An independent validation of the EGNOS Availability, Continuity, and Coverage for Maritime Navigation
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1 SUMMARY

This study assesses the potential use of the European Geostationary Navigation Overlay System (EGNOS) for maritime application compliant with the requirements established by the International Maritime Organization (IMO) in its Resolution A.1046 (27) [1]. In particular, we used the most demanding requirements in harbour entrances, harbour approaches and coastal waters: 99.8% of Signal Availability, 99.8% of Service Availability and 99.7% of Service Continuity assuming 15 minutes as mean time between failures (MTBF). The data campaign lasted from 01/05/2016 to 30/06/2018 and the results obtained provide an independent validation of the EGNOS Availability, Continuity, and Coverage assessment [2] already presented by the European Satellite Services Provider (ESSP) in EN8.

1.1 Purpose of the document

The present contribution shows the compliance of EGNOS with the operational requirements established by the IMO resolution A.1046(27) in a geographic region defined between longitudes -25°W to 37°E and latitudes 25°N to 77°N. The outcome of the study reassures previous Availability, Continuity, and Coverage maps provided by ESSP. The EGNOS Maritime Service met the IMO requirement of Availability, Continuity and Coverage in 67.52%, 34.83%, and 34.37% respectively of the above predefined region, which covers coastal and ocean waters. Besides, the EGNOS signal availability was 99.999%, meeting also the IMO requirement.

2 BACKGROUND

The Global Navigation Satellite System (GNSS) has improved the efficiency and accuracy of transportation means. In terms of safety, the European Geostationary Navigation Overlay System (EGNOS) is providing vertical and lateral guidance to civil aviation since 2011.

The aim of the present study is to assess the potential use of EGNOS for maritime navigation. In particular, to analyse the compliance of EGNOS against the IMO requirements in “harbour entrances, harbour approaches and coastal waters”, as they are more challenging to meet than the “ocean waters”. In particular, the requirement of the Service Continuity is only required for coastal waters.

3 DATA SET

We gathered GPS broadcast navigation files and EGNOS messages from public web servers for the period comprised from 1st May 2016 to 30th June 2018 (i.e., 791 days). In particular, the GPS RINEX navigation files have been download from the International GNSS Service [4], whereas EGNOS differential corrections have been download from the SERENAD Data Server that belongs to National Centre for Space Studies (CNES). In the period three different Pseudo Random Number (PRN) satellites (PRN120, PRN123 and PRN136) broadcast EGNOS corrections through the footprint depicted in Figure 1.

Note that EGNOS performance maps (Signal and Service Availability, Service Continuity and Service Coverage) are based only in the satellite geometry and the availability of differential corrections. Thence, they are computed using only the GPS ephemeris and EGNOS messages, i.e. without needing ranging measurements collected by receivers.
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**Figure 1** Footprint of the operational EGNOS GEOs.

4 METHODOLOGY

The first step of the study was to cleanse the navigation RINEX files following the methodology described in [3], which consists of removing potential errors and inconsistencies from different sources. For instance, data-login errors due to accidental bad receiver data and/or hardware/software bugs, losses of navigation messages, different transmission time, among others. In contrast, the EGNOS files are already consolidated by CNES and did not require further processing.

The second step consists in the evaluation of the Availability, Continuity and Service Coverage (defined as the combined map where both availability and continuity requirements are met). The availability and continuity parameters have been computed following a fault-free receiver approach, in which it is assumed a continuous signal tracking, without cycle-slips, all GPS navigation data and EGNOS corrections available, and no environmental effects.

We have used the ESA/UPC GNSS laboratory (gLAB) tool suite [5] for the computations. In particular, a new version of gLAB has been produced with the updates required to perform the present EGNOS maritime study. Note that the gLAB software is completely independent to the EGNOS Continuous Logging Analyser (ECLAYR) software used by ESSP in [2]. The configuration used in gLAB is the following:

- Elevation mask of 7.5 degrees.
- Disabling of Message Types 10, 27, 28.
- Alarm Limits based on EGNOS protection Levels have been disabled by taking HAL=VAL=100 km.
- Instead, a filtering criterion based on the Dilution of Precision (DOP) is applied, in order to ensure that the position information can be reliably used for navigation purpose. Epochs with satellite geometries with PDOP≥ 6 and HDOP ≥4 are excluded. Hereafter named DOP mask.

5 RESULTS

The present section presents a comparative assessment between the Availability, Continuity and Service Coverage maps of the EGNOS Maritime Service computed by ESSP and UPC. The performance results are crosschecked for the same time interval, i.e. 1 May 2016 to 30 June 2018.

The analysis of such three parameters follows the same systematic way. First, we depict the results of the continental map using ECLAYR and gLAB softwares, using the most appropriate scale. That is, for the availability map we use the range from 70% to 99.8%, whereas for the continuity map we use the range from 90% to 99.7%. Then, it is depicted the compliance with the corresponding requirement in a binary basis (compliant or not compliant).
5.1 Service Availability

Figure 2 depicts the Service Availability maps computed over the whole period, from 1 May 2016 to 30 June 2018. The top panel depicts the results computed by ESSP using the ECLAYR software, whereas the bottom panel depicts the results computed by UPC using the gLAB tool. Both methodologies present a good level of agreement in the shape and distribution of the availability.

Minor discrepancies can be observed in regions where availability gradients occur, for instance, in coordinates (-20°W, 50°N) or (35°E, 60°N). The reason explaining this different behaviour is the grid resolution used in both analyses. ESSP uses pixels of size 2° per 2° and later interpolates to get a grid of 1° per 1°, whereas UPC uses a finer resolution of 1° per 1° without interpolation.

![Service Availability maps](image)

**Figure 2** Service Availability map computed by ESSP (top) and UPC (bottom) without the DOP mask activated. The same GEOs 120, 123 or 136 are used.
Figure 3 depicts the compliance of the Service Availability maps with the most demanding requirements in harbour entrances, harbour approaches and coastal waters: 99.8% of Signal Availability. Both methodologies present an almost coincident level of agreement in the shape and distribution of the availability compliance. This occurs as in the map, we only take the highest bin of previous Figure 2, neglecting the gradients occurring at lower levels of availability.

UPC maps include a numerical evaluation inside the geographic region defined by longitudes -25°W to 37°E and latitudes 25°N to 77°N. Obviously, the use of a more refined areas (e.g., waters within 12 nautical miles of the coast) would lead to different percentage results. Irrespectively of the area chosen, Figure 3 shows that the most stringent IMO requirements in terms of availability in coastal waters are met in the majority (68%) of the continental area. In both independent assessments, only the west extreme of Iceland and Libyan waters are partially covered.

![Service Availability over 99.8% map computed by ESSP (top) and UPC (bottom) without the DOP mask activated. The same GEOs 120, 123 or 136 are used.](image)
5.2 Service Continuity

Figure 4 depicts the Service Continuity maps computed over the whole period, from 1 May 2016 to 30 June 2018. The top panel depicts the results computed by ESSP using the ECLAYR software, whereas the bottom panel depicts the results computed by UPC using the gLAB tool. Both methodologies present a good level of agreement in the shape and distribution of the continuity.

Minor discrepancies can be observed in regions where continuity gradients occur, for instance, in coordinates (0°E, 60°N) or (25°E, 65°N). A reason explaining this different behaviour could be the same as in the availability assessment: the grid resolution used in both analyses. ESSP uses pixels of size 2° per 2° and later interpolates to get a grid of 1° per 1°, whereas UPC uses a finer resolution of 1° per 1° without interpolation. Nevertheless, the larger discrepancy is found in this case should deserve a devoted analysis.

Figure 4  Service Continuity map computed assuming a Fixed Window with 15 min of CTI [AD.2]. ESSP map at top map and UPC map at bottom without the DOP mask activated. The same GEOs 120, 123 or 136 are used.
Figure 5 depicts the compliance of the Service Continuity maps with the most demanding requirements in harbour entrances, harbour approaches and coastal waters: 99.7% of Service Continuity. As in the availability analysis, Figure 5 neglects the gradients occurring at lower levels of continuity. This emphasises the previously observed differences around (0°E, 60°N). In particular, in the northern part of Scotland and Ireland.

The previously referred numerical evaluation of UPC maps in Figure 5 show that the most stringent IMO requirements in terms of continuity in coastal waters are mostly met over land masses in the continental area (34.83%). In particular, Iceland and the waters south of Sicily do not meet the continuity requirement.

*Figure 5  EGNOS 1046 Service Continuity over 99.97% map computed assuming a Fixed Window with 15 min of MTBF. ESSP map at top map and UPC map at bottom without the DOP mask activated. The same GEOs 120, 123 or 136 are used.*
5.3 Service Coverage

Figure 6 depicts the compliance of the Service Coverage maps given by the intersection of the previous Service Availability and Service Continuity maps. That is, to simultaneously achieve a Service availability of 99.8% and Service Continuity of 99.7%. Thus, the previous comments and analysis on the Availability and Continuity hold true in the analysis of the Service coverage. It can be seen that the continuity risk is, by far, the most limiting factor for expanding the EGNOS Maritime Service Coverage along the coastal waters.

Figure 6  EGNOS 1046 Service Coverage for harbour entrances, harbour approaches and coastal waters (with >99.97% Service Continuity, computed assuming 15 minutes as MTBF). ESSP map at top map and UPC map at bottom without the DOP mask activated. The same GEOs 120, 123 or 136 are used.
6 CONCLUSIONS

The study has confirmed the area (Figure 6) where EGNOS is compliant with the availability and continuity requirements according to IMO resolution A.1046 and therefore is suitable for maritime navigation in coastal and oceanic waters. The study has taken into account real data along 26 consecutive months. It is important to note that from 12nm from the coast line (limit of the territorial waters) the continuity requirement is not needed to be fulfilled and that therefore the service area can be expanded towards the boundaries of the availability map (Figure 3). The main difference in the maps computed by gLAB with respect to those generated by ECLAYR is found in the continuity map and particularly in the area of Scotland, which in the refined analysis is inside of the service area (service continuity equal or larger than 99.97% over a period of 15 minutes). Further analysis is needed to clarify the root cause of this difference.

7 REFERENCES

[1] IMO Resolution A.1046(27), WORLDWIDE RADIONAVIGATION SYSTEM, Adopted on 30 November 2011

8 ACKNOWLEDGMENT

The authors acknowledge the use of data and products provided by the International GNSS Service. EGNOS messages are downloaded from SERENAD Data Server that belongs to National Centre for Space Studies (CNES).

9 ACTION REQUESTED TO THE COMMITTEE

The Committee is requested to:

1 Note the information provided in this paper in relation to the performances achieved with EGNOS in Europe and its suitability for maritime navigation.