Input paper: [[1]](#footnote-1) ENG8-11.7

Input paper for the following Committee(s): check as appropriate Purpose of paper:

**□** ARM **⌧** ENG **□** PAP **⌧** Input

**□** ENAV **□** VTS **□** Information

Agenda item [[2]](#footnote-2) (from agenda) 11

Workplan Task Number / Technical Domain 2 3.4.1 and 3.1.2

Working Group WG3 – Radionavigation Services

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EGNOS SIS performance based on IMO Res. A.1046

# Summary

The European Geostationary Navigation Overlay Service (EGNOS) augments the open public service offered by GPS and makes GPS suitable for safety critical applications thanks to enhanced accuracy and integrity. As a Satellite-Based Augmentation System (SBAS), EGNOS offers three services (Open Service, Safety-of-life Service and EDAS) [10]. The EGNOS Safety-of-life (SoL) Service is intended for transport applications in different domains and currently is in use by Aviation.

Since 2014, the development of a new EGNOS service for maritime based on IMO Res. A.1046 (27) [2] is under study with the contribution of the European Commission (EC), the European GNSS Agency (GSA), the EGNOS service provider (ESSP SAS) and the European Space Agency (ESA). This service can complement Differential GNSS (DGNSS) as a back-up or where there is no infrastructure for the provision of enhanced accuracy and integrity. EGNOS functionality is supported by most of the maritime GNSS receivers (85% of receiver models) used in both merchant and leisure market segments.

Annex 1 of this paper details the list of performance parameters to completely characterize the SBAS maritime performance and the level of EGNOS performance attained for maritime. This paper introduces, as well, the work that is being performed in order to define a minimum set of recommendations for receiver manufacturers to provide them with a clear view on how to design their SBAS receivers to be compliant with the requirements defined for such a service. EC, GSA, ESA and ESSP SAS have been working together since 2016 to develop guidelines for manufacturers for the implementation of SBAS in shipborne receiver. These guidelines, together with a set of test specifications, were developed in the frame of the SBAS Working Group created in the Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS) of Radio Technical Commission for Maritime Services (RTCM). The aim of these guidelines is to define the minimum SBAS messages needed to be processed by a SBAS receiver for the maritime sector to be compliant with the International Maritime Organization (IMO) Resolution A.1046.

Annex 2 of this paper presents the set of SBAS message type recommended by these SBAS guidelines as well as the preliminary list of tests that must be fulfilled to be compliant. Lately, GSA and ESSP, with the collaboration of The Norwegian Coastal Administration and Hurtigruten Cruises, have carried out a GNSS data collection campaign of 10 days along the Norwegian coast with the aim of assessing EGNOS performance at user level in the maritime domain at high latitudes in Europe; and, finally, the performances obtained with the receiver are compared with the requirements of the IMO Res. A.1046 (27) to assess the feasibility of EGNOS for some maritime applications.

## Purpose of the document

The purpose of the document is to provide this technical description for the Committee review in order to obtain feedback and comments to be considered in the development of the associated Guidelines.

# References

1. Draft Guidelines for Manufacturers for the Implementation of SBAS in Shipborne Receivers Including Methods of Testing and Required Test Results, 31 July 2017
2. IMO Resolution A.1046(27) Worldwide Radionavigation System, 20 Dec 2011
3. ICAO Standards and Recommended Practices (SARPS) Annex10 Volume I (Radio Navigation Aids)
4. RTCA MOPS DO 229 Revision E
5. IMO Resolution MSC.112(73),”Adoption of the revised performance standards for shipshore Global Positioning System(GPS) receiver equipment, December 2000
6. IMO Resolution MSC.114(73) DGPS and DGLONASS maritime radio beacon receiver equipment
7. IMO Resolution MSC.401(95) performance standards for multi-system shipborne radionavigation receivers
8. gLAB Software <http://www.gage.upc.edu/gLAB>
9. IEC 61108 - Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) <http://www.iec.ch>
10. EGNOS user support website <https://egnos-user-support.essp-sas.eu>
11. Grant, A., Last, D., Kuncheva, L. 2003. Marine DGNSS Availability and Continuity. Journal of Navigation, 56, 353-369
12. IALA Guideline No. 1112 On Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325KHz. Edition 1. May 2015

# Action requested of the Committee

The Committee is invited to consider the information provided in the Annexes and provide feedback and comments so that can be included as input to the work item on SBAS Recommendation.

1. EGNOS 1046 SERVICE PERFORMANCE PARAMETERS AND PRELIMINARY ASSESSMENT
2. INTRODUCTION

EGNOS is the Satellite Based Augmentation System (SBAS) over Europe, currently designed to augment the GPS navigation system constellations by broadcasting additional signals from geostationary (GEO) satellites. Apart from providing positioning and timing service over Europe, EGNOS provides Integrity for Safety of Life applications. Some events of the GNSS system may lead to positioning errors that are greater than the ones allowed in certain safety critical applications. EGNOS provides Integrity by detecting and removing those system errors, and by alerting the user in due time when such errors occur and cannot be discarded.

EGNOS is also used in a wide range of applications (such as agriculture and surveying) that benefits the enhanced position solution with respect to GPS standalone solution. Moreover, EGNOS is widely used in aviation over Europe, which is a safety critical application. In July 2018, 180 airports have at least one EGNOS based procedure for landing and/or taking off.

The list of service performance parameters for a complete characterization of EGNOS maritime service is derived from the list in IMO Res. A.1046 (27) (Table 1) and includes Signal Availability, Horizontal Accuracy 95%, Position update rate, Service Coverage for “Ocean Waters” and two additional parameters such as Service Continuity and Time To Alarm for “Harbour entrances, Harbour approaches and Coastal waters”. Additionally to IMO’s ones, ESSP SAS and GSA consider a new parameter is needed to characterize EGNOS maritime service. This is because EGNOS particularities as radionavigation aid. This parameter is called Service Availability and indicates the percentage of time a position solution, calculated using EGNOS, is available in a specific location. The rationale behind the need of this parameter is explained in this paper following the recommendations in IALA Guidelines 1112 [12] on performance and monitoring of DGNSS services.

1. WWRNS IMO requirements

| Parameter | Maritime requirements based on IMO A.1046 (27) | |
| --- | --- | --- |
| Ocean Waters | Harbour entrances, harbour 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 Alarm1 | Maritime Safety Information as soon as practicable | 10s |
| System coverage | Adequate2 | Adequate2 |
| 1Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities. | | |
| 2Taking into account the radio frequency environment, the coverage of the system should be adequate to provide position-fixing throughout this phase of navigation. | | |

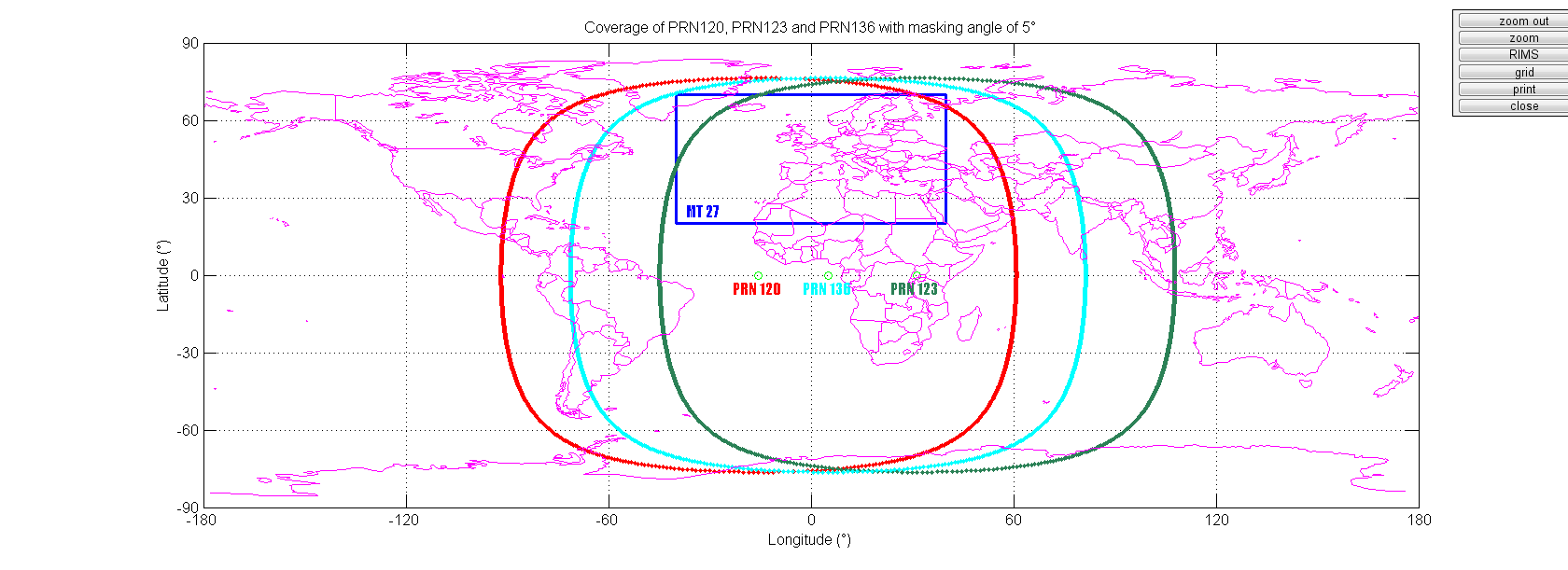
There is a need to identify a full set of service performance parameters required for a complete characterization of EGNOS maritime service and to define a way to measure these parameters for EGNOS because IMO performance requirements in Table 1 come with no detailed definition. In this section, GSA and ESSP SAS propose an approach to both issues. IALA Guideline No. 1112 [12] defines how to calculate the performance parameters for DGNSS and, in this work, ESSP SAS and GSA have used a similar approach to propose definitions for IMO performance parameters.

All IMO Res. A.1046 (27) parameters are addressed below: Signal Availability, Horizontal Accuracy 95%, Service Continuity, Position Update Rate, Time To Alarm and Service Coverage. Additionally, the set of service performance parameters must account for the specific characteristics of EGNOS as a maritime radionavigation aid. That is the reason why, for EGNOS, one additional parameter (Service Availability) is included.

1. Signal availability

*Signal availability exists if the signal is provided according to its specification within the specified area of service.* EGNOS 1046 Signal Availability assesses the percentage of time the EGNOS SiS 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 will benefit EGNOS 1046 receivers capable of instantaneous GEO switching and therefore, signal availability has to be calculated as the combined signal availability of both operational EGNOS GEOs. EGNOS 1046 signal availability reaches the same value in the intersection area of both EGNOS GEOs footprint (Figure 1). Although unlikely, EGNOS GEO satellites change for operational reasons as it happened in March 2017:



1. Operational EGNOS GEOs footprint.

According to the previous practical interpretation, EGNOS 1046 signal availability is the same value through the intersection area of EGNOS operational GEOs footprint (PRN120 & PRN136 until 20th of March, 2017 and PRN120 & PRN123 since 21st of March, 2017 because of the GEO change).

From May 2016 to June 2018, EGNOS GEOs broadcast at least one EGNOS message during 100% of the time (PRN 120 & PRN123/136) and then, Signal Availability reached 100% meeting the IMO requirement of 99.8%.

1. Horizontal Accuracy 95%

*Horizontal Accuracy is the 95% percentile of the Horizontal Position Error (HPE) distribution.* HPE is the 2D radial error of the instantaneous measured position respect to the true instantaneous position. The following table shows the Horizontal Accuracy 95% values in meters in EGNOS stations (Table 2):

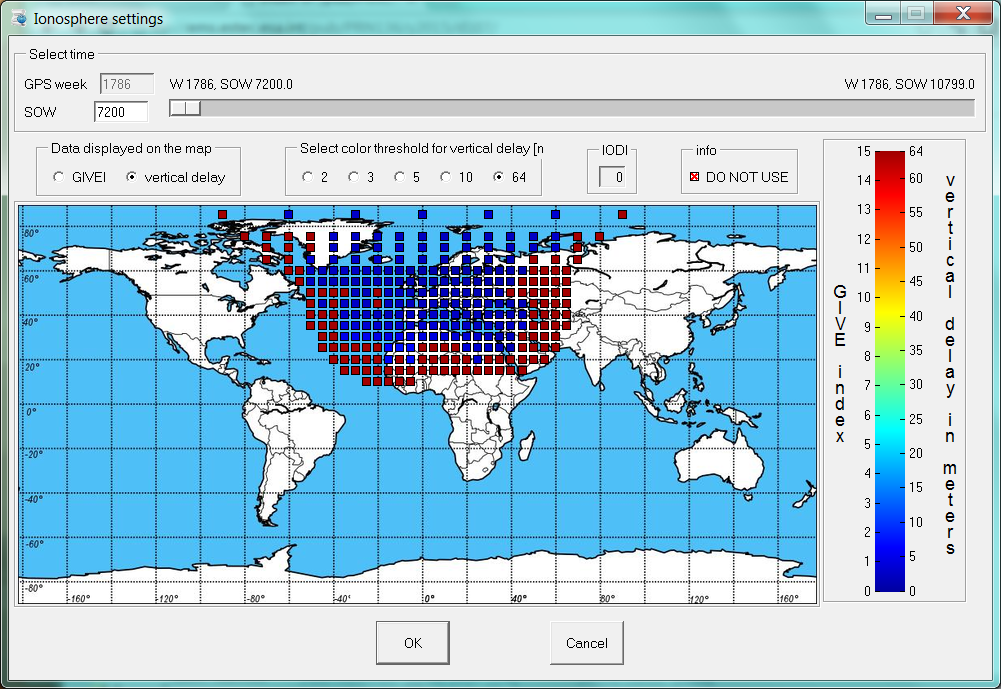
1. Horizontal accuracy 95% from May 2016 to June 2018

| Station | Horiz Acc 95% (m) | Station | Horiz Acc 95% (m) |
| --- | --- | --- | --- |
| Aalborg | 0.8 | Santiago C. | 0.8 |
| Berlin | 0.8 | Sofia | 1.1 |
| Catania | 0.7 | Gävle | 0.7 |
| Cork | 0.8 | Toulouse | 0.7 |
| Warsaw | 0.9 | Trondheim | 0.7 |
| Djerba | 0.8 | Tromsoe | 1.0 |
| Egilsstadir | 0.7 | Zürich | 0.8 |
| Glasgow | 0.9 | Jan Mayen | 1.2 |
| Lisbon | 0.9 | Athens | 0.7 |
| Swanwick | 1.0 | Agadir | 0.9 |
| Madeira | 0.8 | Canary Island | 1.1 |
| Málaga | 0.8 | La Palma Isl. | 1.0 |
| Kirkenes | 0.9 | Azores | 2.8 |
| Palma Mall. | 0.6 | Longyearbyen | 2.1 |
| Reykjavik | 0.9 | Abu Simbel | 2.5 |
| Roma | 0.7 | Alexandria | 1.2 |
| Lappeenranta | 0.7 | Golbasi | 0.9 |

The values above represent the Horizontal Accuracy 95% for those epochs when a navigation solution based on EGNOS was available in the station. All stations meet the IMO requirements of 10m 95% for “harbour entrances, harbour approaches and coastal waters” surrounding Europe and IMO requirements of 100m 95% for “ocean waters”.

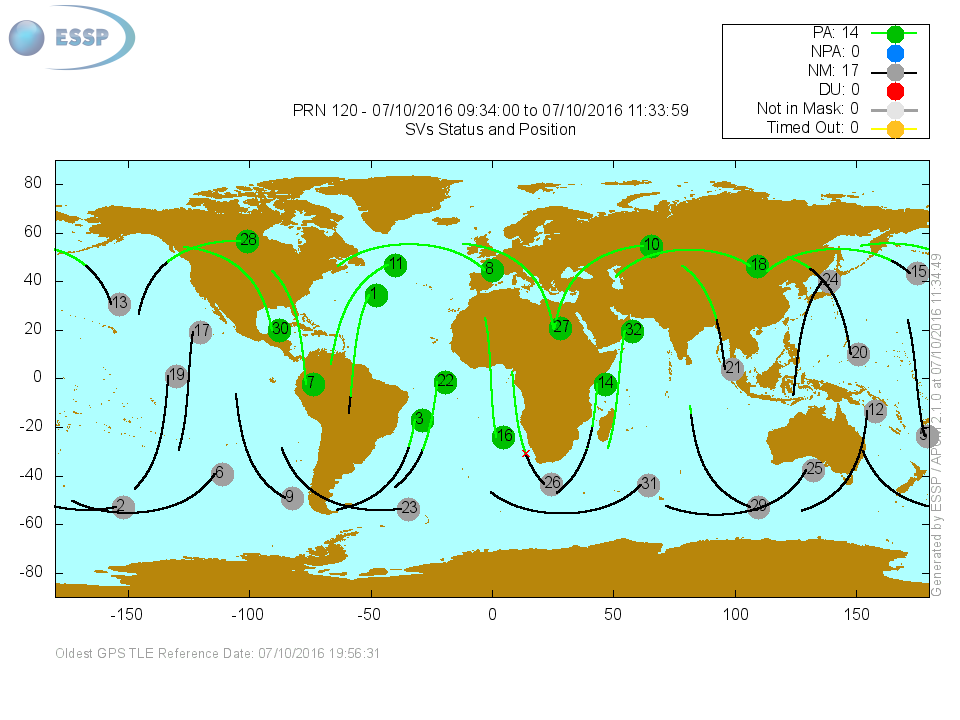
1. Service Availability

Performance parameters in Table 1 come from IMO Res. A.1046 (27). As a radionavigation aid, EGNOS has a particularity: EGNOS GEO satellites broadcast messages over the GEOs footprint (Figure 1) but EGNOS performance is not the same in the whole EGNOS GEO footprint. In some areas, where EGNOS SiS is received (Figure 1), EGNOS 1046 receivers will not be able to compute a navigation solution based on EGNOS (e.g. south of Africa). This happens because EGNOS messages include ionospheric corrections only for a region around Europe (Figure 2) and, for a specific epoch, only for a subset of GPS satellites. This subset of satellites is the specific subset in view from Europe and the surrounding area (Figure 3):



1. Squares represent EGNOS ionospheric grid points (IGP) during a specific epoch for ionospheric differential corrections and integrity information.

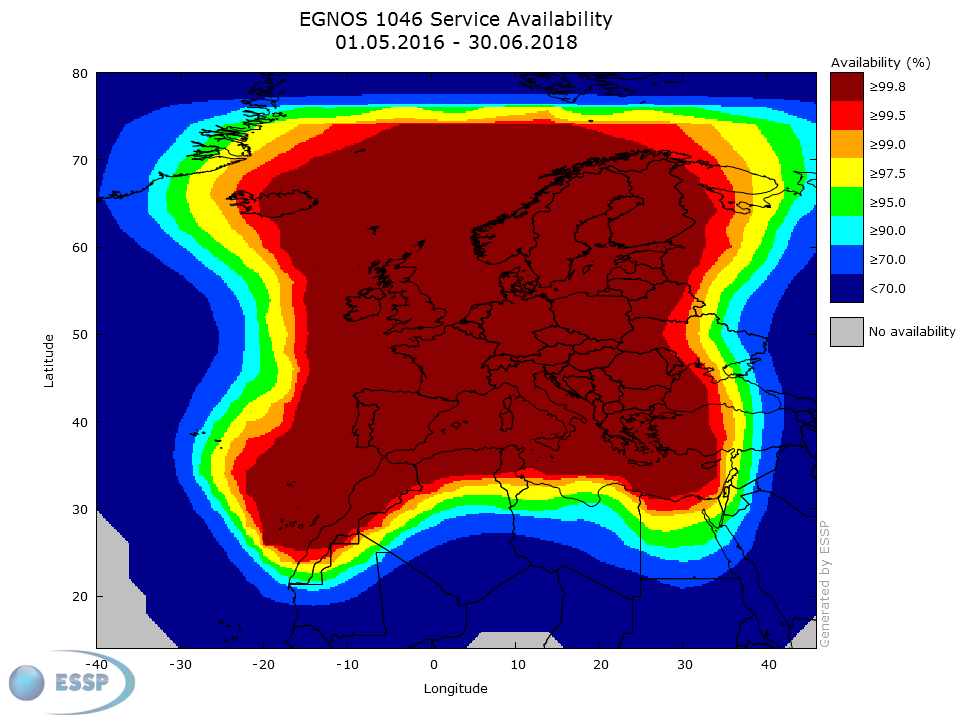
Figure 2 presents in blue IGPs monitored which means the differential corrections and integrity information are available for that IGP and can be used by EGNOS users and in red IGPs not monitored or not valid. A similar situation happens for each GPS satellite. For example, Figure 3 presents in green GPS satellites monitored by EGNOS during a period of two hours and in grey GPS satellites which were not monitored during that period of time:



1. GPS satellites monitored by EGNOS (in green) during a period of two hours

A GPS satellite is monitored if EGNOS differential corrections and integrity information is available for that GPS satellite. Then, this GPS satellite can be used for the EGNOS navigation solution. As a result, users in Europe and the surrounding area can use EGNOS differential corrections and integrity information to improve their positioning. On the other hand, some users within the footprint but located far away from Europe landmasses will not be able to calculate a navigation solution based on EGNOS 1046 service although they have received EGNOS SiS. For example, users located in Africa’s sub-Saharan region receive EGNOS SiS but, as only a few of the satellites in view by them are monitored and none of IGPs are monitored, sub-Saharan users are not capable to calculate an EGNOS PVT solution.

In order to differ EGNOS 1046 service for users that are able to calculate a navigation solution for a particular epoch from those users also within the footprint that are not, a parameter must be defined. This performance parameter is the *EGNOS Service Availability and it is the percentage of time a position calculated using EGNOS for maritime is available in a specific location*. EGNOS 1046 Service Availability shall be calculated considering receivers are able to do instantaneous GEO switching. For Service Availability, which is not an IMO requirement, it is proposed a target value of 99.8% that will ensure very high quality service. Note that the lack of Signal Availability is one of the events affecting the Service Availability. According to this definition, Figure 4 shows the Service Availability from May 2016 to June 2018:

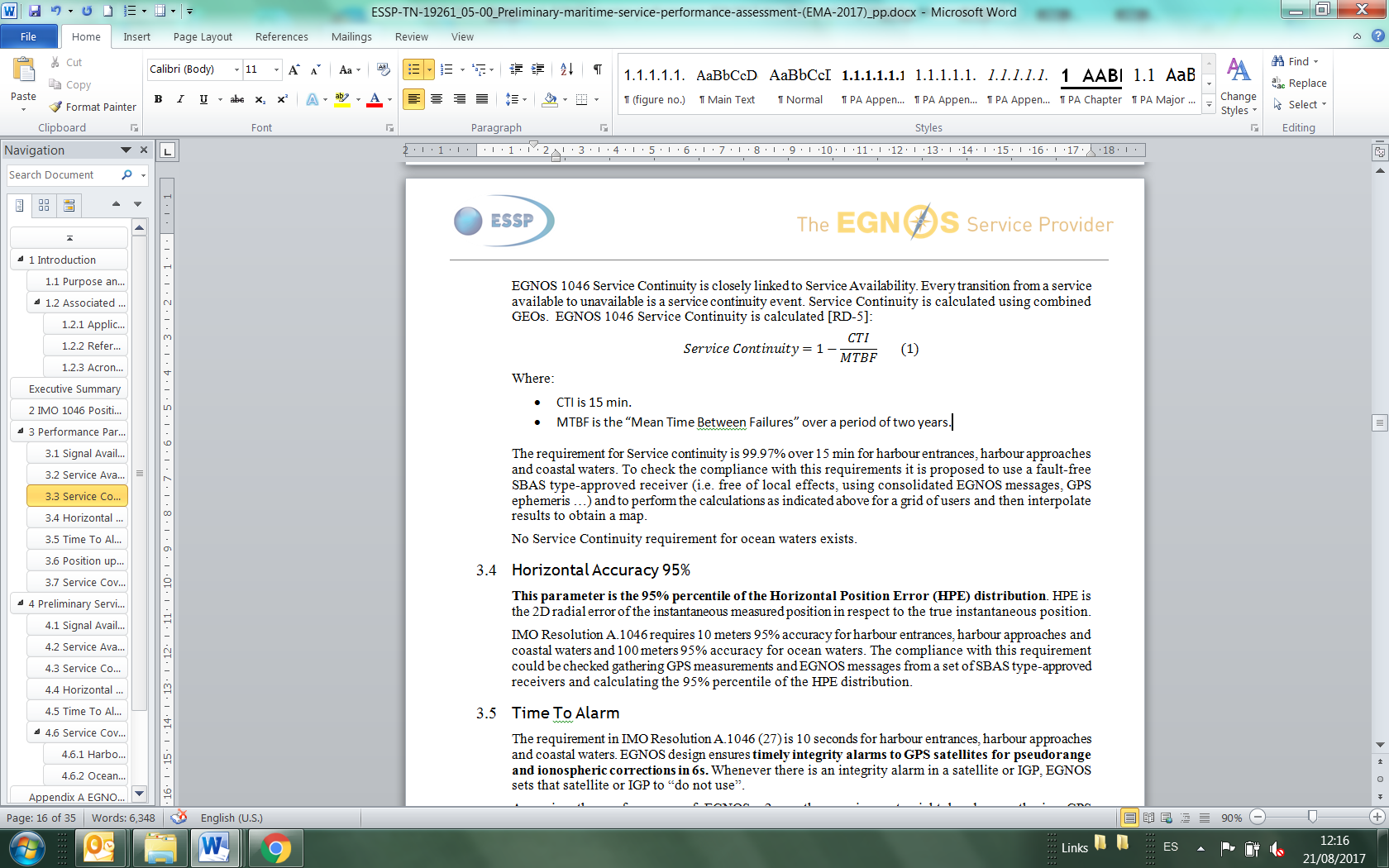
13

1. EGNOS 1046 Service Availability from May 2016 to June 2018

Performance was calculated in a grid of points (2x2 degree) and interpolated to get maps from the grid.

1. Service Continuity

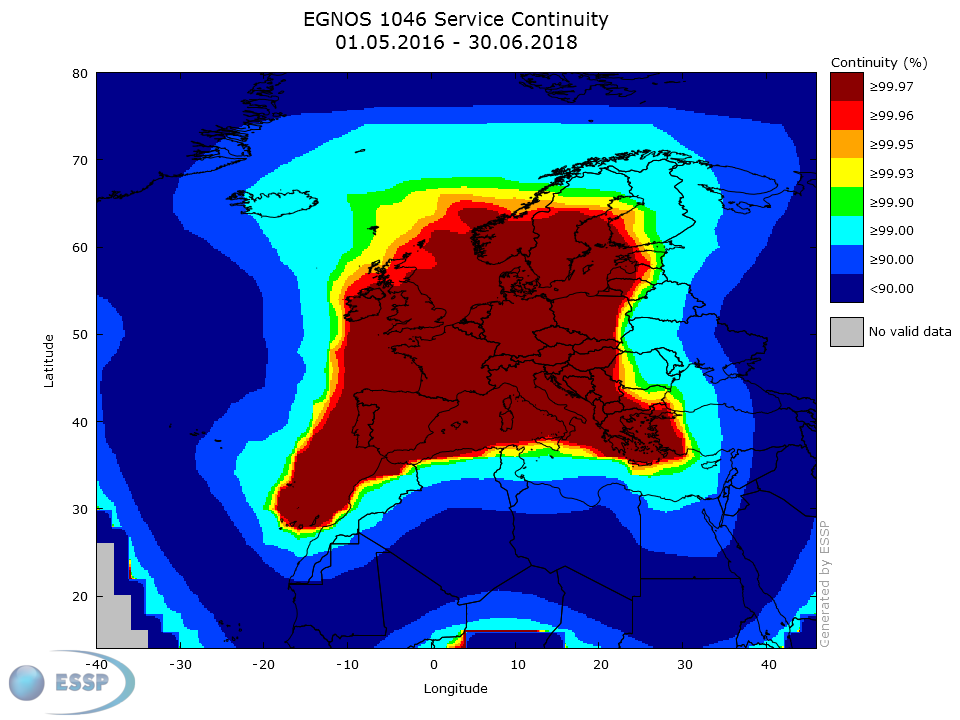
*The Service continuity is the probability that a lack of position-fixing event will start during the Continuity Time Interval (CTI), which is defined to be 15 min [12]*. EGNOS 1046 Service Continuity is closely linked to Service Availability. Every transition from a service available to unavailable is a service continuity event. Service Continuity is calculated using combined GEOs. Next equation (equation 1) shows how EGNOS 1046 Service Continuity is calculated [12]:



1. Service continuity

Where CTI is 15 min and MTBF is the “Mean Time Between Failures”, as measured by the service provider [12] (e.g. over two years). The 99.97% over 15min requirement is a challenging requirement. EGNOS shall present on average only one Service Continuity event per month.

EGNOS SiS monitoring from May 2016 to June 2018, reports the following percentages of Service Continuity for “harbour entrances, harbour approaches and coastal waters” surrounding Europe. Note there is no IMO continuity requirement for “ocean waters” (Figure 5):



1. EGNOS 1046 Service Continuity from May 2016 to June 2018

The reduced area meeting the Service Continuity IMO requirement (99.97% over 15min) over some areas is due to events that affected EGNOS navigation solution either on a major or whole part of the service area; e.g. in September 2016 (e.g. 25/09, 26/09) impacted the coverage in the North and several cases were observed during last months of 2017 and first months of 2018 impacting the west and north of United Kingdom.

1. Position Update Rate

EGNOS 1046 receivers must be designed to meet the 2 seconds update rate required by IMO Resolution A.1046 (27). The compliance to this parameter shall be demonstrated by the receiver/equipment manufacturers. EGNOS 1046 receivers using a subset of RTCA [4] messages broadcast by EGNOS, are expected to be capable of an update rate of 1 second of the computed position.

1. Time To Alarm

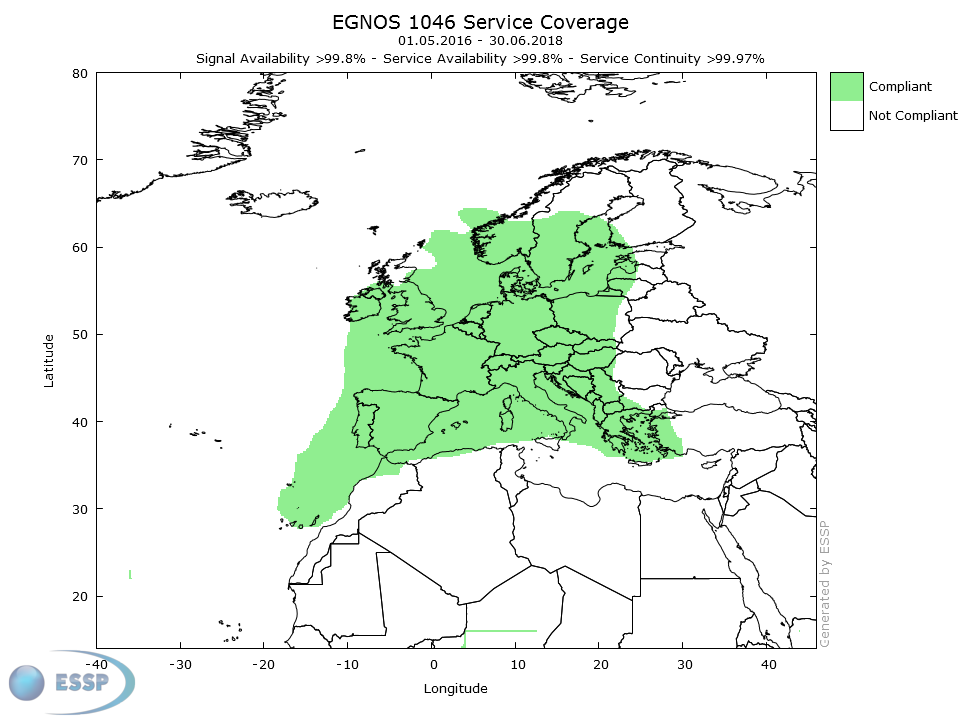
The requirement in IMO Resolution A.1046 (27) is 10 seconds for “harbour entrances, harbour approaches and coastal waters”. EGNOS design ensures timely integrity alarms to GPS satellites for pseudorange and ionospheric corrections in 6 seconds. Whenever there is an integrity alarm in a satellite or IGP, EGNOS sets that satellite or IGP to “do not use”. No Time to Alarm requirement for “ocean waters” is set on EGNOS 1046.

Declared operational for Safety of Life in 2011, EGNOS reacts to GPS anomalies sending alarms linked to its GPS pseudorange and ionospheric corrections in less than 6 seconds. Since operational, EGNOS has successfully responded to GPS satellites and ionosphere anomalies sending timely alerts within the Time to Alarm (TTA). EGNOS TTA response to events is monitored at pseudorange level by ESSP.

1. Service coverage

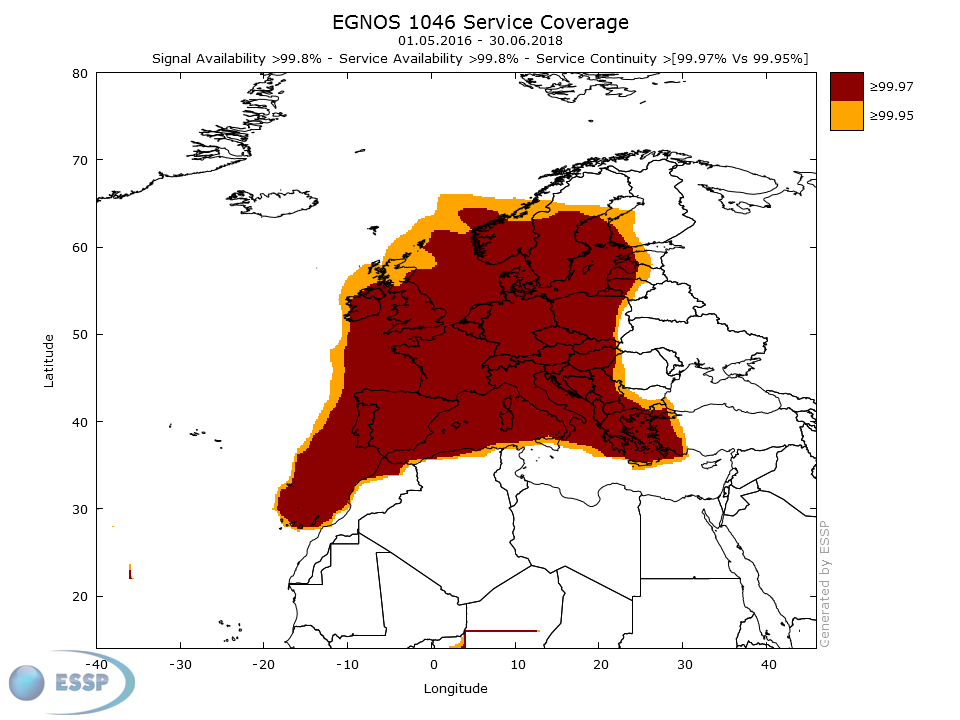
*The service coverage is a designated geographical area where, taking into account the radio frequency environment, EGNOS v2 is adequate to provide required performance throughout a phase of navigation*. By “adequate” it is understood that for a specific location EGNOS 1046 meets for “Ocean Waters”: the Horizontal Accuracy 95%, Signal Availability and Service Availability and for “Harbour entrances, Harbour approaches and coastal waters” the Horizontal Accuracy 95%, Signal Availability, Service Availability, Service Continuity and Time to Alarm.

For “harbour entrances, harbour approaches and coastal waters”, performance results on Signal Availability, Service Availability and Service Continuity showed in previous sections identify a geographical area where EGNOS V2 met IMO requirements. Horizontal accuracy 95% and Time to Alert were also met. In this area EGNOS was adequate to provide required performance throughout for the period from 1st May 2016 to 30th June 2018. The intersection of the different maps is the Service Coverage for “harbour entrances, harbour approaches and coastal waters” (Figure 6):

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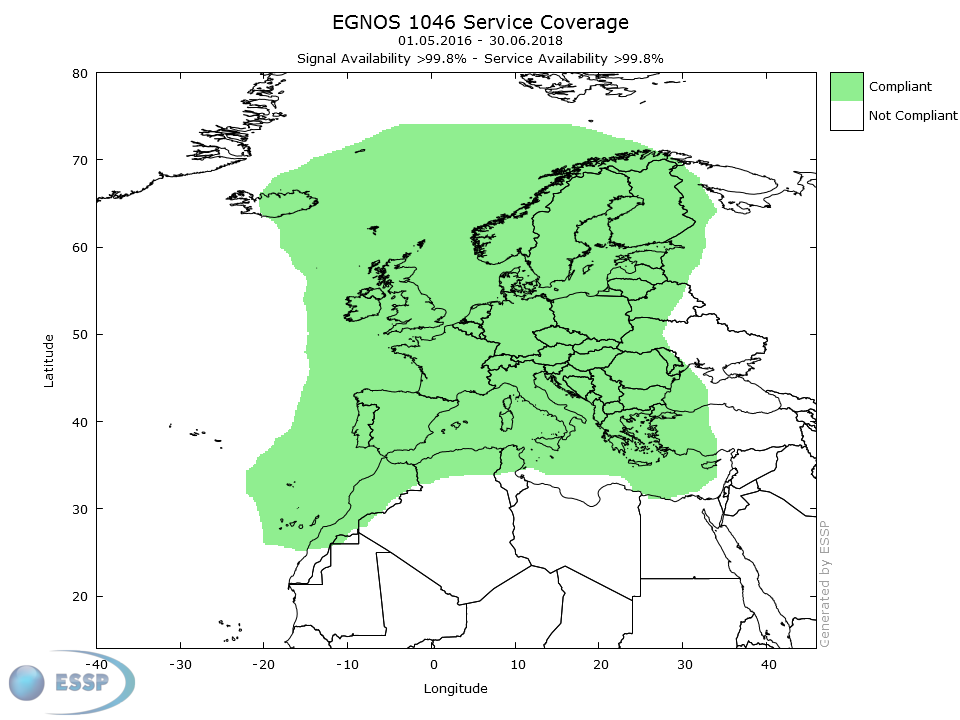
1. EGNOS 1046 Service Coverage for “harbour entrances, harbour approaches and coastal waters” from May 2016 to June 2018

Service Continuity (Figure 5) is the driver behind the Service Coverage results. In case that EGNOS would be used as a back-up for existing IALA DGNSS services, the continuity requirement could be relaxed from 99.97% to 99.95% following the logic of overlapping services described in IALA Guidelines 1112. Figure 7 shows the impact in the service coverage area depending on the continuity requirement.



1. EGNOS 1046 Service Coverage for harbour entrances, harbour approaches and coastal waters (with Service Continuity >99.97% vs. with Service Continuity >99.95%) for May 2016-June 2018 period

For “ocean waters”, performance results on Signal Availability and Service Availability showed in previous sections identify a geographical area where EGNOS V2 met IMO requirements. Horizontal accuracy 95% and Time to Alert were also met. In this area EGNOS was adequate to provide required performance throughout for the period from 1st May 2016 to 30th June 2018. The intersection of the different maps is the Service Coverage for “ocean waters” (Figure 8). Note that the green area represented is only valid for ocean waters and not for coastal waters although they are also represented for simplicity.

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1. EGNOS 1046 Service Coverage for “ocean waters” from May 2016 to June 2018

Service Coverage maps presented in this work are preliminary results. Taking into account several Service Continuity events arose during the period of analysis, both “harbour entrances, harbour approaches and coastal waters” the Service Coverage maps are considered sufficiently good.

1. SBAS Guidelines for Shipborne Receiver based on IMO Res. A.1046 (27): EGNOS PERFORMANCE ASSESSMENT IN NORWEGIAN COAST
2. INTRODUCTION

In the maritime sector, more than 80% of receiver models are SBAS compatible according to their specification. However, there are no guidance for the implementation SBAS system in maritime receivers, other than a sentence in IMO MSC.401 and in IEC 61108-4 allowing its use.

In the scope of the maritime regulatory framework, the International Maritime Organisation (IMO) published the IMO resolution A.1046(27) [2], which establishes the requirements that a certain radionavigation system shall fulfil to be recognized by IMO as a component of the Worldwide Radionavigation Systems. This means that the system is recognized to be able to provide adequate position information within its service area and that the carriage of receiving equipment for use with the system satisfies the relevant requirements of the 1974 SOLAS Convention. In addition, the International Maritime Organisation (IMO) developed a number of performance standards covering other GNSS algorithms than SBAS, such as GPS [5] and DGPS [6]. Accordingly the International Electrotechnical Commission (IEC) produced several test specifications to accompany these IMO performance standards, which are covered in the IEC 61108 [9], named *"Maritime navigation and radiocommunication equipment and systems - Global navigation satellite systems (GNSS)".* For example IEC 61108-1 refers to GPS and IEC 61108-4 to DGPS/DGLONASS. Although IEC 61108-4 allows the use of SBAS, there is no guidance for its implementation.

EGNOS meets the accuracy and availability requirements for general maritime navigation established in the IMO resolution A.1046 (27) [2] and EGNOS provides integrity, which can be suitable for safety critical applications in the maritime sector. Because of that, EC (EGNOS owner), GSA (EGNOS Services Programme Manager), ESA (EGNOS design agency) and ESSP (EGNOS service provider) are working in close collaboration to support the standardisation of SBAS in maritime receivers.

Firstly, a guidelines document for manufacturers for the development of SBAS receivers for the maritime domain ([1]) has been presented and discussed at RTCM. These guidelines, together with a set of test specifications, were developed in the frame of the SBAS Working Group created in the Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS) of Radio Technical Commission for Maritime Services (RTCM). This document presents recommendations on the set of SBAS messages to be processed by an SBAS receiver for the maritime sector to be compliant with the International Maritime Organization (IMO) Resolution A.1046 (27) [2]. The way messages should be processed as well as the system alerts applicable to comply with the requirements in [2] are also explained. It also includes the tests specifications to be passed. A summary of these guidelines will be presented in this paper.

Secondly, GSA and ESSP, with the collaboration of The Norwegian Coastal Administration and Hurtigruten Cruises, have carried out a GNSS data collection campaign of 10 days and 9 nights along the Norwegian coast with the aim of assessing EGNOS performance at user level in the maritime domain at high latitudes in Europe. SBAS performance results of this data campaign will be presented to show the added value of EGNOS in maritime applications. A SBAS compatible receiver and a Software Receiver (both compliant with the developed SBAS guidelines) will be used to analyse the performance results in terms of accuracy and availability.

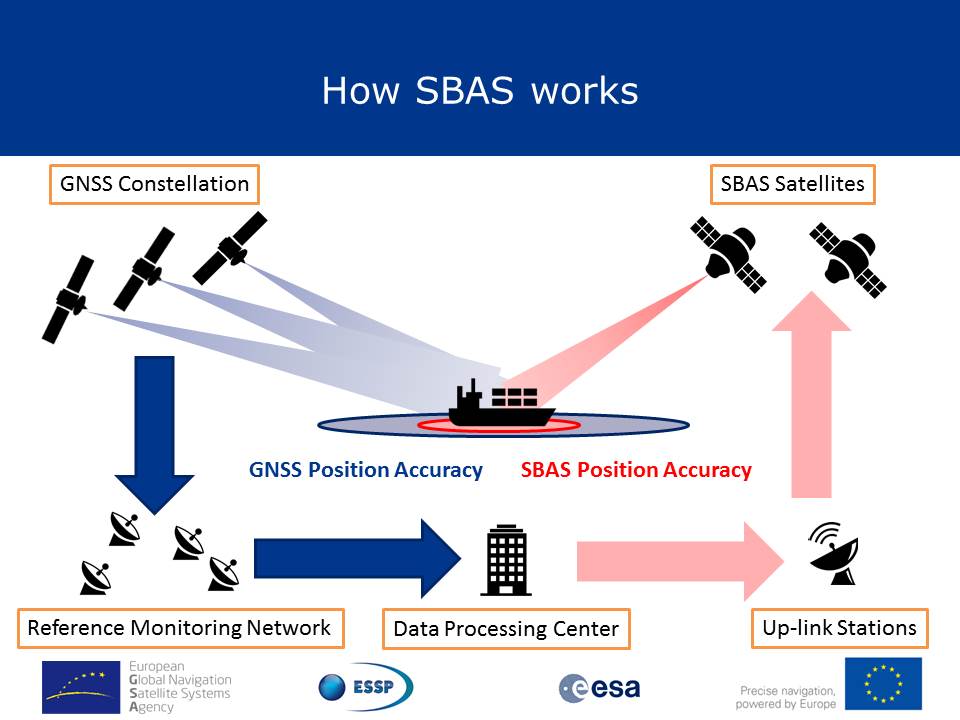
Finally, the performances obtained with the receiver will be compared with the requirements of the IMO Resolution A.1046 (27) [2] to demonstrate the feasibility of EGNOS for some maritime applications. This resolution is particularly important as it states the minimum operational requirements that the maritime community requires from any navigation system in order to be accepted.

The work presented in this paper, which gathers the SBAS guidelines document and the SBAS performance results obtained in this Norway data campaign, are intended to support the integration of SBAS in the standardization process for maritime navigation and radiocommunication equipment and systems (IEC 61108, [9]).

1. SBAS Guidelines

EGNOS is the Satellite Based Augmentation System (SBAS) over Europe. EGNOS enhances the GPS navigation solution by broadcasting additional signals from geostationary (GEO) satellites. As shown in Figure 8, the architecture consists of a set of reference monitoring stations (at very well-known position) to receive GNSS constellation signals that will be processed in data processing centres to obtain some estimations of these errors that are also applicable to the users (i.e. ionospheric errors, satellite position/clock errors, etc.). Once these estimations have been computed, they are transmitted in the form of “differential corrections” by means of at least two SBAS Geostationary satellites, which covers Europe.

In consequence, vessels can receive these SBAS corrections from SBAS GEO satellites and apply them in order to obtain an enhanced navigation position with respect to GPS standalone. In addition, vessels could get advantage of the Integrity provided by SBAS, which warn users when there is an alert or issue in the system that could impact the positioning error.



1. EGNOS architecture

EGNOS corrections are composed of a number of different Message Types (MT). The format and detailed information on the content and their use for SBAS certified receivers for aviation are given in ICAO SARPs [3] and RTCA SBAS MOPS [4].

Among those SBAS messages, the SBAS guidelines [1] document proposes the use of the following Message Types to fulfil IMO Res A.1046 (27) [2] performance requirements using the SBAS SiS corrections and integrity data:

* Decode and apply fast corrections information broadcast through **Message Types 2** to **5** and **24** corresponding to satellites selected by **Message Type 1**.
* Decode and apply long-term satellite error corrections broadcast though **Message Types 24** and **25**.
* Decode and apply ionospheric corrections if available broadcast through **Message Type 26** for ionospheric grid points defined by **Message Type 18**.
* Apply tropospheric error corrections.
* Consider major warnings broadcast by the SBAS system:
  + Satellite alerts in **Message Types 2** to **6 and** **24**,
  + Ionospheric alerts in **Message Type** **26**.
* Use the augmentation satellite ranging function if available broadcast through **Message Type 9**.

Additionally, an SBAS receiver should also process the following information in order to be compliant with IMO Res A.1046 (27) [2] performance requirements:

* Information on the availability of the IMO Resolution A.1046 (27) [2] compliant service broadcast by the system through **Message Type 0**.
* Time-out intervals for the validity of the messages as defined below. **Message Type 7** contains information for computing the timeout interval for fast corrections.
* Almanac data from SBAS satellites broadcast through **Message Type 17**.

Once all corrections have been considered, the equipment shall compute its three-dimensional position, velocity and time (PVT) using a linearized, weighted least-squares solution as defined in [1] and [4].

Moreover, the SBAS guidelines [1] also includes the tests that SBAS maritime receiver manufacturers can perform to verify that the receiver is complaint with the requirements at system level, with the Signal-In-Space RF characteristics and with the SBAS messages processing indicated in that document [1].

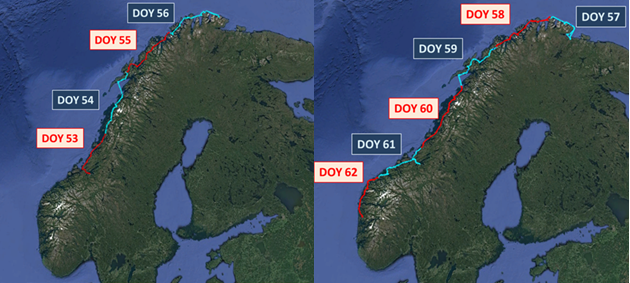
For detailed information on the added value of the specific messages recommended, on the particularities of the way SBAS messages shall be processed and its interrelations, please refer to the SBAS Guidelines document [1].

1. Data Campaign
   1. Description

In order to assess the EGNOS performance at user level in the maritime domain at high latitudes in Europe, a data campaign was carried out along the Norwegian Coast between the 22nd of February and the 3rd of March, 2018.

The vessel, MS Finnmarken (more information in <https://www.hurtigruten.co.uk/our-ships/ms-finnmarken>), departed from Trondheim on the 22nd of February (DOY 53) and arrived to Kirkenes on the 26th (DOY 57); then, departed again from Kirkenes on the 26th and arrived to Bergen on the 3rd of March (DOY 62).

Figure 9 shows the route followed by the vessel along the mission.



1. Data collection geographical path

For the data collection, the following equipment was used:

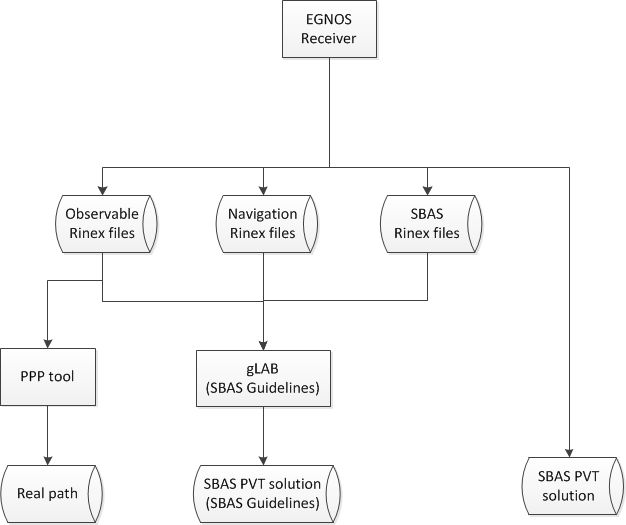
* GNSS Dual-frequency Receiver with the following characteristics:
  + GPS/GLONASS L1/L2
  + SBAS
* GNSS Antenna.
* L1 RF Recorder (Labsat 3).
* Coaxial cable RG214 (25 m).
* Splitter 1 In SMA – 2 Out SMA.

The position of the GNSS antenna installed in the MS Finnmarken vessel is showed in Figure 10.



1. Antenna position in MS Finnmarken
   1. Methodology

The EGNOS receiver installed in the vessel directly reported the PVT solution based on EGNOS. Additionally, this receiver provided dual frequency observations which were injected offline to Precise Point Positioning (PPP) algorithms in order to compute the precise position of the vessel at any time. Besides, these dual frequency observations were also injected in the Software receiver, gLAB [8], to compute the EGNOS performance in line with the Guidelines for Manufacturers for the Implementation of SBAS in Shipborne Receivers ([1]). It is noted that gLAB was developed following the SBAS guidelines and that it passed the test specification provided in those guidelines [1]. A schema of the followed process is showed in Figure 11.



1. Data process scheme

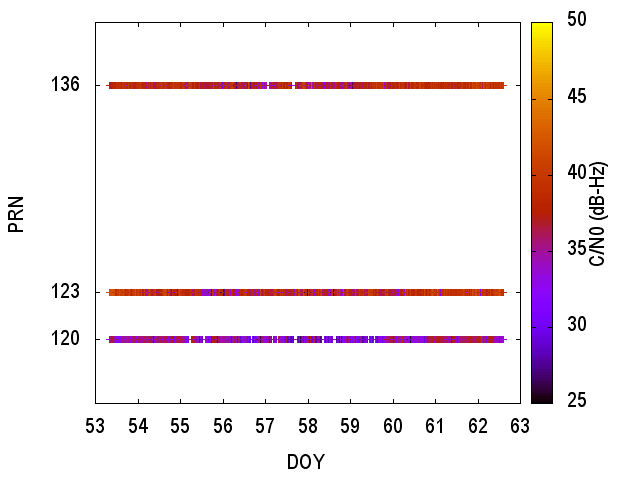
Finally, the L1 RF data recorded by Labsat 3 was injected in a GPS standalone receiver to obtain the GPS standalone PVT solution. The aim of that was to provide a comparison between GPS and EGNOS performance in that region.

* 1. Performance results

In this section the comparison between the PVT solutions obtained using the data sets indicated in the previous section are provided.

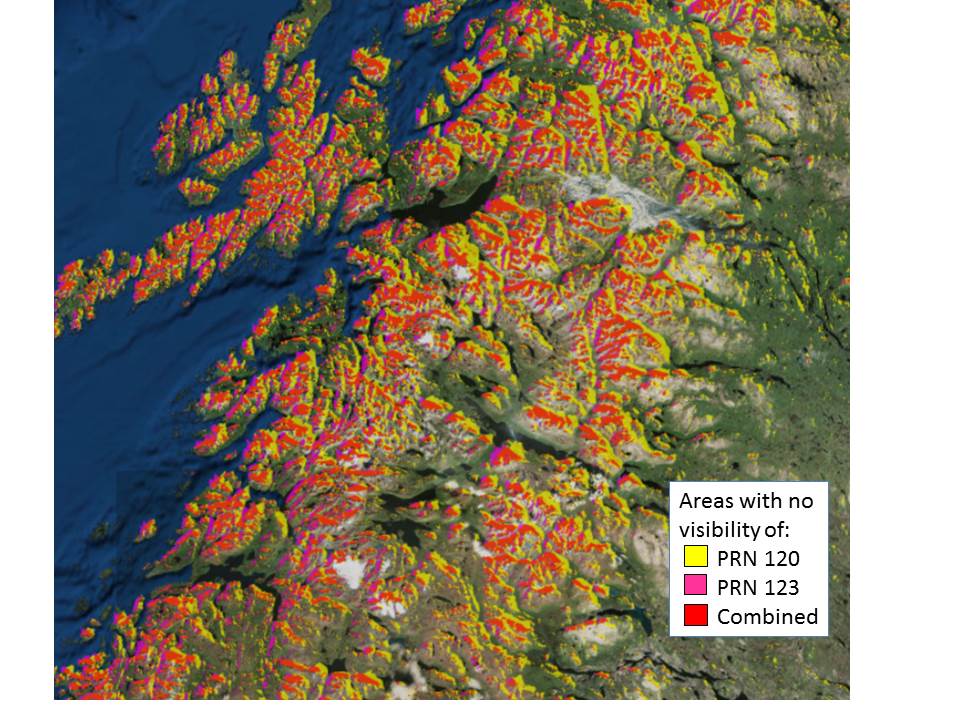
Firstly, the EGNOS signal availability is checked. This performance is computed using system data by the EGNOS Service Provider. The EGNOS monitoring information shows that the **EGNOS signal in space (SIS) availability was 100%** during the data campaign period.

The strength of the EGNOS signal along the route is also checked. Figure 12 shows the temporal evolution of the carrier-to-noise ratio (C/N0) values for the three EGNOS GEO satellites. During the data collection, PRN 120 and 123 were operational, whereas PRN 136 was set in test mode. The analysis depicts that PRN 123 and PRN 136 signal were received with a high strength. PRN 120 was received with lower C/N0 especially during the days that the vessel was in the North of Norway (doy from 55 to 59), because it was observed from low elevations, i.e. in the border of the PRN 120 coverage area.



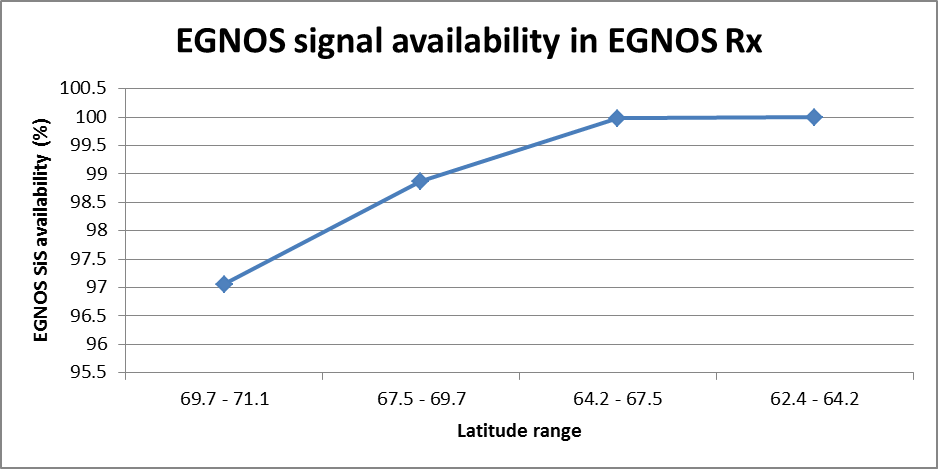
1. Strength of all EGNOS GEO signals.

Although the EGNOS SIS availability was 100%, some data gaps were detected, that is, lack of EGNOS signal tracking by the receiver, linked to the orography of the region, not to the EGNOS system. The EGNOS user support website (https://egnos-user-support.essp-sas.eu/new\_egnos\_ops/resources-tools/egnos-visibility-maps) shows the areas over Europe where there is no visibility of one or both EGNOS operational geostationary satellites (PRN 120 and PRN 123 by the time of the data campaign). In Figure 13 an example of this EGNOS Geostationary satellites visibility map is presented, covering longitudes from 13 to 20 degrees East and latitudes from 67 to 69 degrees North. As you can see, there are some areas close to mountains or fiords in which a GEO satellite could not be observed.



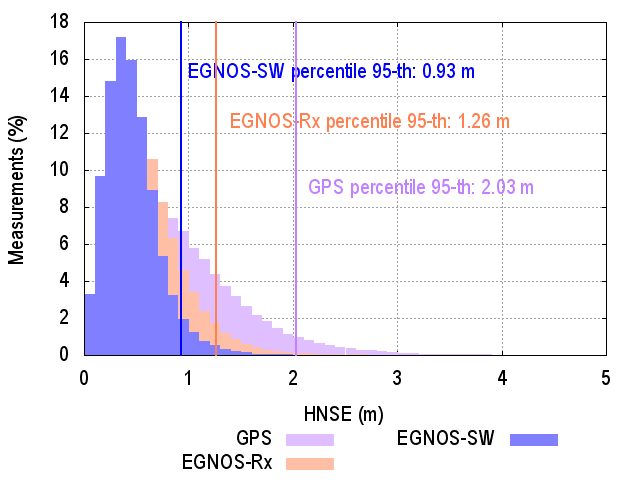
1. EGNOS GEO satellites visibility map

The impact of the orography in the availability of the EGNOS signal received by the receiver is greater according to the elevation angle of the SBAS Geo satellite. Figure 14 depicts the EGNOS signal availability in the EGNOS receiver as function of the latitude. This figure confirms that the impact of the orography is greater according the latitude is increasing (or the SBAS Geo satellite elevation angle decreased).



1. EGNOS signal in space availability in function of latitude obtained from EGNOS Rx.

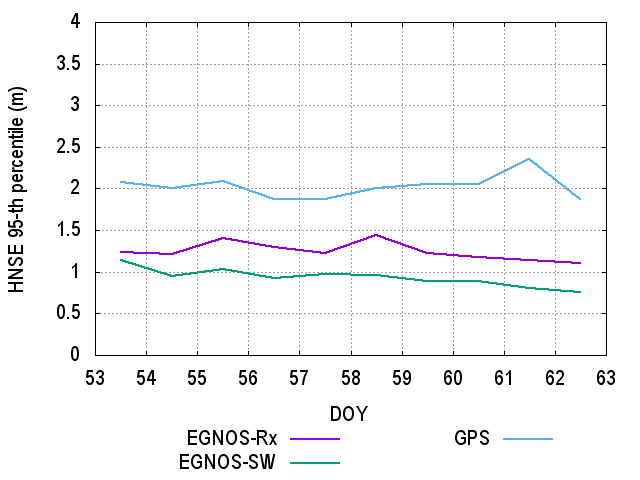
Finally the accuracy of the computed solution is evaluated. The Horizontal Navigation Solution Error (HNSE) is defined as the 2D radial error of the GNSS estimated position (PVT solution provided by the receiver) with respect to the actual position (Position solution provided by PPP algorithms) of the vessel. The HNSE histogram is computed for the EGNOS receiver (blue), the EGNOS software receiver (coral) and the GPS standalone receiver (purple) and presented in Figure 15.



1. HNSE histogram and 95-th percentile values.

This figure shows that EGNOS software receiver (gLAB) presents the lowest horizontal navigations system errors and a HNSE 95-th percentile of 0.93 m, which are better than the ones provided by GPS standalone solution. The EGNOS receiver also presents enhanced position solution with respect to GPS and a 95% percentile of 1.26 m. Finally, the GPS standalone receiver presents the worst accuracy values and, consequently, the greatest HNSE 95-th percentile with a 2.03 m value. As expected, these results confirm that EGNOS provides better accuracy performance than GPS standalone receiver.

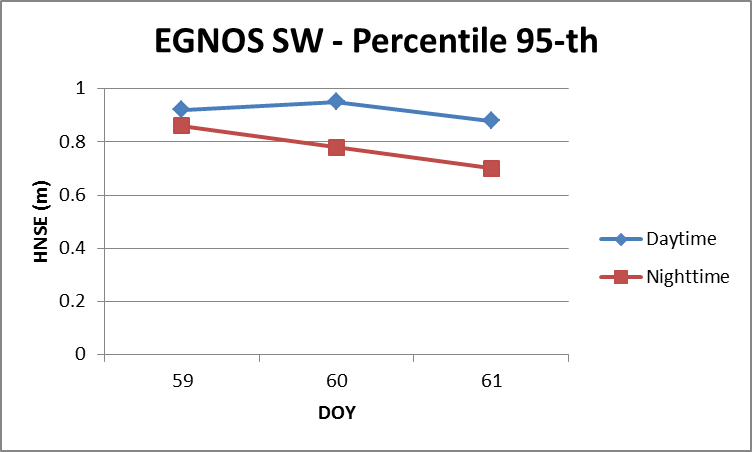
Figure 16 shows the daily HNSE 95-th percentile values obtained for the EGNOS receiver (purple line), gLAB – EGNOS software receiver - (green line) and GPS standalone receiver (blue line).



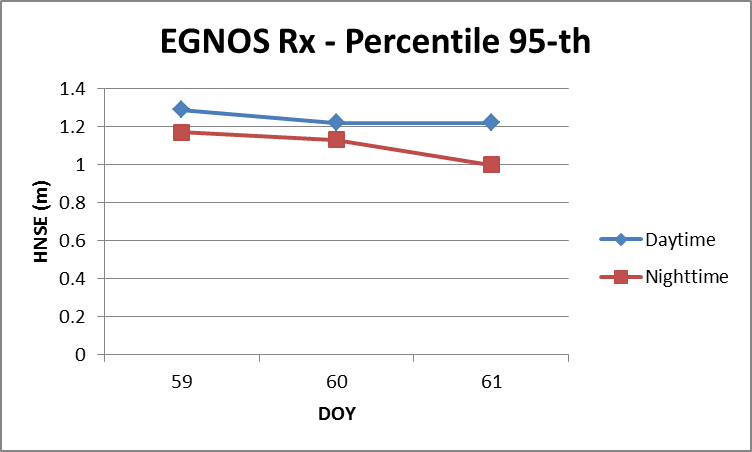
1. HNSE 95-th percentile values obtained using EGNOS and using GPS standalone.

The daily HNSE 95-th percentile values showed above confirm that EGNOS software receiver (gLAB) provides the best (the lowest HNSE values) accuracy performances with values about 1 m. It is remarked that this software receiver is aligned with the SBAS guidelines [1]. It is also observed that the EGNOS receiver provides a very good HNSE 95-th percentile values, about 1.2 m, slightly greater than those obtained from EGNOS SW receiver. Considering that gLAB is a Software tool in post-processing, it does not have time processing restrictions like the real-time receiver. In addition, other algorithms considerations (such as smoothing filter using phase, Kalman filter, least squares applicability, dynamic conditions configuration, EGNOS message type processing …) could provide slightly different position results. As expected, the GPS standalone receiver provides the worst HNSE 95-th percentile values, almost always greater than 2 m. These values show that the receiver that used EGNOS provides a more accurate position during the whole period evaluated that the receiver GPS standalone.

In [11], it is analysed the availability and continuity of DGNS service in the UK coast. This paper presents different behaviour of DGNSS availability and continuity performances during daytime and night-time. Hereafter, a similar analysis is done. Figure 17 and Figure 18 compare the HNSE percentile-95 values obtained during the daytime and the night-time for DOY 59, 60 and 61 with the EGNOS SW and EGNOS Rx, respectively. Both cases present the same behaviour: HNSE percentile-95 values are greater for the daytime than for the night-time, which means that accuracy performances are “degraded” during daytime. That degradation can be linked to the atmospheric delay than impact to GNSS observations as ionospheric behaviour is more quite during night-time than daytime.

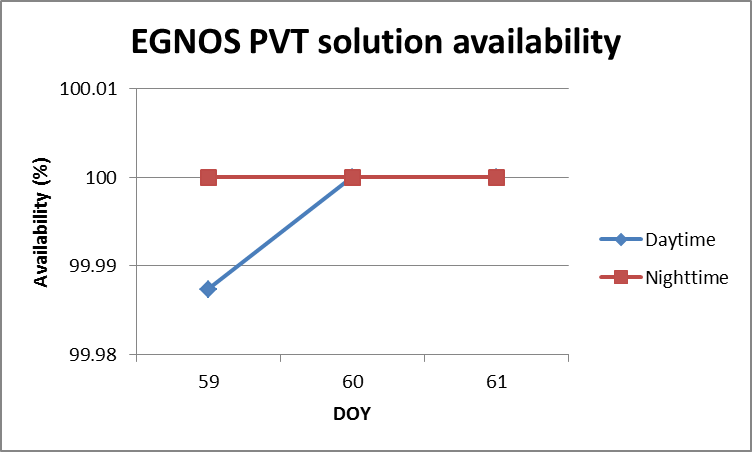


1. Comparison of HNSE 95-th percentile daytime and night-time values obtained from EGNOS SW.



1. Comparison of HNSE 95-th percentile daytime and night-time values obtained from EGNOS Rx.

Regarding to the availability, Figure 19 shows the EGNOS PVT solution availability obtained from days 59, 60 and 61 during daytime and night-time. This availability is defined as the number of epochs when the EGNOS Rx provided PVT solution using EGNOS divide by the number of epochs of the period selected (daytime and night-time). From this figure can be observed that EGNOS provides the same performance during daytime and night-time, although a slight degradation of the PVT solution availability is observed during daytime of DAY 59.



1. Comparison of EGNOS PVT availability daytime and night-time values obtained from EGNOS Rx.
2. Conclusions

A summary of the document providing guidelines to receiver manufacturers for the development of SBAS receivers in compliance with the International Maritime Organization (IMO) Resolution A.1046 (27) [2] have been presented. A software receiver has been developed that implements the proposal in [1] to confirm that the expected performance requirements are satisfied.

* The EGNOS monitoring information shows that the **EGNOS signal in space availability** was 100% during the data campaign period. But it should be noted that some data gaps were detected, that is, lack of EGNOS signal tracking by the receiver, linked to the orography of the region, not to the EGNOS system.
* As expected, it is also demonstrated that EGNOS provides **better accuracy** performance than GPS Standalone, including outside the EGNOS Service Area defined in Message Type 27. Accuracy figures are degraded between 30% and 50% in GPS standalone.
* EGNOS presents the similar behaviour along the whole day, even given the best performances (accuracy and availability) during night-time. That improves DGNSS performances and can justify the use of EGNOS as DGNSS backup system.
* Additionally to this better accuracy performance, **EGNOS provides integrity i** as added value to the PVT solution with regards to the use of GPS Standalone. That added value (integrity) allows the use of EGNOS for some operation that GPS Standalone cannot be used.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Input papers should be assigned to a work task as listed in the Committee work plan which is available in input papers. Leave open if uncertain but consider how the paper is to be processed if not relevant to a work task [↑](#footnote-ref-2)