EGNOS PERFORMANCE FOR MARITIME USERS

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1 Introduction

The European Tripartite Group (ETG), composed of the Commission of the European Union (CEU), the European Space Agency (ESA) and Eurocontrol, is implementing the European contribution to the Global Navigation Satellite System (GNSS-1) which will provide and guarantee navigation signals for aeronautical, maritime and land mobile trans-European transport network and other applications. This European contribution consists of the design and development of the EGNOS AOC (European Geostationary Navigation Overlay Service - Advanced Operational Capability) System. It is based on the use of the American Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS) complemented by the use of two INMARSAT III satellite navigation transponders through lease contracts and the ARTEMIS satellite developed by ESA. It is planned that EGNOS will be operational in 2003/4. A key characteristic of the EGNOS system is its *multi-modal* capability: the EGNOS system is based on a specific signal that allows many different classes of users to benefit from its signal-in-space.

Many of the early performance analyses have focussed on the potential of EGNOS to meet aviation requirements. This is because the aviation community is well organised with clear requirements, which have been driving the design of EGNOS. System designers have adopted the civil aviation recommended navigation performance (RNP) parameters (accuracy, integrity, availability, and continuity) because they are well defined mathematically and are ideal for performance simulations and analysis. As part of its multi-modal activity, however, one of the major tasks of the European Tripartite Group has been to gather requirements from other user-groups and to transform these into the RNP parameters. The European GNSS Maritime Advisory Forum (now the European Maritime Radionavigation Forum) was established by the European GNSS Secretariat in 1998. It has identified a large number of maritime applications and has transformed its requirements into the standard RNP format. The work performed by the European Maritime Radionavigation Forum has formed the basis of proposed revisions to International Maritime Organisation (IMO) Assembly Resolution A860(20), which specifies the maritime requirements for a future GNSS.

The aim of this paper is to identify the potential of EGNOS to meet maritime users' requirements as laid out in the proposed revision to Resolution A860(20). The paper considers the users' requirements in terms of the RNP parameters in Section 1, and these are presented as four generic cases. Section 1 describes the simulations that have been performed to assess the EGNOS service from a maritime perspective. Section 4 identifies service provision issues from the perspective of users equipped with either an EGNOS receiver or a more conventional GPS receiver. This includes an exploration of the potential for co-operation with terrestrial communications systems (e.g. marine radio beacons and Loran C/EUROFIX). Finally, the paper concludes by summarising the potential of EGNOS to meet users' requirements and what needs to be done to bring it to the operational environment.

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	GNSS System level parameters				Service level parameters			
	Predictable Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[2] (seconds)
	Horizontal (metres)	Alert limit (metres)	Time to alarm[2] (Seconds)	Integrity risk (per hour)				
Ocean	10	25	10	10^{-7}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-7}	99.8	N/A[1]	Global	1
Port approach and restricted waters	10	25	10	10^{-7}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-7}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-7}	99.8	99.97	Regional	1

Notes: 1: Continuity is not relevant to ocean and coastal navigation
2: More stringent requirements may be necessary for ships operating above 30 knots

Table 1 Minimum maritime performance requirements

2 Maritime user requirements

The recommended navigation performance (RNP) parameters applied in the maritime context are defined in the following way:

- Accuracy is defined[2] as the degree of conformance between the estimated or measured position and the true position of the user at a given level of confidence at any given instant in time and at any location in the coverage area. It is specified as the position error at 95% confidence level. There are several definitions of position accuracy, each depending on the particular application: *predictable* accuracy - the accuracy of the system's position solution with respect to the charted solution; *absolute* accuracy - the accuracy of a position with respect to the geographic or geodetic co-ordinates of the earth; *repeatable* accuracy - the accuracy with which a user can return to a position whose co-ordinates have been determined previously using uncorrelated measurements from the same navigation system; and *relative* accuracy - the accuracy to which a user can determine its position relative to another user of the same navigation system at the same time. This paper is generally concerned with absolute accuracy.

- Integrity is defined as the ability to provide users with warnings within a specified time when the system should not be used for navigation. This leads to a position-based approach to integrity monitoring where there are three key parameters: the alert limit (horizontal for most but not all maritime applications), the time to alarm, and the integrity risk.

- Availability is defined as the percentage of time that an aid or a system of aids is performing a required function under stated conditions. In this case it is the availability of a radio signal at a specified level in a specified coverage area.

- Continuity is defined as the probability that a user will be able to determine position with the specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within the coverage area. This definition assumes that the user is equipped with a fault-free receiver.

The proposed revision of resolution A.860(20) prepared by the European Maritime Radionavigation Forum submitted for discussion at the 46th Session of the IMO Sub-Committee on the Safety of Navigation (NAV 46) identifies applications whose requirements have been quantified, and partitions them into four generic categories (see Table 1). It should be clear the EGNOS will not meet the requirements summarised for port activities, and these are not considered further within this document.

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2 This definition is consistent with that used in Resolution A860(20) but the statistical, temporal and spatial nature of accuracy is emphasised. The definition is focussed on position as this is the most relevant parameter at this stage but acknowledges that it can be applied to other parameters

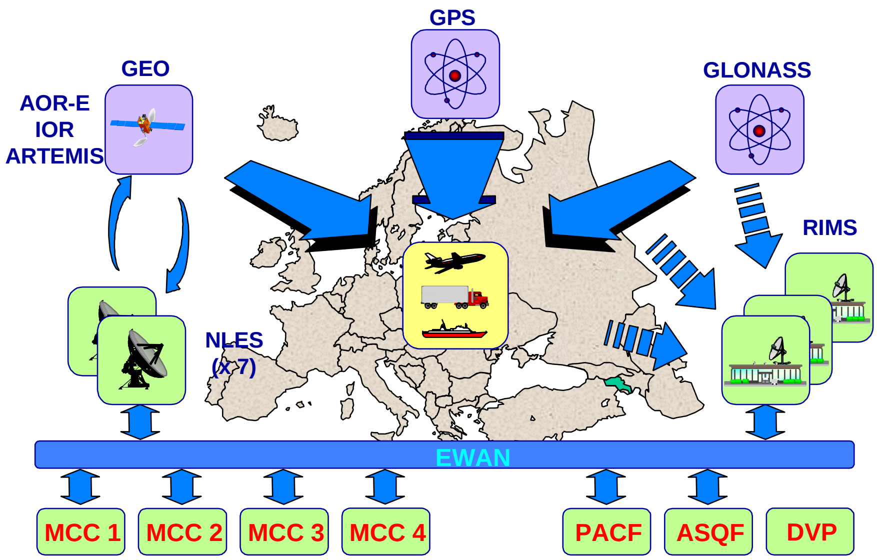

Figure 1 EGNOS AOC Architecture

3 The EGNOS service from a maritime perspective

3.1 EGNOS Overview

This section provides a summary description of the EGNOS AOC architecture [1]. The EGNOS Reference architecture is depicted in Figure 1. It is composed of four segments: ground segment, space segment, user segment and support facilities.

The EGNOS *Ground Segment* consists of GNSS (GPS, GLONASS, GEO) *Ranging and Integrity monitoring Stations* (called RIMS) which are connected to a set of redundant control and processing facilities called *Mission Control Centre* (MCC). The system will deploy 34 RIMS located in mainly in Europe and 4 MCCs located in Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). RIMS are equipped with external oscillators and dual frequency GPS/GLONASS/GEO receivers to track the three satellite constellations. These tracked data are then transmitted over the EGNOS Wide Area Network (EWAN) to the Master Control Centres (MCC). The MCCs produce the so-called EGNOS data products – Wide Area Differential (WAD) corrections and integrity information for each satellite. The data products are then transmitted to the Navigation Land Earth Stations (NLES) where they are scheduled to meet time-to-alarm requirements, packed into the standard message form, modulated on a GPS look-alike signal, and uplinked to the EGNOS GEOs. The system will deploy 2 NLESs (one primary and one back up) per GEO navigation transponder and an NLES for Test and Validation purposes, located in Torrejon (E), Fucino (I), Aussaguel (F), Raisting (D), Goonhilly (UK), and Sintra (P) respectively. Each GEO broadcasts a GPS look-alike signal that is modulated with the EGNOS data products. This is beneficial because each GEO ranging signal can be included in the navigation solution. However, it is also important to emphasise that the use of this signal is just one convenient solution for delivering the SBAS data products to the users.

The EGNOS AOC *space segment* consists of three navigation payloads on Geostationary Earth Orbit (GEO) satellites. Two of these are on Inmarsat's third generation satellites stationed at 15.5º W (Atlantic Ocean Region East (AOR-E)) and 64º E (Indian Ocean Region (IOR)). The third is on the European Space Agency's ARTEMIS satellite that will be stationed at 15º E and launched in 2000/2001. The navigation payloads on all these satellites are essentially bent-pipe transponders such that a message uploaded to the satellite is broadcast to all users in its Geostationary Broadcast Area (GBA). Those three satellites are expected to be operational up to 2007-2009. A GEO replenishment policy is to be defined to guarantee the 15 years of operational life of EGNOS [3].

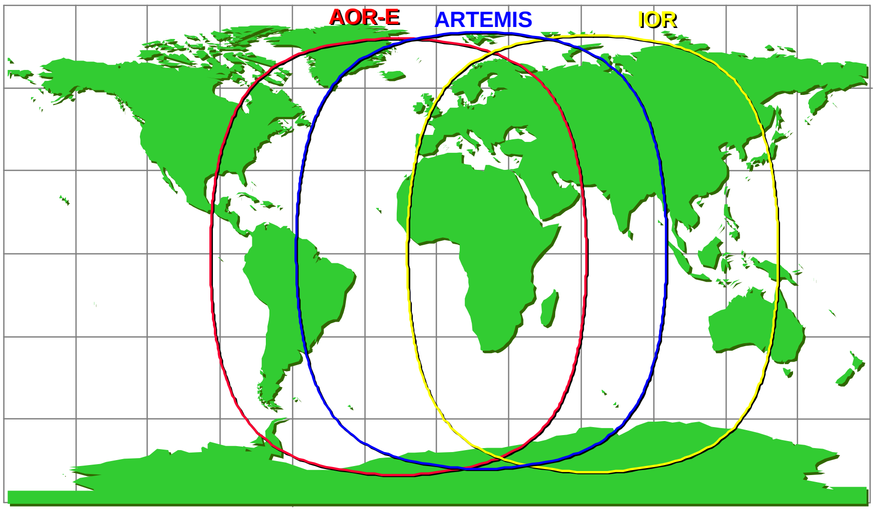

Figure 2 EGNOS GEO Broadcast Areas

The EGNOS *User Segment* consists of an EGNOS Standard receiver, to verify the Signal-In-Space (SIS) performance, and a set of prototype User equipment for civil aviation, land and maritime applications. That prototype equipment will be used to validate and eventually certify EGNOS for the different applications being considered.

Finally, the EGNOS support facilities include the Development Verification Platform (DVP), the Application Specific Qualification Facility (ASQF) located in Torrejon (Spain) and the Performance Assessment and System Checkout Facility (PACF) located in Toulouse (France). Those are facilities needed to support System Development, Operations and Qualification.

3.2 EGNOS Performance Simulations

3.2.1 ESPADA simulation software

These simulations were performed using the EGNOS Simulation Tool for Performance Assessment and Design analysis (ESPADA), developed by the ESA GNSS Project Team [4]. This is a complete Service Volume Simulator tool for the Project internal use, primarily concerned with the availability of the accuracy and integrity of the EGNOS positioning service. The ESPADA time/space parameters used for all the simulations are presented in Table 2.

3.2.2 Simulation results and analysis

This section illustrates the performance that maritime users should expect from EGNOS within the EGNOS core region derived from the European Civil Aviation Conference area. The expected accuracies and protection levels are based on the required levels of availability defined in Table 1. Ocean, coastal, port-approach and inland water requirements call for a horizontal accuracy of at least 10 metres (2-sigma), with a protection level of 25 metres. The integrity time to alarm is 10 seconds.

Simulation Time/Space Parameters	
Time (h)	24
Time step (min)	10
User grid (degrees)	5
User mask angle (degrees)	5
Simulation target (specify details)	ECAC
Level of service budget	3A
Error Budget Assumptions	
GEO Rx (1 sigma) in m	0.5
GPS Rx (1 sigma) in m	1
GLONASS Rx (1 sigma) in m	0
Multipath (1 sigma) in m	0.2
Latency (1 sigma) in m	0.252
UIVD and UIVE interpolated from GIVE and GIVD following SARPS, GIVE and GIVD calculated according to CPF PIDS Iono worst cases	
Space Configuration	
GPS	24
GEO	AOR-E, IOR, ARTEMIS
RIMS Configuration	
Network	33 RIMS over ECAC
RIMS mask angle (degrees)	5
RIMS Filtering (Y,N)	Y
Number of RIMS for satellite to be monitored	3

Table 2 ESPADA parameters used within the simulations

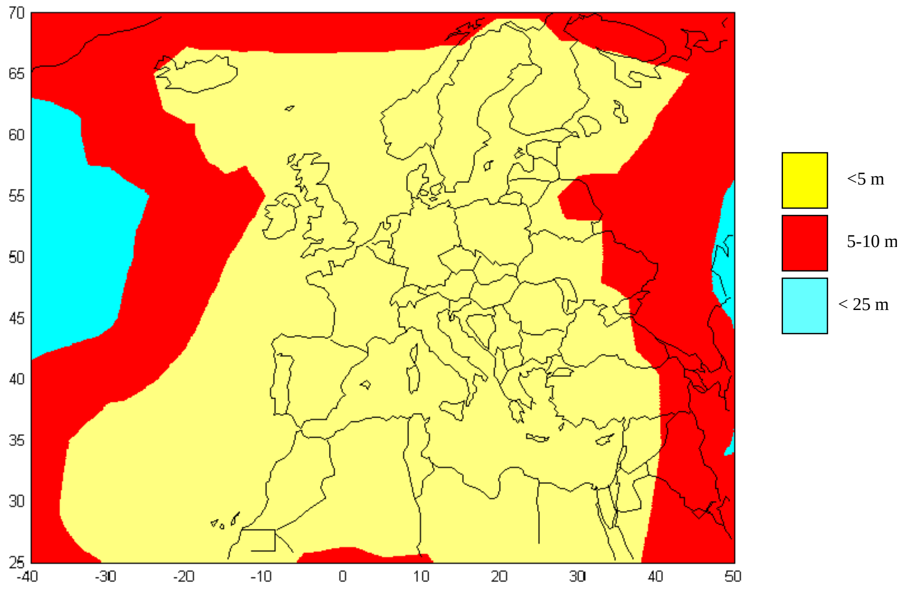

Figure 3 Estimated Horizontal Navigation System Error (HNSE)

Figure 3 illustrates the expected horizontal accuracy that maritime users should expect from EGNOS Service Level 3A – GPS augmented by EGNOS without GLONASS. Three areas have been plotted: the area with an expected accuracy better than 5 m, the area with an expected accuracy better than 10 m, and the area with an expected accuracy better than 25 m.

Figure 4 illustrates the expected horizontal protection level from EGNOS Service Level 3A. This shows the area where EGNOS is expected to guarantee a horizontal protection level better than 25 metres. Clearly, it is possible to conclude that the whole European coastal area, in-land waters, and a large part of the EGNOS core area will be provided with the required protection levels and integrity.

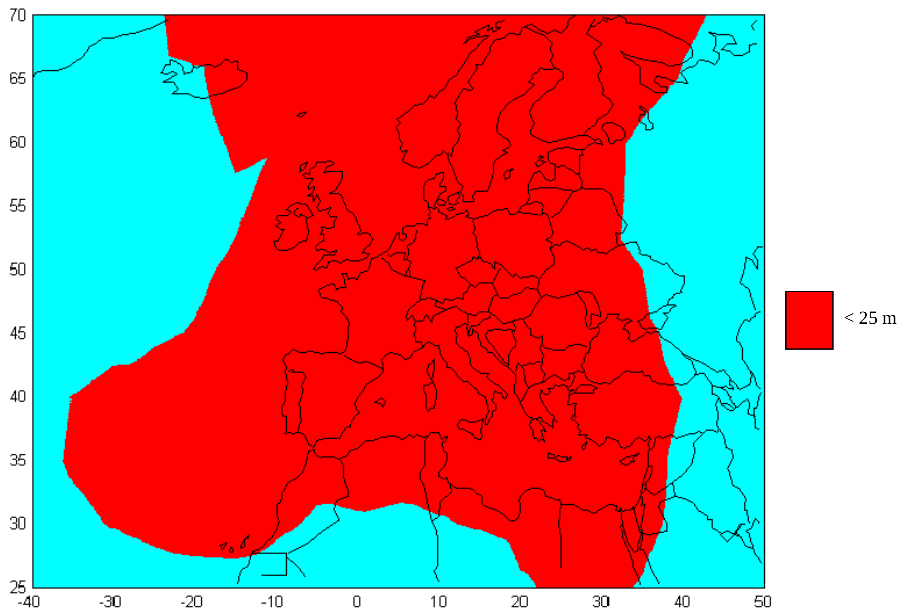

Figure 4 Estimated Horizontal Protection Level (HPL)

It is important to assert that these results may be assumed to be conservative. The simulations are based on a standard GPS constellation with 24 satellites (there are 27 available at the time of writing), a non-optimised minimum operational receiver (MOPS-like [2]), and the highest selective availability acceleration. Furthermore, GLONASS satellites are not considered in the simulation, and even Service Level 3B with the current degraded GLONASS constellation should provide a significant improvement. Moreover, recent real test-results obtained using the EGNOS System Test Bed (ESTB), which is based on non-optimised correction/integrity algorithms and a limited network of 8 RIMS, show that accuracies between 2 m and 3 m are already readily achievable (see Figure 5 and Figure 6).

It is important to highlight that EGNOS will provide these accuracies with the required, availability, integrity and time to alarm (N.B. EGNOS specified time to alarm in EGNOS is 6 seconds).

4 Service-related Issues for Maritime Users

4.1 Equipped with an EGNOS receiver

EGNOS offers the following benefits to users equipped with an EGNOS receiver capable of tracking the GPS, GLONASS, and GEO constellations:

1. A single antenna can receive both the GPS/GLONASS signals and the GEO signals incorporating the EGNOS data products.

2. A single GPS/GLONASS/GEO receiver assesses the integrity and applies the corrections.

3. No additional communications link is required for DGNSS accuracies.

Conversely, loosing track of the GEO satellites results in the loss of the EGNOS data products at the receiver - i.e. the integrity and correction messages - and the user positioning accuracy reverts to the equivalent uncorrected GPS/GLONASS solution.

The simulations presented in the previous section were made assuming that the user is equipped with an EGNOS receiver compliant with the Minimum Operational Performance Specifications (RTCA-MOPS [2]). There is the implicit assumption that the earth's topography is insignificant and does not block the line of sight between the receiver and the GEO satellites. This is not always true in practice.

EGNOS will broadcast its data products through three GEO satellites stationed at 15.5º W, 64º E, and 15º E (see Section 3.1 and Figure 2), and users see each of the GEO satellites at different elevation angles. This is an advantage of the EGNOS system that guarantees the availability and the continuity required. Figure 7 shows the elevation angle contours for each of the three GEOs overlaid on the European core service area. If one assumes that only one GEO-link is needed for the EGNOS service provision (at any given moment), then Figure 8 shows the maximum observable elevation in the EGNOS core service area when the optimum GEO (in terms of elevation) is used. It may be concluded that the user is always able to observe a GEO with an elevation angle greater than 20 º below a latitude of 60 ºN (largest part of Europe), greater than 15 º below a latitude of 65 ºN, and greater than 10 º below a latitude of 70 ºN. Clearly, there may be problems in the most northern latitudes, on inland waterways, and in coastal areas where cliffs might obstruct satellite visibility.

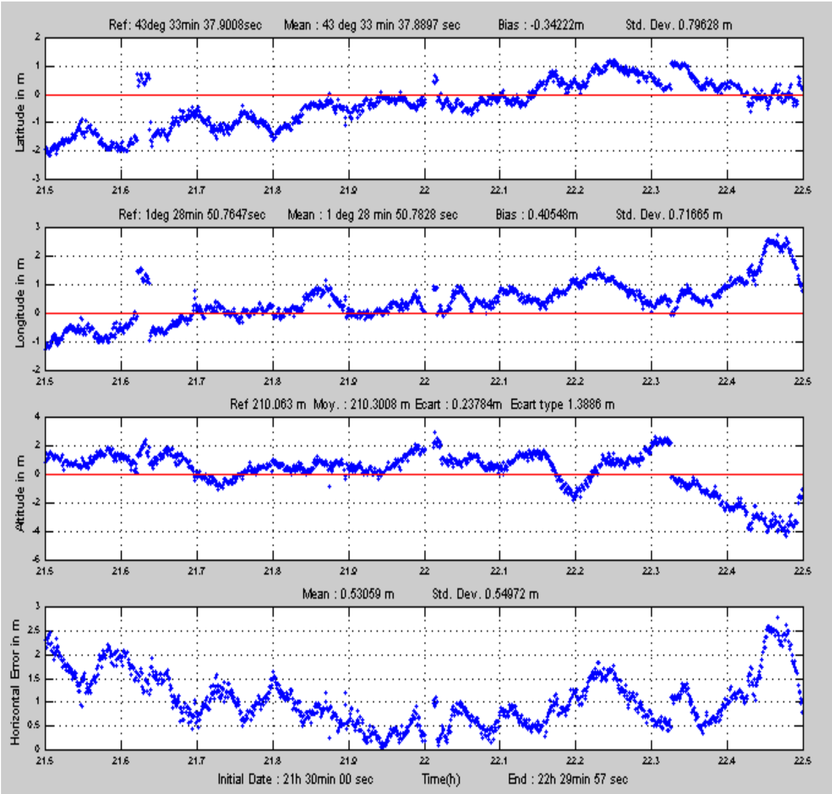

Figure 5 ESTB test results obtained on January 19th at Toulouse Latitude

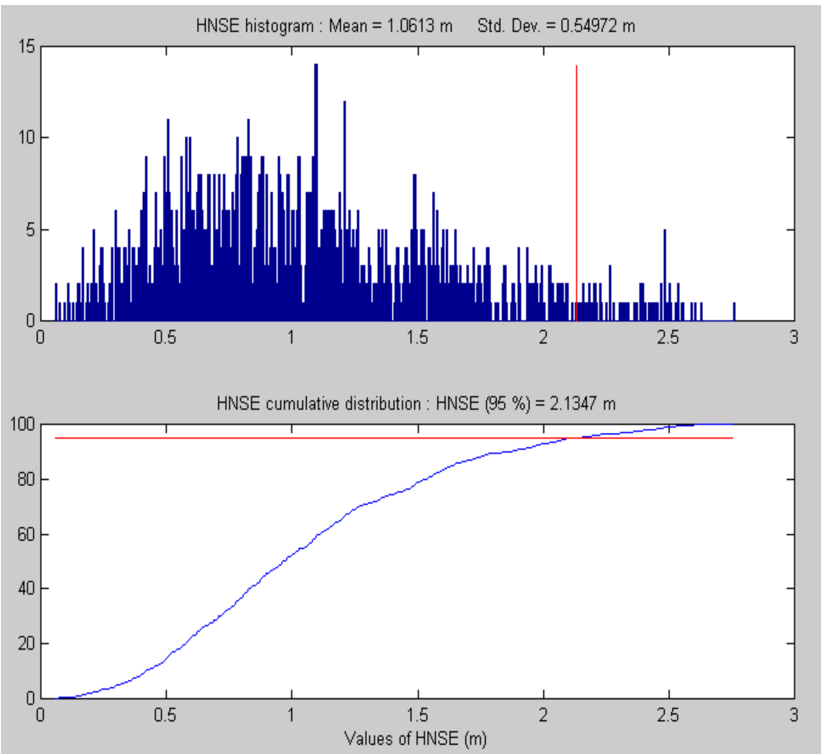

Figure 6 ESTB test results obtained on January 19th at Toulouse

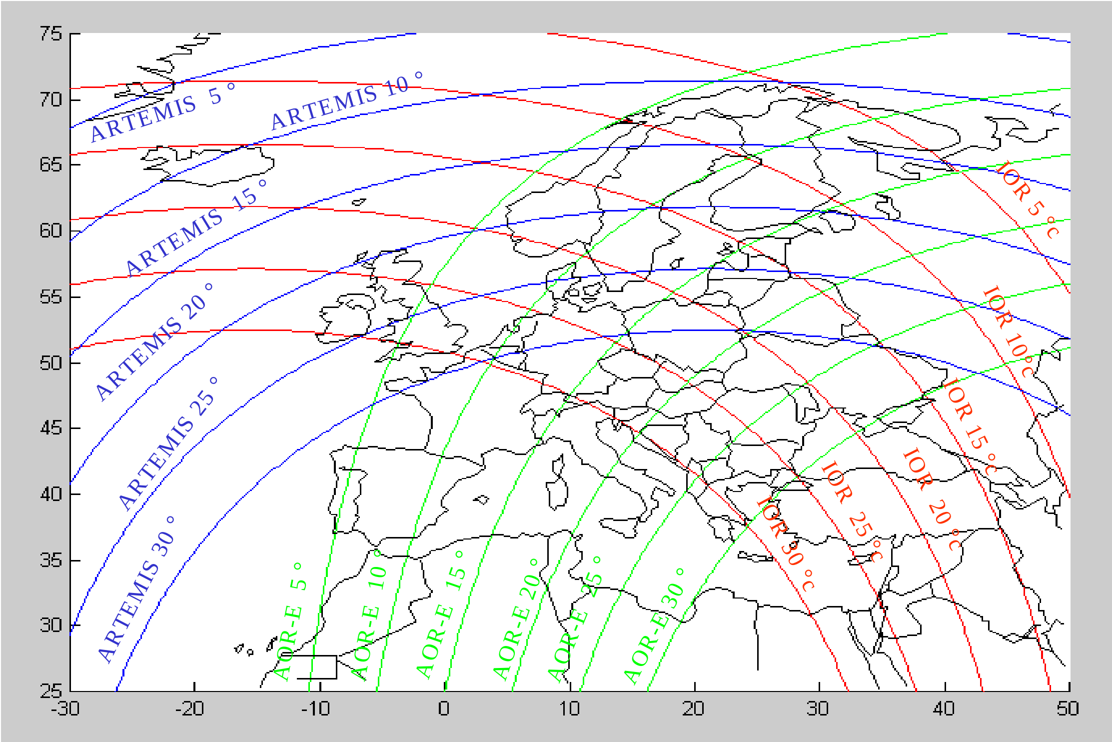

Figure 7 EGNOS GEO elevation curves overlaid on the EGNOS core service area

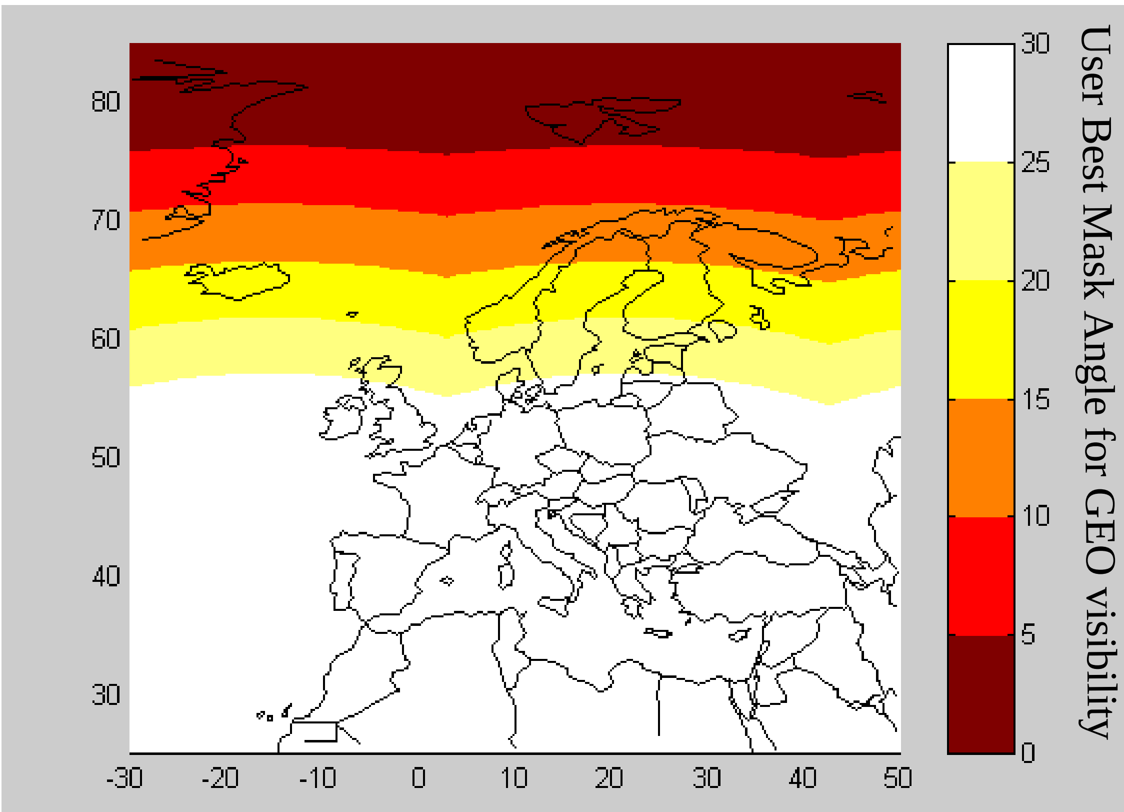

Figure 8 Maximum elevation angle in the EGNOS core area when the best of the three GEOs is used

The EGNOS Test Bed is currently (April 2000) only broadcasting through the Inmarsat AOR-E satellite, and will be upgraded during May/June 2000 to broadcast through both the Inmarsat AOR-E and IOR satellites. This will enable a number of system-level tests to be performed, and will enable an assessment of the impact of low-elevation GEO satellites at high latitudes.

4.2 Equipped with a conventional RTCM receiver

At this point it is helpful to consider EGNOS as two separate items: firstly a high-integrity, high-availability Data Product Generator (DPG); and secondly, a delivery mechanism (DM). The DPG includes the RIMS, the EWAN, and the MCC, while the DM includes the NLES.

Many users (including differential service providers) will not be equipped with EGNOS receivers when EGNOS AOC is declared operational in 2003/4. Many of them will own and operate conventional GPS receivers that are capable of receiving a differential correction in RTCM (Radio Technical Committee Maritime) format. This is a mature industry standard for the broadcast of local area differential corrections, and is very different to the RTCA wide area differential format adopted by EGNOS and other SBAS systems. However, this class of users can also benefit from EGNOS.

Service providers should perceive EGNOS as a complementary as opposed to a competing service. The EGNOS DPG has been engineered to produce high-quality wide-area corrections and integrity information. There are a number of ways in which service providers might consider using the EGNOS data products:

1. Quality Assurance - comparing observed local differential corrections against computed local differential corrections generated from the independent EGNOS data products.

2. Quality Assurance - using the ionospheric information provided by EGNOS to assess the varying performance of both the local area differential corrections and the data link.

3. Service Enhancement - using the EGNOS orbit and ionospheric data to enhance the performance of their current services.

4. Service Provision - converting the RTCA format corrections to RTCM format corrections and providing a differential service without having to invest in GPS reference station hardware.

In general, users will rely on service providers to deliver benefits from EGNOS, thus emphasising the complementary nature of EGNOS and existing service providers. These may be perceived indirectly (see items 1 and 2 in the above list), or directly (see items 3 and 4 in the above list).

5 Conclusions

This paper has compared the expected performance from EGNOS with the maritime user requirements formulated in Resolution A860(20). EGNOS will meet most of the maritime users' requirements in the EGNOS core service area. When operational, EGNOS will provide a complementary service to those already provided using marine radio-beacons. There is significant potential for co-operation between EGNOS and service providers using other communications links, and this may bring benefits to users. There is a need for operational validation to include an assessment of impact of low elevation angles on service availability. This should begin by building experience using the signals provided by the ESTB, and move towards institutional acceptance of EGNOS. EGNOS AOC will be declared operational in 2003/4, and is the first step towards a civil-controlled satellite navigation system, i.e. GALILEO.

6 References

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