and the European Commission (EC) have launched the MARESS (MAritime Receiver SBAS Standardisation) project, where ESSP, BNAE, CEREMA, University Gustave Eiffel will be working during 2021 in the production of technical documentation to support the International Electrotechnical Commission (IEC) standardisation.
- Second, CEN, the European Standardisation Committee through its Technical Committee 5 dedicated to Space has created the Working Group 8 (CEN/CLC JTC5 /WG 8) of SBAS receiver performance for maritime applications in September 2020. In this group, MARESS project's outputs will be presented to commonly agree on the draft of IEC-61108 Part 7 for SBAS receiver equipment, which will be submitted to IEC Technical Committee 80 (Maritime navigation and radiocommunication equipment and systems).

The New Work Item Proposal IEC 61108-7 standard was submitted to IEC TC80 in February 2021, starting the international process. The ballot is open until beginning of June 2021 and thus, National bodies interested and with representation in IEC are encouraged to vote in favour with participation. This ballot will be a key milestone since it is required to pass the approval criteria in terms of participation and positive support in order to continue with the process.

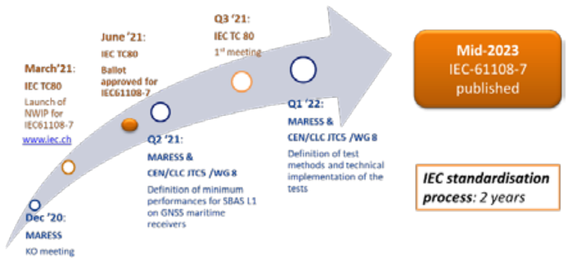

Figure 2. Tentative plan for standardisation process

As presented in Figure 2, the approval of the New Work Item Proposal (NWIP) IEC 61108-7 standard for SBAS is expected to be approved in Q2 2021. When the New Work Item Proposal is approved, the IEC standardisation process within IEC Technical Committee 80 group will start.

Assuming that the NWIP is approved considering the support expected for several countries, by June the first meeting of the European Working Group CEN/CLC JTC5 /WG 8 is planned to discuss the inputs provided by MARESS Project, which would include an outline of the IEC standard and the proposal for the definition of the minimum performances for SBAS L1 on GNSS Maritime receivers. Later in Q3 2021, the first meeting of IEC TC 80 could be held presenting the draft agreed within CEN/CLC JTC5 /WG 8. Finally, in 2022 a Committee Draft for IEC 61108-7 standard is expected to be under assessment within IEC TC 80. Note that these dates are tentative milestones; the final plan will be scheduled by IEC TC 80.

4 MARITIME REQUIREMENTS BASED ON IMO RESOLUTION A.1046 (27)

EGNOS L1 maritime service is fully characterised by a list of performance parameters derived from the list in IMO Res. A.1046 (27), [9], (see Table 1) which are Signal Availability, Horizontal Accuracy 95%, Position update rate, Service Coverage, Service Continuity and Time To Alarm for "Harbour entrances, Harbour approaches and Coastal waters" and for "Ocean Waters".

Table 1. Operational requirements based on IMO A.1046 (27), [9]

	Ocean Waters	Harbour entrances/ approaches and coastal waters
Horizontal Accuracy 95%	100m	10m
Signal Availability	99.8%	99.8%
Service continuity (over 15min)	-	99.97%
Position update rate	2s	2s
Time to Alarm[1]	Maritime Safety Information as soon as practicable	10s
System coverage	Adequate[2]	Adequate[2]

[1] Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities.
[2] Taking into account the radio frequency environment, the coverage of the system should be adequate to provide position-fixing throughout this phase of navigation.

This paper focuses in the requirements of accuracy, signal availability and continuity. EGNOS provides a service performance compatible with this 2s update rate. The compliance to update rate shall be demonstrated by the receiver/equipment manufacturers. The receivers used in this assessment were configured to provide an update rate of 1 second.

5 GNSS PERFORMANCE ASSESSMENT ALONG FINNISH COAST ON BOARD MASTERA OIL TANKER

A GNSS campaign was performed along the Gulf of Finland in order to analyse the EGNOS performance in the border of Northeast EGNOS coverage area. Two kinds of receivers were configured to use SBAS. Then, this paper presents the results of a maritime receiver and a high-end receiver. The EGNOS performance results were compared with respect to the GPS standalone solution, to evaluate the improvement of EGNOS for maritime community. The performance obtained with those receivers was compared with the operational requirements defined in the IMO Resolution A.1046 (27), [9], (Table 1) to assess the feasibility of EGNOS for ocean waters, coastal waters and harbour entrances/approaches, being beneficial for maritime community over the Finnish coast.

5.1 *Characteristics of GNSS data campaign*

The characteristics of this GNSS data campaign in maritime domain were:

- Route: the vessel, Mastera, departed from Porvoo (Finland) to Primorsk (Russia) then until Naantali (Finland). Afterwards, the vessel went from Naantali (Finland) to Primorsk (Russia) being two days stopped close to Uusimaa waiting for orders (adrift) and finally arrived at Porvoo (Finland).
- Time framework: the vessel departure was on 01.11.2019 and arrived on 14.11.2019 at Porvoo.
- Vessel: Mastera. This is a Finnish Aframax crude oil tanker operated by Neste Shipping. This icebreaking tanker transports crude oil year-round from the Russian oil terminal in Primorsk to Neste Oil refineries in Porvoo and Naantali. https://www.neste.com/

Figure 3. Mastera oil tanker

Figure 4. GNSS data collection path

The equipment installation consisted of two GNSS MFMC high-end receivers and a maritime receiver connected to a GNSS MF antenna.

Additionally, a RF signal recorder was connected to the same GNSS MF antenna to log the same RF L1 signal as the rest of the GNSS receivers.

RF L1 signal recorded during the maritime dynamic data campaign was replayed in the maritime receiver to obtain GPS standalone solution. It has to be stressed that the SIS recorder capability is only of five days (from November 1st to 6th 2019).

After the GNSS data campaign, high-end receiver's output files were post-processed using high precision techniques to obtain the real followed route.

5.2 *Methodology of computing*

The activity for the GNSS performance assessment consists of three general lines:

1. Real position. It was obtained in post-processing using high precision techniques (PPP, Precise Point Positioning) with the GNSS data obtained by the receiver. Figure 5 describes the flow of data through different tools to obtain the precise path of the Mastera vessel in order to compute GNSS performance.
   It is stressed that both high-end receivers are with the same configuration. One is the back-up of the other one.
2. SBAS Navigation solution. This was computed directly with the GNSS maritime receiver. The computation of the performance analysis is done using internal Analysis Tools developed by ESSP. Figure 5 summarises the process of the methodology followed.
3. GPS-only solution. RF L1 signal recorded during the maritime dynamic data campaign was replayed in the maritime receiver to obtain GPS standalone solution. It has to be stressed that this recorded scenario only lasts five days (from November 1st to 6th 2019).

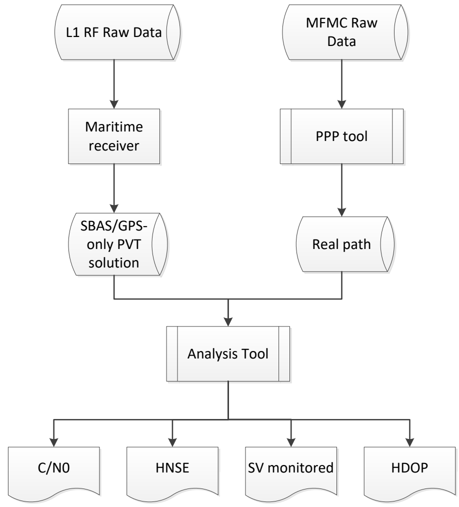

Figure 5. Process of GNSS PVT solution

5.3 *GNSS performance analysis*

GNSS performance analysis is based on the position solution obtained with some GNSS receivers installed in the vessel:

- a high-end receiver;
- a maritime receiver.

Besides, the RF L1 signal in space recorded during almost six days on-board was replayed in the following receivers in order to analyse their GNSS performance:

- a maritime receiver (to analyse GPS position solution);
- a high-end receiver (to analyse GPS position solution).

5.4 *EGNOS signal in space*

EGNOS signal availability refers to the percentage of time during which reliable information is provided by the system within the specified area of service. Thus, EGNOS 1046 Signal Availability assesses the percentage of time the EGNOS signal in space is provided by the GEOs according to messages that can be processed by an SBAS receiver aligned with the receiver guidelines.

EGNOS broadcasts through two operational GEO satellites. This redundancy benefits EGNOS receivers which can instantaneously GEO switch and therefore, EGNOS signal availability is calculated as the combined signal availability of both operational EGNOS GEO satellites.

EGNOS signal unavailability happens when there is a simultaneous signal in space outage in both EGNOS GEO satellites.

During the whole period of Mastera vessel trip (November 2019) the operational EGNOS GEO satellites were PRN 123 and PRN 136.

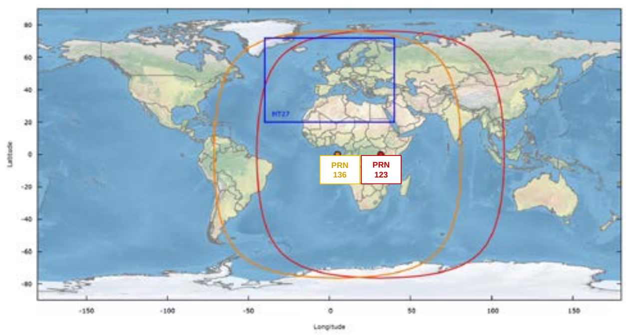

Figure 6. EGNOS operational satellites (November 2019)

The EGNOS monitoring information shows that the EGNOS signal in space availability was 100% during the whole data campaign period, which meets the 99.8% EGNOS signal in space availability requirement.

The EGNOS service continuity was 100% during the data campaign period meeting the 99.97% over a period of 15 minutes of IMO Res. A.1046 (27) [9], since no service interruption occurred during that period.

5.5 *EGNOS / GPS standalone position availability*

EGNOS as a radio-navigation system has a particularity which is EGNOS GEO satellites broadcast messages over the GEO satellite footprint (Figure 6) but EGNOS can be used only within the Message Type 27 service area. EGNOS is a regional augmentation system that provides ionospheric and satellite corrections for Europe.

Therefore, EGNOS position availability is the percentage of time an user is able to compute a position based on EGNOS.

Table 2 shows the percentage of time the receiver is computing the position solution using EGNOS and GPS standalone.

N. B. GPS standalone performance assessment for Maritime receivers is only between 01.11.2019 16:15 UTC and 06.11.2019 19:43 UTC (5 days) due to the capacity of the Signal recording equipment.

Analysing these results, it can be concluded that:

- EGNOS position availability was 100% for both receivers.
- No EGNOS position continuity events were detected during the data campaign period.

Table 2. Position availability obtained using EGNOS and using GPS standalone

	EGNOS Position Availability [%]		GPS standalone Position Availability	
DOY	High-end receiver	Maritime receiver	High-end receiver	Maritime receiver
305	100	100	100	100
306	100	100	100	100
307	100	100	100	100
308	100	100	100	100
309	100	100	100	100
310	100	100	100	100
311	100	100	100	--
312	100	100	100	--
313	100	100	100	--
314	100	100	100	--
315	100	100	100	--
316	100	100	100	--
317	100	100	100	--
318	100	100	100	--

5.6 *EGNOS / GPS accuracy*

Horizontal Accuracy is the 95% percentile of the Horizontal Position Error (HPE) distribution. HPE is the 2D radial error of the instantaneous measured position by the GNSS receiver respect to the true instantaneous position.

Table 3 compares the horizontal accuracy between the user performance obtained using EGNOS and GPS standalone.

Table 3. HPE (95%) obtained using EGNOS and using GPS standalone

	EGNOS HPE 95% percentile [m]		GPS standalone HPE 95% percentile [m]	
DOY	High-end receiver	Maritime receiver	High-end receiver	Maritime receiver
305	1.179	0.869	4.073	1.444
306	0.935	0.791	3.284	1.809
307	0.970	0.792	1.653	1.222
308	0.970	0.747	2.103	1.638
309	1.023	0.835	1.738	1.307
310	0.967	0.841	2.235	2.000
311	0.950	0.907	1.832	--
312	0.956	0.718	3.818	--
313	0.873	0.762	3.312	--
314	1.000	0.786	3.527	--
315	1.057	0.808	3.860	--
316	0.911	0.784	1.208	--
317	0.870	0.792	1.228	--
318	1.049	0.872	1.688	--
TOTAL	0.971	0.815	3.149	1.551

Table 3 presents daily HPE (95%) quite close to 1m when using EGNOS solution against GPS standalone, in particular, there is a global HPE (95%) for the 13 days using the maritime receiver, of 0.815m whereas the global value for the same receiver reproducing the recorded RF L1 signal to compute GPS standalone solution during 5 days is 1.551m. In contrast, the high-end receiver shows more extreme results: 0.971m of HPE (95%) when using EGNOS solution against 3.149m when using GPS standalone solution.

To be more precise, it can be compared EGNOS HPE (95%) against GPS standalone HPE (95%) exactly for the same period (since 01.11.2019 at 16:15 UTC to

06.11.2019 at 19:43:21 UTC) using the same Maritime receiver and replaying the same RF L1 signal-in-space.

Table 4. HPE (95%) obtained using EGNOS and GPS with maritime receiver since 01.11.2019 at 16:15 UTC until 06.11.2019 19:43:21 UTC

	EGNOS solution		GPS standalone	
DOY	HPE (95%)	Max. HPE	HPE (95%)	Max. HPE
305	0.869	1.219	1.444	1.721
306	0.791	0.910	1.809	2.184
307	0.792	1.088	1.222	1.552
308	0.747	0.970	1.638	2.132
309	0.835	1.353	1.307	1.804
310	0.798	1.092	2.000	2.544
TOTAL	0.800	1.353	1.551	2.544

Table 4 shows the clear improvement of EGNOS horizontal accuracy between 54% and 103% for the case of the maritime receiver against GPS standalone.

Analysing these results, it can be concluded that:

– Percentiles at 95% of Horizontal position errors were lower than 1.2 meters for both high-end and maritime receivers in all days and usually lower than 1 meter.
– EGNOS Horizontal accuracy (95%) was lower than 1.2 meters for both receivers, which is compliant with 10 meters accuracy requirement in IMO Res. A.1046 (27) [9] for "Harbour entrances, Harbour approaches and Coastal waters" and for "Ocean Waters".
– EGNOS provides a clear improvement of horizontal accuracy between 54% and 103% for the case of the maritime receivers with regards to the use of GPS standalone.

6 GENERAL CONCLUSIONS

Results from two receivers (one maritime and other high-end receiver) on board the vessel that navigated during thirteen days along the Gulf of Finland show that:

1. The EGNOS signal in space availability was 100% during the data campaign period meeting the 99.8% requirement of IMO Res. A.1046 (27), [9]. In fact, the two GNSS receivers were able to track EGNOS messages from both operational GEO satellites (PRN123 and PRN 136) the 100% of time.
2. The EGNOS service continuity was 100% during the data campaign period meeting the 99.97% over a period of 15 minutes of IMO Res. A.1046 (27) [9], since no service interruption occurred during that period.
3. EGNOS position availability was 100% for both GNSS receivers during the whole period.
4. EGNOS position continuity was 100% for both receivers during the whole period since no EGNOS position continuity events were detected during the data campaign period.
   It is noted that this continuity parameter is at receiver level considering local effect, along receiver and antenna characteristics.
5. 95th percentile of the Horizontal Position Error meets the 10 meter requirement for "harbour entrances, harbour approaches and coastal waters" and the 100-meter requirement of "Ocean waters" established in IMO Res. A.1046 (27), [9], with both GNSS receivers.
   EGNOS horizontal position accuracy is enhanced between 54% and 103% with respect to GPS standalone solution for the case of the maritime receiver.

In consequence, the EGNOS performance observed on board the oil tanker, Mastera, indicates that EGNOS can support "Harbour entrances/approaches and coastal/ocean waters" according to IMO Res A.1046 (27) [9], meeting the 10 meters confidence level at 95%, the signal-in-space availability requirement of 99.8% and the service continuity of 99.97%.

ACKNOWLEDGMENTS

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Finally, the authors would like to acknowledge the efforts done by EC, GSA and ESA to work at programme level for the future provision of EGNOS L1 maritime service.

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