EGNOS Open Service (OS)

Service Definition Document

DOCUMENT CHANGE RECORD

Revision	Date	Summary of changes
1.0	01/10/2009	Preliminary version of the document
1.1	30/10/2009	First release of the document
2.0	18/03/2013	Update of the document according to: • Section 3.1.2.3: Including the active GEO information at present, updating the number of RIMS and updating the picture of the RIMS location. • Section 6.2: Including the improvements derived from the past EGNOS system releases. • Including Appendix A (EGNOS OS performances from ESR2.3.1) and Appendix B (Satellite Navigation Concept).
2.1	19/12/2014	• EGNOS system information updated. • OS Commitment Map updated. • Observed performance figures updated. • New appendix C on the impacts of ionospheric activity on GNSS.
2.2	12/02/2015	Figure 4-1 corrected
2.3	03/10/2017	• OS Commitment Map updated • EGNOS system and service information updated • Performance figures observed over the new period of time updated

EGNOS Open Service (OS)

Service Definition Document

European
Global Navigation
Satellite Systems
Agency

The European GNSS Agency produced this document
under tasks entrusted by the European Commission

Precise navigation,
powered by Europe

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1 EXECUTIVE SUMMARY

The European Geostationary Navigation Overlay Service (EGNOS) provides an augmentation service to the Global Positioning System (GPS) Standard Positioning Service (SPS). Presently, EGNOS augments GPS using the L1 (1575.42 MHz) Coarse/Acquisition (C/A) civilian signal function by providing correction data and integrity information for improving positioning, navigation and timing services over Europe.

This version of the "EGNOS OS Service Definition Document" (EGNOS OS SDD) is intended to give information on the EGNOS Open Service (EGNOS OS).

The document describes the EGNOS system architecture and Signal-In-Space (SIS) characteristics, the OS service performance achieved, and provides information on the established technical and organisational framework, at European level, for the provision of this service. It is intended to be of use for receiver manufacturers, GNSS application developers and final users of the EGNOS OS.

The document also includes complementary high level information on GNSS concepts, the GPS Service, the EGNOS System and services, the EGNOS management structure and EGNOS interfaces with users, as well as the minimum performance characteristics of EGNOS OS.

This document is not intended to address EGNOS SoL service nor EDAS performance. Information about the EGNOS SoL is available in a separate document called the "EGNOS Service Definition Document – Safety of Life Service" (EGNOS SDD SoL – [RD-5]), whilst information regarding EDAS can be found in another separate document called the "EGNOS Data Access Service (EDAS) – Service Definition Document" (EDAS SDD – [RD-6]).

This document will be updated in the future as required in order to reflect any changes and improvements to the EGNOS OS Service.

2 INTRODUCTION

2.1 Purpose and Scope of the Document

The EGNOS Service Definition Document – Open Service (EGNOS SDD OS) presents the characteristics of the service offered to users by the EGNOS Open Service (EGNOS OS) highlighting the positioning and timing performance currently available to suitably equipped users using both the GPS SPS broadcast signal and the EGNOS OS augmentation signal.

This document is intended to all potential users of EGNOS OS: road applications service providers and end users, precision agriculture community, telecommunication and computer operators, maritime users, or any user community interested in obtaining better positioning accuracy in those applications where safety is not critical (i.e. a failure in EGNOS OS performance do not imply any direct or indirect personal damage).

The EGNOS OS SDD comprises 7 main sections and 4 appendixes:

- **Section 1** is an Executive Summary of the document.
- **Section 2 Introduction** defines the scope of the document and the relevant reference documentation. In addition, this section clarifies the terms and conditions of EGNOS OS use, including liability and its intended lifetime.
- **Section 3 Description of the EGNOS System and EGNOS OS Provision** gives a brief overview of the EGNOS system, as well as the technical and organisational framework for EGNOS service provision.
- **Section 4 EGNOS SIS** introduces the EGNOS Signal In Space characteristics and performance in the range domain.
- **Section 5 EGNOS Receivers** summarizes the main functionalities that should be fulfilled by any GNSS receiver to use EGNOS OS.
- **Section 6 EGNOS OS** Performance describes the positioning Service offered to users by the EGNOS OS and the minimum EGNOS OS performance in the position domain.
- **Section 7 EGNOS Time Service Performance** deals with the EGNOS Time Service, giving its expected performance.
- **Appendix A** reports on the EGNOS performance achieved during the period March – August 2017 at 29 EGNOS reference stations locations.
- **Appendix B** contains fundamental information of the satellite navigation (GNSS) as complementary concepts for the rest of the document.
- **Appendix C** presents relevant definitions.
- **Appendix D** assesses the impact of the ionospheric activity on GNSS and in particular on SBAS systems.
- **Appendix E** includes the list of acronyms of the document.

This document does not address the Safety of Life Service (SoL) and the EGNOS Data Access Service (EDAS), which are described in separate dedicated Service Definition Documents.

2.2 Terms and Conditions of Use of EGNOS Open Service, Including Liability

EGNOS has been designed and developed with the general goal to improve first GPS and then Galileo performance in Europe and neighbouring regions. Its OS is intended to offer these benefits for general-purpose applications users. It is freely accessible through a GPS/SBAS compatible receiver within the EGNOS OS area (see Figure 6-1) without any direct charge and does not require specific authorisation. EGNOS OS can only be used for non-safety critical purposes, i.e. purposes that have no impact on the safety of human life and where a failure in availability, integrity, continuity or accuracy of the EGNOS SIS could not cause any kind of direct or indirect personal damage, including bodily injuries or death.

OS is not meant to offer a service guarantee or liability from the EGNOS service provider, the European Union, GSA or ESA. The minimum level of performance committed, as well as data of actual performance, is provided in this document solely for the reasons of transparency in order to enable the user to make an informed decision regarding EGNOS OS use. However, actual EGNOS OS performance may differ in the future.

2.2.1 SCOPE OF THE EGNOS OS COMMITMENT

The EGNOS Open Service (further "EGNOS OS") comprises the provision of an augmentation signal to the Global Positioning System (GPS) Standard Positioning Service (SPS) with the specific committed performance and subject to the service limitations described here in the EGNOS OS SDD.

Only minimum performance characteristics are included in the commitment even though the users can usually experience a better performance. These characteristics are expressed in statistical values under given assumptions.

The minimum level of performance of the EGNOS OS, as specified in the EGNOS OS SDD, is obtained under the condition that compliance is ensured with:

- The main GPS SPS SIS characteristics and performance defined in the GPS ICD [RD-4], in SBAS MOPS appendix B [RD-2] and in GPS SPS Performance Standard [RD-3];
- The receiver characteristics as described in chapters 4 and 6 and;
- Use of EGNOS OS Service within the conditions and limitations of use set forth in the EGNOS OS SDD.

2.2.2 USER RESPONSIBILITIES

The user retains his responsibility to exercise a level of care appropriate with respect to the uses to which he puts the EGNOS OS, taking into account the considerations outlined above.

Before any use of the EGNOS OS, all users should study this document in order to understand how they can use the service, as well as to familiarise themselves with the performance level and other aspects of the service they can rely on.

In case of doubt, the users and other parties should contact the EGNOS helpdesk (see section 3.2.2 for contact details).

DISCLAIMER OF LIABILITY

The European Union, as the owner of EGNOS system, the European GNSS Agency (GSA) as EGNOS Programme manager and ESSP SAS, as EGNOS services provider, expressly disclaim all warranties of any kind (whether expressed or implied) with respect to the Open Service including, but not limited to the warranties regarding availability, continuity, accuracy, integrity, reliability and fitness for a particular purpose or meeting the users´ requirements. No advice or information, whether oral or written, obtained by a user from the European Union, GSA or ESSP SAS and its business partners shall create any such warranty.

By using the EGNOS Open Service, the user agrees that neither the European Union nor GSA nor ESSP SAS shall be held responsible or liable for any direct, indirect, special or consequential damages, including but not limited to, damages for interruption of business, loss of profits, goodwill or other intangible losses, resulting from the use of, misuse of, or the inability to use the EGNOS Open Service.

Any damage as result or consequence of the use of EGNOS OS Service beyond the conditions and limitations of use set forth in this EGNOS OS SDD shall not be entitled to any claim against ESSP SAS and/or the European Union and/or the GSA.

2.3 The Use of EGNOS OS

The EGNOS OS is intended to deliver a wide range of benefits to European commercial organisations, public entities and ultimately citizens in the multimodal domains.

Shown below are some examples of applications of EGNOS OS in different areas:

- In agriculture, EGNOS OS enables the high-precision spraying of fertilisers and pesticides, reducing the amount of chemicals needed for achieving optimal yield and productivity. It can also support other innovative applications.
- EGNOS OS is used in combination with geodetic techniques to improve methods in the area of property boundary mapping, land parcel identification and geo-traceability.
- In road transport, EGNOS OS allows for the development of new applications such as "pay-per-use" insurance or automatic road tolling, reducing the need for more costly alternative infrastructure. It can also be used to improve fleet tracking solutions in any road or maritime application domain.
- In rail, EGNOS OS can be used for non-safety critical applications such as passenger information systems or asset management.
- In maritime domain, the EGNOS OS could be used for general navigation (i.e. coastal, port approach and inland waters) and recreation and leisure applications.
- EGNOS OS improves the precision of all personal navigation applications, giving rise to a myriad of new possibilities such as, emergency localisation, friend finding or geo-localised advertising.

EGNOS OS also broadcasts a reliable time standard with unprecedented accuracy to be used by computer and telecommunication networks.

2.4 EGNOS OS Lifetime

The EGNOS Services are intended to be provided for a minimum period of 20 years, as from its first declaration date, with 6 years advance notice in case of significant changes in the Services provided.

2.5 Reference Documents

RD	Document Title
[RD-1]	ICAO Standards and Recommended Practices (SARPS) Annex10 Volume I (Radio Navigation Aids)
[RD-2]	RTCA MOPS DO 229 (Revisions C, D Change 1 or E)
[RD-3]	GPS Standard Positioning Service Performance Standard – 30th September 2008 4th Edition
[RD-4]	IS GPS 200– NAVSTAR GPS Space Segment / Navigation User Interface
[RD-5]	EGNOS Safety of Life Service - Service Definition Document (SoL SDD) https://www.gsa.europa.eu/library/technical-documents
[RD-6]	EGNOS Data Access Service – Service Definition Document (EDAS SDD) https://www.gsa.europa.eu/library/technical-documents
[RD-7]	REGULATION (EU) No 1285/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013 on the implementation and exploitation of European satellite navigation systems and repealing Council Regulation (EC) No 876/2002 and Regulation (EC) No 683/2008 of the European Parliament and of the Council
[RD-8]	EC/ESA/CNES User Guide for EGNOS Application Developers Ed. 2.0 – 15th December 2011

3 DESCRIPTION OF THE EGNOS SYSTEM & EGNOS OS PROVISION ENVIRONMENT

3.1 High Level Description of the EGNOS Technical Framework

3.1.1 OBJECTIVE OF EGNOS

Satellite navigation systems are designed to provide a positioning and timing service over vast geographical areas (typically continental or global coverage) with high accuracy performance. However, a number of events (either internal to the system elements or external, due to environmental conditions) may lead to positioning errors that are in excess of the typically observed navigation errors. For a large variety of users, such errors will not be noticed or may have a limited effect on the intended application. However, for a number of user communities, they may directly impact the quality of operations. Therefore, there is an absolute need to correct such errors, or to warn the user in due time when such errors occur and cannot be corrected. For this reason, augmentation systems have been designed to improve the performance of existing global constellations.

EGNOS is a Satellite Based Augmentation System (SBAS). SBAS systems are designed to augment the navigation system constellations by broadcasting additional signals from geostationary (GEO) satellites. The basic scheme is to use a set of monitoring stations (at very well-known position) to receive the navigation signals that will be processed in order 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 a GEO satellite. Today, EGNOS augments GPS signals and will augment Galileo signal in the future.

Along with these correction messages which increase accuracy, some integrity data for the satellites that are in the view of this network of monitoring stations are also broadcast, increasing the confidence that a user can have in the satellite navigation positioning solution.

The reader is invited to read Appendix B for background information about the Satellite Navigation Concept.

3.1.2 EGNOS OVERVIEW

3.1.2.1 EGNOS Services

EGNOS provides corrections and integrity information to GPS signals over a broad area centred over Europe and it is fully interoperable with other existing SBAS systems. EGNOS provides three services:

- Open Service (OS), freely available to any user;
- Safety of Life (SoL) Service, that provides the most stringent level of signal-in-space performance to all Safety of Life user communities;
- EGNOS Data Access Service (EDAS) for users who require enhanced performance for commercial and professional use.

All of these EGNOS services are available and granted throughout their respective service areas.

Open Service (OS)

The main objective of the EGNOS OS is to improve the achievable positioning accuracy by correcting several error sources affecting the GPS signals. The corrections transmitted by EGNOS contribute to mitigate the ranging error sources related to satellite clocks, satellite position and ionospheric effects. The other error sources (tropospheric effects, multipath and user receiver contributions) are local effects that cannot be corrected by a wide area augmentation system. Finally, EGNOS can also detect distortions affecting the signals transmitted by GPS and prevent users from tracking unhealthy or misleading signals.

The EGNOS OS is accessible as per the map provided in section 6.2.2 to any user equipped with an appropriate GPS/SBAS compatible receiver for which no specific receiver certification is required.

The EGNOS OS has been available since 1st October 2009 being this document the applicable SDD.

Safety of Life Service (SOL)

The main objective of the EGNOS SoL service is to support civil aviation operations down to Localiser Performance with Vertical Guidance (LPV) minima. At this stage, a detailed performance characterisation has been conducted only against the requirements expressed by civil aviation but the EGNOS SoL service might also be used in a wide range of other application domains (e.g. maritime, rail, road…) in the future. In order to provide the SoL Service, the EGNOS system has been designed so that the EGNOS Signal-In-Space (SIS) is compliant to the ICAO SARPs for SBAS [RD-1].

Two EGNOS SoL Service levels (NPA and APV-I) were declared with the first issue of the EGNOS SoL SDD v1.0 in March 2011 and an additional one (LPV-200) was declared with the EGNOS SoL SDD v3.0 in September 2015 enabling the following SBAS-based operations in compliance with requirements as defined by ICAO in Annex 10 [RD-1]:

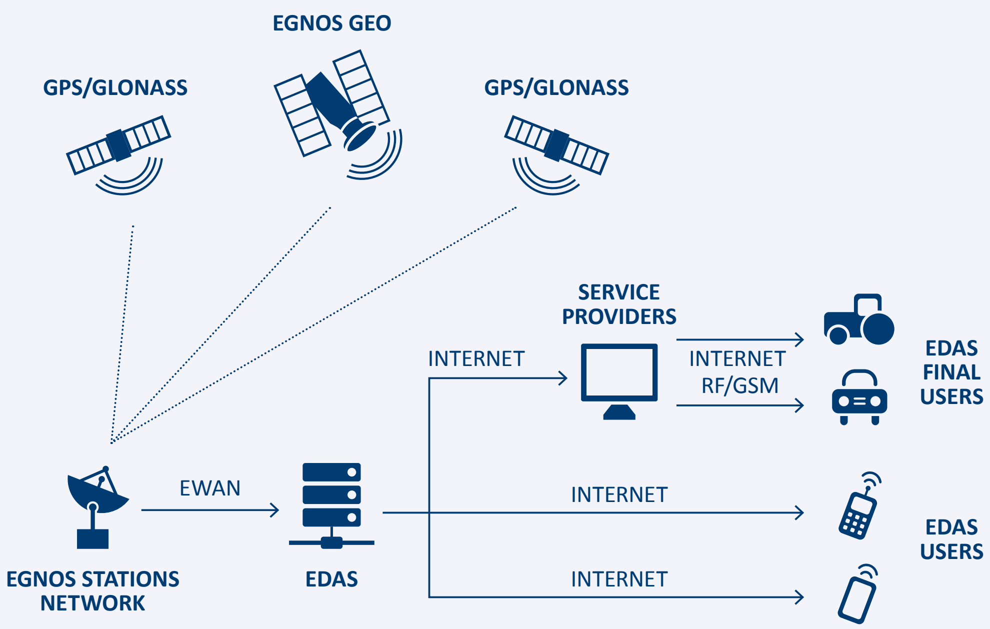
- Non-Precision Approach operations and other flight operations supporting PBN navigation specifications other than RNP APCH, not only for approaches but also for other phases of flight.
- Approach operations with Vertical Guidance supporting RNP APCH PBN navigation specification down to LPV minima as low as 250 ft.
- Category I precision approach with a Vertical Alert Limit (VAL) equal to 35m and supporting RNP APCH PBN navigation specification down to LPV minima as low as 200 ft.

The EGNOS SoL Service has been available since March 2nd 2011 and the corresponding SDD is [RD-5].

EGNOS Data Access Service (EDAS)

EDAS is the EGNOS terrestrial data service which offers ground-based access to EGNOS data in real time and also in a historical FTP archive to authorised users (e.g. added-value application providers). EDAS is the single point of access for the data collected and generated by the EGNOS ground infrastructure (RIMS and NLES) mainly distributed over Europe and North Africa.

Figure 3-1 EDAS High-Level Architecture



Application Providers will be able to connect to the EGNOS Data Server, and exploit the EGNOS products, offering high-precision services[1] to final customers.

The EGNOS EDAS is available since July 26th 2012 and the corresponding SDD is [RD-6].

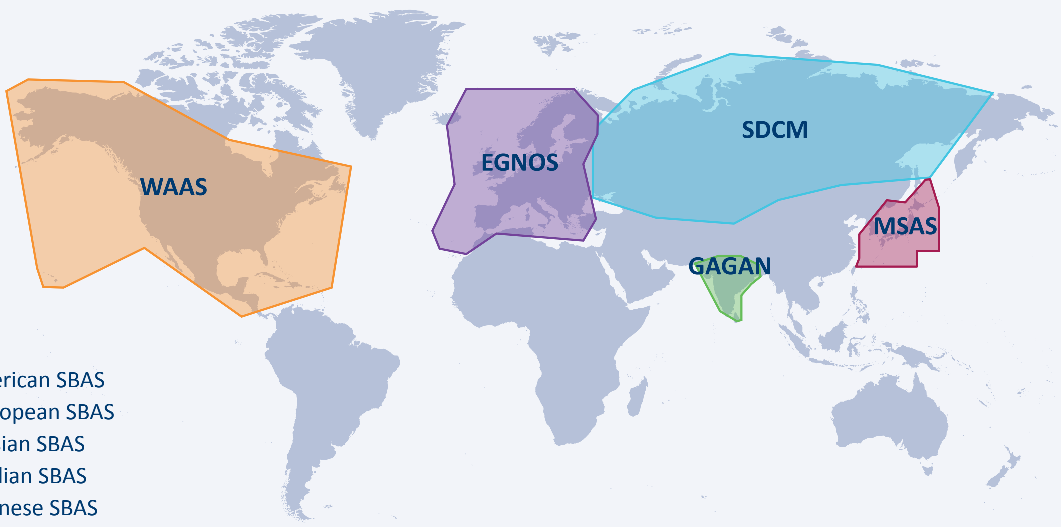
3.1.2.2 EGNOS: The European SBAS

EGNOS is part of a developing multi-modal inter-regional SBAS service, able to support a wide spectrum of applications in many different user communities, such as aviation, maritime, rail, road, agriculture. Similar SBAS systems, designed according to the same standard (i.e. SARPs [RD-1]), have already been commissioned by the US (Wide Area Augmentation System – WAAS), Japan (MTSAT Satellite based Augmentation System - MSAS) and India (GPS Aided GEO Augmented Navigation – GAGAN in India). Analogous systems are under commissioning or deployment in other regions of the world (e.g. System of Differential Correction and Monitoring – SDCM in Russia) or under investigation (e.g. Korea Augmentation Satellite System – KASS in South Korea and SBAS-ASECNA in West Africa). The worldwide existing and planned SBAS systems are shown in Figure 3-2.

For additional information, the reader is invited to visit the following websites:

- WAAS, Federal Aviation Administration (FAA): https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/
- SDCM, Federal Space Agency ("Roscosmos"): http://www.sdcm.ru/index_eng.html
- MSAS, Japanese Ministry of Land, Infrastructure, Transport and Turism (MLIT): https://www.mlit.go.jp/koku/15_hf_000105.html
- GAGAN, Indian Space Research Organisation (ISRO): http://www.isro.gov.in/applications/satellite-navigation-programme

Figure 3-2 Existing and planned SBAS systems



WAAS: American SBAS
EGNOS: European SBAS
SDCM: Russian SBAS
GAGAN: Indian SBAS
MSAS: Japanese SBAS

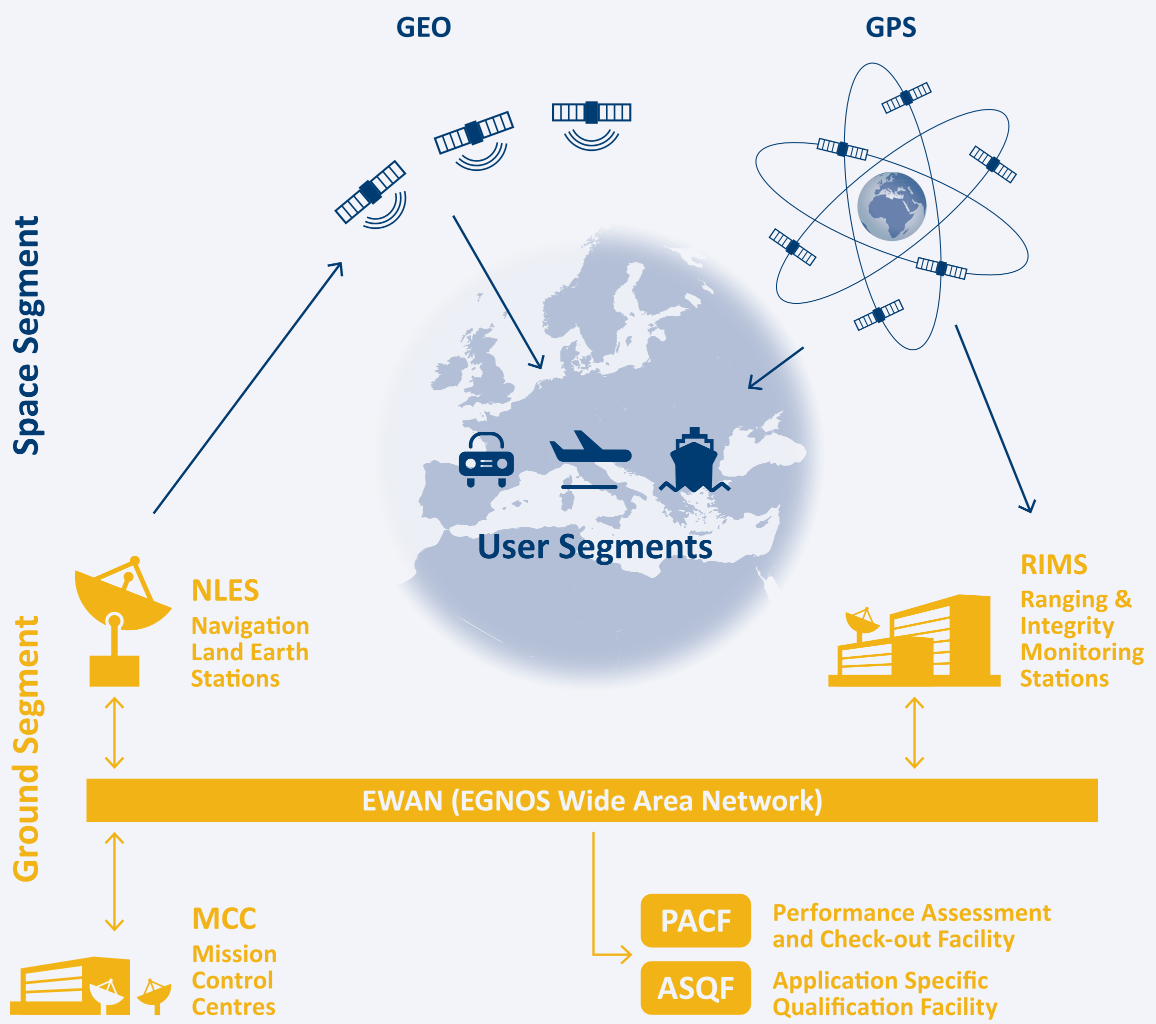
1 Examples of potential applications that could be provided are: EGNOS pseudolites; provision of EGNOS services through RDS, DAB, Internet; accurate ionospheric delay/TEC maps; provision of performance data (e.g. XPL availability maps, GIVE maps, etc.); provision of EGNOS message files.

In addition, most of these systems, like EGNOS, have plans to extend their service areas to neighbouring regions, thus paving the way for near global SBAS coverage.

3.1.2.3 EGNOS Architecture

The EGNOS functional architecture is shown in Figure 3-3:

Figure 3-3 EGNOS architecture



In order to provide its services to users equipped with appropriate receivers, the EGNOS system comprises two main segments: the Space Segment, and the Ground Segment.

EGNOS Space Segment

The EGNOS Space Segment comprises geostationary (GEO) satellites broadcasting corrections and integrity information for GPS satellites in the L1 frequency band (1575.42 MHz). At the date of publication the GEOs used by EGNOS are (see table 3-1).

This space segment configuration provides a high level of redundancy over the whole service area in case of a geostationary satellite link failure. The EGNOS operations are handled in such a way that, at any point in time, at least two GEOs broadcast an operational signal, the others remaining in backup and broadcasting a test signal. Since it is only necessary to track a single GEO satellite link to benefit from the EGNOS Services, this secures a switching capability in case of interruption and ensures a high level of continuity of service.

EGNOS users are advised not to use the test SIS data. The detailed configuration of Operational and Backup satellites is reported in the EGNOS user support webpage (https://egnos-user-support.essp-sas.eu).

It is intended that the EGNOS space segment will be replenished over time in order to maintain a similar level of redundancy. The exact orbital location of future satellites may vary, though this will not impact the service offered to users. Similarly, different PRN code numbers may be assigned to future GEOs. It is important to remark that these changes in the EGNOS GEO space segment are performed in a seamless manner without any interruption from an EGNOS user point of view and without compromising at any moment EGNOS performance. For this purpose, and whenever there could be any relevant information complementing the SDD, an EGNOS Service Notice is published in the EGNOS user support webpage (https://egnos-user-support.essp-sas.eu/new_egnos_ops/content/service-notices) and distributed.

EGNOS Ground Segment

The EGNOS Ground Segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), two Mission Control Centres (MCC), two Navigation Land Earth Stations (NLES) per GEO, and the EGNOS Wide Area Network (EWAN) which provides the communication network for all the components of the ground segment. Two additional facilities are also deployed as part of the ground segment to support system operations and service provision, namely the Performance Assessment and Checkout Facility (PACF) and the Application Specific Qualification Facility (ASQF), which are operated by the EGNOS Service Provider (ESSP SAS).

- **Ranging Integrity Monitoring Stations (RIMS)**

The main function of the RIMS is to collect measurements from GPS satellites and to transmit these raw data every second to the Central Processing Facilities (CPF) of each MCC. The current RIMS network comprises 40 RIMS sites located over a wide geographical area. Glonass measurements are also collected by some stations and are available in EDAS.

Figure 3-4 shows the geographical distribution of the RIMS already in operation (in grey the ones not yet contributing to the EGNOS solution).

- **Central Processing Facility (CPF)**

The Central Processing Facility (CPF) is a module of the MCC that uses the data received from the network of RIMS stations to:

1. Elaborate clock corrections for each GPS satellite in view of the network of RIMS stations. These corrections are valid throughout the geostationary broadcast area (i.e. wherever the EGNOS signal is received).
2. Elaborate ephemeris corrections to improve the accuracy of spacecraft orbital positions. In principle, these corrections are also valid throughout the geostationary broadcast area. However, due to the geographical distribution of the EGNOS ground monitoring network, the accuracy of these corrections will degrade when moving away from the core service area.

Table 3-1 GEOs used by EGNOS

GEO Name	PRN Number	Orbital Slot
ASTRA-5B	PRN 123	31.5 E
ASTRA SES-5	PRN 136	5 E
INMARSAT 4F2 EMEA	PRN 126	64 E
INMARSAT 3F2 AOR-E	PRN 120	15.5 W

Figure 3-4 EGNOS RIMS sites

3. Elaborate a model for ionospheric errors over the EGNOS service area in order to compensate for ionospheric perturbations to the navigation signals.

This function requires a dense network of monitoring stations. For this reason, the ionospheric model broadcast by EGNOS is not available for the whole geostationary broadcast area but is only provided for a region centred over Europe.

These three sets of corrections are then broadcast to users to improve positioning accuracy.

In addition, the CPF estimates the residual errors that can be expected by the users once they have applied the set of corrections broadcast by EGNOS. These residual errors are characterised by two parameters:

- User Differential Range Error (UDRE): this is an estimate of the residual range error after the application of clock and ephemeris error correction for a given GPS satellite.
- Grid Ionospheric Vertical Error (GIVE): this is an estimate of the vertical residual error after application of the ionospheric corrections for a given geographical grid point.

These two parameters can be used to determine an aggregate error bounded by the horizontal and vertical position errors. Such information is of special interest for Safety of Life users but may also be beneficial to other communities needing to know the uncertainty in the position determined by the user receiver.

Finally, the CPF includes a large number of monitoring functions designed to detect any anomaly in GPS and in the EGNOS system itself and is able to warn users within a very short timeframe in case of an error exceeding a certain threshold. These monitoring functions are tailored to the Safety of Life functions and will not be further detailed in this document.

- **Navigation Land Earth Stations (NLES)**

The messages elaborated by the CPF are transmitted to the NLESs. The NLESs (two for each GEO for redundancy purposes) transmit the EGNOS message received by the CPF to the GEO satellites for broadcast to users and to ensure the synchronisation with the GPS signal.

- **Central Control Facility (CCF)**

The EGNOS system is controlled through a Central Control Facility (CCF) located in each of the Mission Control Centres. These facilities are manned on a 24/7 basis in order to ensure permanent service monitoring and control.

3.2 EGNOS Organisational Framework

3.2.1 BODIES INVOLVED IN THE EGNOS PROGRAMME AND SERVICE DELIVERY

The European Union (EU) is the owner of the EGNOS system. The European GNSS Agency (GSA) according to the delegation agreement with the European Commission (EC) is in charge of the tasks associated with the exploitation phase of EGNOS, overall EGNOS operational programme management and as such, is responsible for taking decisions regarding the system exploitation, evolutions and promotion of the services and applications.

The European Space Agency (ESA) led the technical development of the EGNOS system in the past and is now mandated by the European Commission to be responsible for:

1. Conception, design, monitoring, procurement and validation in the framework of the development of future generations of the systems;
2. technical support in the framework of operation and maintenance of the existing generation of the systems.

The European Satellite Services Provider (ESSP) SAS is the current EGNOS Services Provider within Europe, certified according to the Single European Sky (SES) regulation as Air Navigation Service Provider (ANSP). ESSP SAS provides the EGNOS OS, EDAS Services and SoL Service compliant with ICAO (International Civil Aviation Organization) Standards and Recommended Practices throughout the European Civil Aviation Conference (ECAC) region.

ESSP SAS has been awarded the operations and service provision contract by GSA for EGNOS until the end of 2021. An operator for the next period will be chosen in due time.

3.2.2 HOW TO GET INFORMATION ON EGNOS AND EGNOS APPLICATIONS OR CONTACT THE SERVICE PROVIDER

A number of websites and e-mail addresses are made available by the EC, GSA, ESA, ESSP SAS and other organisations to provide detailed information on the EGNOS programme, the system status and system performance, as well as a number of useful tools. Table 3-2 below lists the main sources of information about EGNOS.

EGNOS OS SDD readers are also invited to refer to the GPS SPS PS [RD-3]. EGNOS also meets the ICAO Annex 10, Standards and Recommended Practices (SARPs) for Global Navigation Satellite System (GNSS) Satellite Based Augmentation System (SBAS), [RD-1].

Table 3-2 Where to find information about EGNOS

Topic	Organisation	Web/contact details
EGNOS Programme EC institutional information about the EGNOS Programme	EC	http://ec.europa.eu/growth/sectors/space/egnos/index_en.htm
EGNOS general information and EGNOS applications	GSA	http://www.egnos-portal.eu
EGNOS User Support ESSP dedicated service to users on EGNOS status and performance, system description, real time services performance, forecasts, EGNOS applicable documentation, FAQs, etc. A specific EDAS section is also available.	ESSP	http://egnos-user-support.essp-sas.eu/
EGNOS Service provider activity ESSP official reporting of the service provider activities, news etc.	ESSP	http://www.essp-sas.eu
EGNOS Helpdesk Direct point of contact for any question related with the EGNOS system, its performance and applications.	ESSP	egnos-helpdesk@essp-sas.eu +34 911 236 555
EGNOS System ESA dedicated services and detailed technical information on EGNOS.	ESA	http://www.esa.int/esaNA/egnos.html
EGNOS certified receivers EASA mailbox for any question related to service difficulties or malfunctions of EGNOS certified receivers.	EASA	egnos@easa.europa.eu
EDAS General information about EDAS	GSA/EC/ ESSP	http://www.gsa.europa.eu/egnos/edas
EGNOS Working Agreements (EWA) Formalization between ESSP and a specific ANSP for introducing EGNOS LPV approaches within the associated country.	ESSP	EGNOS-working-agreement@essp-sas.eu

4 EGNOS SIS

4.1 EGNOS SIS Interface Characteristics

The EGNOS Signal In Space format is compliant with the ICAO SARPs for SBAS [RD-1]. This section provides an overview of the EGNOS SIS interface characteristics, related to carrier and modulation radio frequency (section 4.1.1) and structure, protocol and content of the EGNOS message (section 4.1.2).

4.1.1 EGNOS SIS RF CHARACTERISTICS

The EGNOS GEO satellites transmit right-hand circularly polarised (RHCP) signals in the L band at 1575.42 MHz (L1). The broadcast signal is a combination of a 1023-bit PRN navigation code of the GPS family and a 250 bits per second navigation data message carrying the corrections and integrity data elaborated by the EGNOS ground segment.

The EGNOS SIS is such that, at all unobstructed locations near ground level from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the output of a 3dBi linearly polarised antenna is within the range of –161dBW to –153dBW for all antenna orientations orthogonal to the direction of propagation.

4.1.2 EGNOS SIS MESSAGE CHARACTERISTICS

The EGNOS SIS Navigation Data is composed of a number of different Message Types (MT) as defined in the SBAS standard. Table 4-1 describes the MTs that are used by EGNOS and their purpose. An OS receiver might only use a subset of them (see section 5).

The format and detailed information on the content of the listed MTs and their use at SBAS receiver level are given in ICAO SARPs [RD-1] and RTCA SBAS MOPS [RD-2].

4.2 EGNOS Time and Geodetic Reference Frames

Strictly speaking, the time and position information that are derived by an SBAS receiver that applies the EGNOS corrections are not referenced to the GPS Time and the WGS84 reference systems as defined in the GPS Interface Specification. Specifically, the position coordinates and time information are referenced to separate reference systems established by the EGNOS system, namely the EGNOS Network Time (ENT) timescale and the EGNOS Terrestrial Reference Frame (ETRF). However, these specific EGNOS reference systems are maintained closely aligned to their GPS counterparts and, for the vast majority of users, the differences between these two time/terrestrial reference frames are negligible.

4.2.1 EGNOS TERRESTRIAL REFERENCE FRAME – ETRF

EGNOS was initially designed to fulfil the requirements of the aviation user community as specified in the ICAO SBAS SARPS [RD-1]. [RD-1] establishes the GPS Terrestrial Reference Frame, WGS84, as the terrestrial reference to be adopted by the civil aviation community.

The EGNOS Terrestrial Reference Frame (ETRF) is an independent realisation of the International Terrestrial Reference System (ITRS[2]) which is a geocentric system of coordinates tied to the surface of the Earth and in which the unit distance is consistent with the International System of Units (SI[3]) definition of the metre. ITRS is maintained by the International Earth Rotation and Reference Systems Service (IERS[4]) and is the standard terrestrial reference system used in geodesy and Earth

2 Detailed information on ITRS (concepts, realisation, materialization ...) can be found on the official website: http://itrf.ensg.ign.fr/

3 Information on the International System of Units (SI) can be obtained from http://www.bipm.org/en/si/

4 Information on IERS can be obtained from http://www.iers.org/

Table 4-1 **EGNOS SIS transmitted MTs**

Message Type	Contents	Purpose
0	Don't Use (SBAS test mode)	Discard any ranging, corrections and integrity data from that PRN signal. Used also during system testing
1	PRN Mask	Indicates the slots for GPS and EGNOS GEO satellites provided data
2-5	Fast corrections	Range corrections and accuracy
6	Integrity information	Accuracy-bounding information for all satellites in one message
7	Fast correction degradation factor	Information about the degradation of the fast term corrections
9[4]	GEO ranging function parameters	EGNOS GEO satellites orbit information (ephemeris)
10	Degradation parameters	Information about the correction degradation upon message loss
12	SBAS network Time/UTC offset parameters	Parameters for synchronisation of EGNOS Network time with UTC
17	GEO satellite almanacs	EGNOS GEO satellites Almanacs
18	Ionospheric grid point masks	Indicates for which geographical point ionospheric correction data is provided
24	Mixed fast/long-term satellite error corrections	Fast-term error corrections for up to six satellites and long-term satellite error correction for one satellite in one message
25	Long-term satellite error corrections	Corrections for satellite ephemeris and clock errors for up to two satellites
26	Ionospheric delay corrections	Vertical delays/accuracy bounds at given geographical points
27	EGNOS service message	Defines the geographic region of the service
63	Null message	Filler message if no other message is available

WARNING

Under some circumstances, which would necessitate the ceasing of use of the EGNOS service for Safety of Life applications, the contents of MT0 will be similar to the one that should normally be broadcast through a MT2 (i.e. fast corrections) and could be processed by a non-SoL receiver like a regular MT2. This kind of message is usually named MT0/2. The performance experienced by OS users should be unchanged.

Since April 2003, the Message Type 0/2 is implemented under the MOPS Do229 specifications. It consists of broadcasting a message type 2, providing fast corrections and ranging data, on the frame reserved to the message type 0. It still indicates that the system is on test mode, but it also optimizes the use of the SIS data capacity.

OS users are advised not to use SIS data on any mode broadcast by the EGNOS GEO satellites in Test.

5 MT 9 is broadcast with some information about the orbital position of the broadcasting GEO satellite. At this stage, the EGNOS system does not support the Ranging function which is described in ICAO SARPs as an option. This is indicated by a special bit coding of the Health and Status parameter broadcast in MT 17.

research. Realizations of ITRS are produced by the IERS under the name International Terrestrial Reference Frames (ITRF). Several realizations of the ITRS exist, being ITRF2014 the last one.

In order to define the ETRF, the ITRF2000 coordinates and velocities of the RIMS antennas are estimated using space geodesy techniques based on GPS data. Precise GPS ephemeris and clock corrections produced by the International GNSS Service (IGS[6]) are used to filter the GPS data collected over several days at each RIMS site and to derive the antenna coordinates and velocities with geodetic quality. This process is repeated periodically (at least once per year) in order to mitigate the degradation of the ETRF accuracy caused by the relative drift between the two reference frames.

The ETRF is periodically aligned to the ITRF2000 in order to maintain the difference between the positions respectively computed in both frames below a few centimetres. The same can be said about the WGS84 (WGS84 (G1150) aligned to ITRF2000). Conversion of ETRF data into WGS84 (G1150) is obtained by applying the offset that exists at a certain epoch between the ETRF and the ITRF2000 to the ITRF2000 to WGS84 (G1150) frame. Note that currently these last two reference frames are almost equivalent (offsets minor than 2cm).

This means that, for the vast majority of applications, it can be considered that the positions computed by an EGNOS receiver are referenced to WGS84 and can be used with maps or geographical databases in WGS84.

4.2.2 EGNOS NETWORK TIME: ENT – GPS TIME CONSISTENCY

The time reference used by EGNOS to perform the synchronisation of the RIMS clocks is the EGNOS Network Time (ENT). The ENT timescale is an atomic timescale that relies on a group of atomic clocks deployed at the EGNOS RIMS sites. The EGNOS CPFs compute the ENT in real time, using a mathematical model which processes timing data collected from a subset of the RIMS clocks.

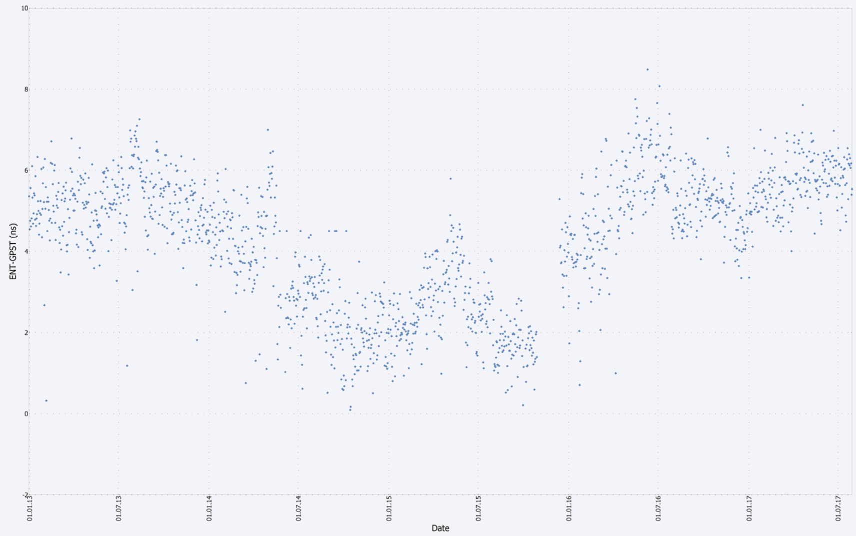
The ENT is continuously steered towards GPS Time (GPST) by the EGNOS Ground Control Segment and the relative consistency between the two timescales is maintained at the level of tens of nanoseconds as observed in Figure 4-1.

All satellite clock corrections computed by the EGNOS Ground Segment and transmitted to the EGNOS users are referenced to the ENT timescale. Moreover, the offset between ENT and UTC is broadcast in the EGNOS navigation message. Applying EGNOS corrections on GPS measurements, a precise time and navigation solution referenced to ENT is obtained. Therefore, the assessment of the time difference between ENT and UTC is a key issue for time users as described in section 7.2.

Despite the high level of consistency between the ENT and GPST timescales, EGNOS users are advised not to combine uncorrected GPS measurements (i.e. those referenced to GPST) and GPS measurements which have been corrected using EGNOS parameters (i.e. those referenced to ENT), when computing a navigation solution. Indeed, this approach might noticeably degrade the accuracy of the solution (by up to 10 to 20 metres). EGNOS users who want to combine GPS measurements referenced to different timescales should account for an additional unknown corresponding to the time offset between the two time references in the receiver navigation models.

6 Information on IGS can be obtained from http://igscb.jpl.nasa.gov/

Figure 4-1 **Figure 4-1: ENT GPS time offset evolution (Period January 13 - July 17)**



4.3 EGNOS SIS Performance in the Range Domain

This section focuses on the EGNOS SIS accuracy performance in the range domain. Accuracy in the range domain is defined as the statistical difference between the range measurement made by the user and theoretical distance between the true satellite position and the true user position. The EGNOS system has been qualified using conservative models that take into account the detailed behaviour of the EGNOS system under a number of operating conditions.

The accuracy performance at range level is characterised by two parameters, representing respectively the performance of the time and orbit determination process, and the ionospheric modelling process:

- The Satellite Residual Error for the Worst User Location (SREW) in the relevant service area, representing the residual range error due to the ephemeris and clock errors once EGNOS corrections are applied.
- The Grid Ionospheric Vertical Delay (GIVD) which represents the residual range error due to ionospheric delay after applying the EGNOS ionospheric correction at each of the grid points predefined in the MOPS [RD-2]. The ionospheric vertical delay relevant for a given user/satellite pair is the delay at the geographical point where the satellite signal crosses the ionospheric layer. This is called the User Ionospheric Vertical Delay (UIVD) and it is computed by interpolation of GIVDs of the neighbouring grid points.

Table 4-2 provides the comparison of the pseudorange error budget when using the EGNOS OS and GPS stand-alone to correct for clock, ephemeris and ionospheric errors.

Table 4-2 Typical EGNOS and GPS stand-alone SIS UERE

Error sources (1σ)	GPS - Error Size (m)	EGNOS - Error Size (m)
GPS SREW	**4.0** (see note 1)	**2.3**
Ionosphere (UIVD error)	**2.0 to 5.0** (see note 2)	**0.5**
Troposphere (vertical)	*0.1*	***0.1***
GPS Receiver noise	*0.5*	***0.5***
GPS Multipath (45º elevation)	*0.2*	***0.2***
GPS UERE 5 º elevation	**7.4 to 15.6**	**4.2** (after EGNOS corrections)
GPS UERE 90 º elevation	**4.5 to 6.4**	**2.4** (after EGNOS corrections)

Note 1: As of GPS Standard Positioning Service Performance Standard [RD-3].

Note 2: This is the typical range of ionospheric residual errors after application of the baseline Klobuchar model broadcast by GPS for mid-latitude regions.

The shaded parameters in the EGNOS columns are provided for information only and give an idea of the overall range accuracy performance that can be expected when using the EGNOS OS in a clear sky[7] environment with high-end receiver equipment properly accounting for tropospheric effects. Only the SREW and User Ionospheric Vertical Delay (UIVD) parameters do not depend on the type and brand of receiver.

Please note that the values in the GPS column are provided for information only and that the actual applicable UERE budget can be found in GPS SPS PS [RD-3]. In case where there are discrepancies between Table 4-2 and [RD-3], the latter shall prevail.

As stated above, the EGNOS SREW and UIVD values in Table 4-2 relate to the "Worst User Location" (WUL) inside the service area and are calculated with conservative models. EGNOS SIS Users will usually experience better performance.

Statistical data on the actually achieved range availability of EGNOS SIS are given in Appendix A.

7 Clear sky makes reference to the situation where no obstacles are causing obstructions or reflections in the GPS/EGNOS signals. In this scenario, all the satellites above the horizon (or above 5º elevation) are visible and can be used in positioning computation.

5 EGNOS RECEIVERS

Since the SBAS standards have been initially derived to meet the stringent navigation performance requirements applicable to civil aviation approach and landing operations, the reference SBAS receiver standards have also been developed by the civil aviation community. These standards are called SBAS Minimum Operational Performance Standards (MOPS) and are published by the Radio Technical Commission for Aeronautics (RTCA) under the reference DO-229 [RD-2] . This receiver standard has been designed by and for the aviation community and therefore supports both horizontal and vertical navigation and implements a large number of features aimed at ensuring the integrity of the derived position.

A number of these specific message processing techniques are not required for non – Safety of Life applications and may even result in degraded performance over what could be reached if implementing a tailored processing of EGNOS signals for OS. However, at this stage, no unique standard exists describing the use of EGNOS messages for OS users and therefore, different types of implementation have been selected by receiver manufacturers.

Typically, SBAS receiver designed to support the OS is expected to:

- Use the geostationary satellite ranging function if available (broadcast through message types 9 and 17). This function is not currently supported by EGNOS.
- Decode and apply satellite clock corrections (broadcast through message types 2 – 5 and corresponding to satellites selected by message type 1).
- Decode and apply satellite ephemeris corrections (broadcast though message types 24 – 25).
- Decode and apply ionospheric corrections (broadcast through message type 26 for ionospheric grid points selected by message type 18).
- Take into account major warnings sent through the SBAS messages (broadcast through message types 2 – 5 and 6).

Additionally, an OS receiver may use the content of message type 12, if used for time determination.

For the purpose of assessing the EGNOS OS performance as reported in section 6, the following assumptions have been made for the OS user equipment processing:

The system performance shall be met with any receiver that implements the MOPS DO-229 navigation weighted solution and message processing (equivalent to Class 3 GPS/WAAS receiver requirements) but which does not take into consideration the protection level criteria to declare that a solution is available.

Note that in the monitoring of satellites/Ionospheric Grid Points, an EGNOS OS receiver is assumed to take into account the UDRE/GIVE indicator status as a MOPS receiver Class 3 (i.e. those satellites or IGPs which are either "Not Monitored" or are labelled as "Don't Use" will be discarded).

Many GNSS receivers currently available on the market are able to receive and process EGNOS signals and can be used to support numerous non – Safety of Life applications. A non-exhaustive list of EGNOS compatible receivers available on the market with general information on their suitability for a set of identified applications can be found in the EC/ESA/CNES publication "Use Guide for EGNOS Application Developers" [RD-8] with the latest information available on the EGNOS Portal website (see section 3.2.2).

6 EGNOS OS Performances

6.1 EGNOS OS Description and Characteristics

The EGNOS OS was the first EGNOS Service declared operational on the 1st October 2009. It is intended for general purpose applications and consists of signals for augmenting GPS, freely accessible without any direct charge.

The EGNOS OS is available to any users equipped with a SBAS enabled receiver. The minimum performance reported in this section is the one that can be experienced when using receiving equipment compliant with RTCA MOPS DO229 Class 3 specifications as described in section 5. It also assumes GPS characteristic/performance as mentioned in section 2.1 and a clear sky environment with no obstacle masking satellite visibility greater than 5° above the local horizontal plane.

The OS will also be available to users having receivers not fully compliant to the MOPS, but which are able to process the following Message Types transmitted by EGNOS: 1, 3, 4, 5, 6, 9, 12, 17, 18, 24, 25, 26, 0/2 or 2. However, in this case, the observed performance may deviate (positively or negatively depending on the implementation chosen by the receiver manufacturer) from that reported in this section.

The "minimum" performance figures shown in this section tend to be more conservative than the "observed" figures presented in Appendix A, as those in Section 6 take into account a number of abnormal system states or non-typical environmental conditions that can statistically be expected to occur during the lifetime of the system.

Actually during periods with high ionospheric activity, as happens during the current solar cycle maximum activity intervals, the impact on observed figures is limited even when some degradations could be observed in some regions of Europe (mainly in the North and South west). Refer to Appendix D for additional information about how the ionospheric activity impacts GNSS and in particular EGNOS. These two types of characterisation are considered to provide valuable and complementary insights into EGNOS service performance for receiver manufacturers, for GNSS application developers and for end users of the EGNOS OS.

The performance reported in this document is the one that can be obtained with the version of EGNOS currently in operation. It is the objective that future versions will deliver, as a minimum, an equivalent level of performance. The SDD will be updated whenever necessary.

6.2 EGNOS OS Standard Performance

6.2.1 POSITIONING ACCURACY

The EGNOS OS minimum accuracy is specified in Table 6-1. Statistical values of the measured OS accuracy over Europe are provided in Appendix A.1.

6.2.2 POSITIONING ACCURACY COMPLIANCE AREA

The EGNOS OS compliance area has been defined as the minimum area where at least 99% of the time:

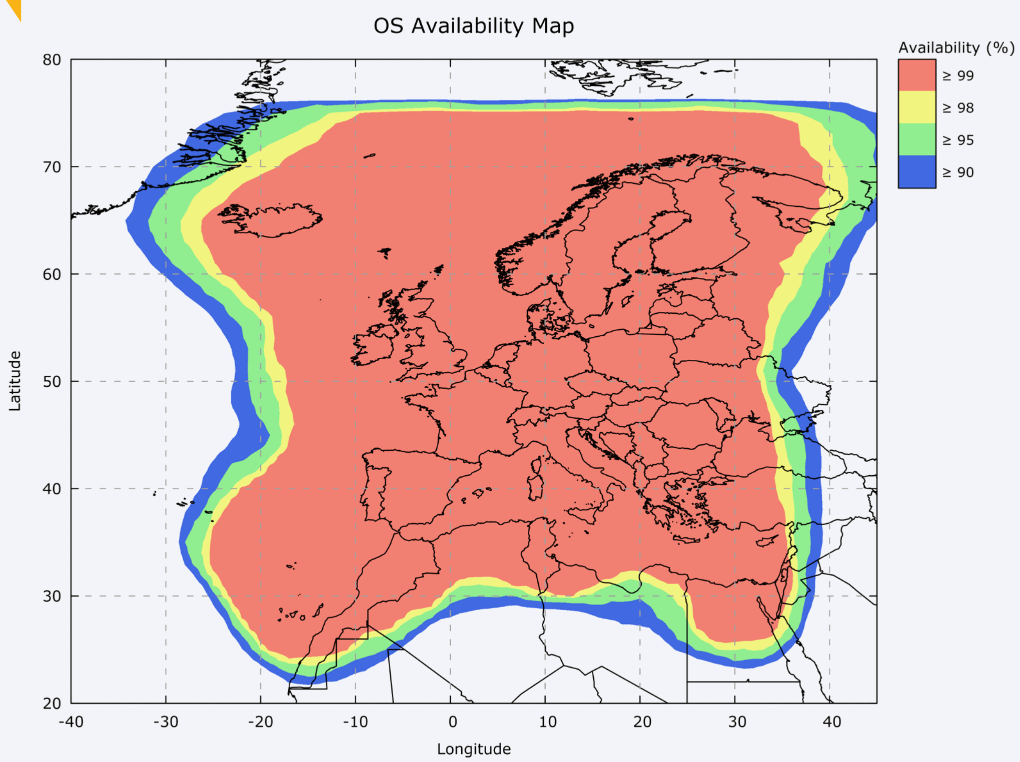
- the user is able to calculate its position and
- the instantaneous HNSE (Horizontal Navigation System Error) is lower than 3 meters and the VNSE (Vertical Navigation System Error) is lower than 4 meters.

This area is given in red in Figure 6-1. It has been elaborated on the basis of the results of several months of observation of EGNOS performance. The map represents the minimum level of performance which can be expected under the same conditions to those under which it has been computed. These conditions, which refer to both the internal status of the system (number of RIMS used, number of GEOs, etc) and the external conditions (GPS constellation status, environmental conditions, etc) are representative enough of nominal Open Service performance. Users can usually experience better performance as reported in Appendix A.2.

Table 6-1 OS Horizontal and Vertical Accuracy

Accuracy	Definition	Value
Horizontal	Corresponds to a 95% confidence bound of the 2-dimensional position error[8] in the horizontal local plane for the Worst User Location	3m
Vertical	Corresponds to a 95% confidence bound of the 1-dimensional unsigned position error in the local vertical axis for the Worst User Location	4m

Figure 6-1 EGNOS OS compliance area



8 As for the case of range errors, the horizontal and vertical positioning accuracies correspond to a composition of residual errors from different sources (EGNOS ground and space segments, local environment and user segment). The assumptions taken on residual error sources beyond the control of EGNOS (e.g. tropospheric effects, receiver noise and multipath) are similar to the ones described in section 4.3.

Use of the EGNOS OS is possible beyond the red area defined in Figure 6-1,

- however, the service performance will gradually degrade as the user moves away from the nominal compliance area as shown in Figure 6-1
- for a given accuracy performance, the service will become progressively less available as the user gets further from the compliance area (for example, 98% of the time in the yellow area). Alternatively, in order to maintain a given service availability performance (for example, 99% of the time), the user will have to accept statistically higher positioning errors than the ones described in section 6.2.1.

6.3 EGNOS OS Limitations

The EGNOS OS has been designed to improve the accuracy of the navigation solution over that available from a GPS – only receiver. In the vast majority of cases, the EGNOS OS will be available and will provide performance in line with or beyond the minimum performance levels described in the previous sections of this document. However, in a limited number of situations, users may experience non-nominal navigation performance levels. The most common causes for such abnormal behaviour are listed below in Table 6-2.

Table 6-2 EGNOS OS Limitations

Root Cause	Most Likely Symptoms
Broadcasting Delays As explained in section 3.1.2.3, one of the functions of EGNOS is to elaborate a model of the ionosphere and to broadcast this model to users so that they can correct the related errors. When using the SBAS standard, the reception of all the parameters that are necessary to build such a model may take up to 5 minutes to be received, depending on the receiver. Therefore, the full positioning accuracy may not be reached as soon as the receiver is turned on.	**EGNOS SoL Service Not Immediately Available** The receiver does not immediately use EGNOS to compute a navigation solution and therefore the position accuracy improvement is not available until a few minutes after the receiver is turned on.
GPS or EGNOS Signal Attenuation The receiver power level of GPS and EGNOS signals is extremely low. Using satellite navigation under heavy foliage or in an in-door environment will weaken further the signals up to a point where the receiver will either lose lock of such signals or have a very degraded performance.	**Degraded Position Accuracy** The position solution may demonstrate instability with higher error dispersion than usual. It may also be affected by sudden jumps when satellites are lost due to excessive attenuation. The performance of the receiver in such a difficult environment may be improved with a high quality receiver and antenna design.

Root Cause	Most Likely Symptoms
EGNOS Signal Blockage The EGNOS signals are broadcast by two geostationary satellites. This ensures some level of redundancy in case a satellite link is lost due to shadowing by a close obstacle (e.g. local orography or buildings). In addition, when moving North to high latitudes, the geostationary satellites are seen lower on the user's horizon and therefore are more susceptible to masking. At any latitude, it may happen that, in an urban environment, the EGNOS signals are not visible for some time.	**Degraded Position Accuracy After Some Time** The effect of losing the EGNOS signal (on both GEOs) on the receiver will be equivalent to reverting to a GPS-only receiver. The navigation solution will still be available but will demonstrate a degraded accuracy since no clock ephemeris or ionospheric corrections will be available to the user receivers. However, such degradation will not be instantaneous since the SBAS standard has been designed to cope with temporary signal blockages. The exact time the receiver can continue to provide good accuracy in case of the loss of signal depends on the receiver design.
Local Multipath In urban environments, the GPS and EGNOS signals will be prone to reflections on nearby objects (building, vehicles…). This may cause significant errors which cannot be corrected by the EGNOS system due to their local nature.	**Degraded Position Accuracy** The navigation solution will tend to meander around the true position and may demonstrate deviations of a few tens of metres. This effect will have a greater impact on static users or in those users moving at slow speed. High-quality receiver and antenna design is able to attenuate the effect of multipath in some specific conditions.
Local Interference GPS and EGNOS use a frequency band that is protected by the International Telecommunication Union (ITU). However, it is possible that in some specific locations, spurious transmissions from services operating in adjacent or more remote frequency bands could cause harmful interference to the satellite navigation systems. In most cases, national agencies are in charge of detecting and enforcing the lawful use of spectrum within their national boundaries.	**Degraded position accuracy or complete loss of service** Depending on the level of interference, the effect on the user receiver may be a degradation of the position accuracy (unusual noise level affecting the positioning) or a total loss of the navigation service in case the interfering signals preclude the tracking of navigation signals. The detection, mitigation and control of potential spurious transmissions from services operating in frequency bands that could cause harmful interference and effects to the satellite navigation systems (degrading the nominal performance) is under the responsibility of local authorities.

Root Cause	Most Likely Symptoms
Ionospheric Scintillation Under some circumstances due to solar activity and in some specific regions in the world (especially for boreal and subtropical latitudes), ionospheric disturbances (called scintillation) will affect the GPS and EGNOS navigation signals and may cause the complete loss of these signals for a short period of time.	**Degraded position accuracy** The position solution may be affected by sudden jumps when satellites are lost due to scintillation. If the number of tracked satellites drops seriously, a 3-dimensional position may not be available. Eventually, the navigation service may be completely lost in case less than 3 satellites are still tracked by the user receiver. In cases when only the EGNOS signal is lost, the impact will be similar to the one described for “EGNOS signal blockage” above.
Receiver Design and Configuration Refer to WARNING in section 4.1.2.	**Variable** Depending on the nature of the receiver implementation and configuration, the impact on the positioning may vary within different accuracy levels[9].
Degraded GPS Core Constellation The GPS constellation is under continuous replenishment and evolution. On rare occasions, it may happen that the basic GPS constellation (as described in the GPS SPS PS [RD-3]) becomes temporarily depleted and that it does not meet the GPS SPS PS commitment.	**Degraded EGNOS SoL Service performance** In such a case, the EGNOS OS performance can be degraded. The performance experienced by the receiver may be worse than the minimum performance indicated in section 6.2.1.

9 User should take into account that manufacturers are able to choose the most convenient way to apply EGNOS corrections, as far as any of these methods comply with MOPS (see [RD-2]). Thus, the receiver design will also affect the final performances of the user.

7 EGNOS Time Service Performance

In addition to positioning and navigation, EGNOS also offers timing service which is about the provision of a precise and stable atomic time reference which allows EGNOS users to have a highly accurate common time reference, for:

- Synchronization: using EGNOS Network Time (ENT) as an absolute atomic time reference to synchronize GNSS receivers in different locations.
- Timing: accurately measuring time against a standard and global time reference such as UTC.

The EGNOS Network Time (ENT) is not a recognised metrological timescale standard. In order to effectively support timing applications, the EGNOS system transmits specific corrections that allow the tracing of ENT to the physical realisation of the UTC by Observatoire de Paris, UTC (OP).

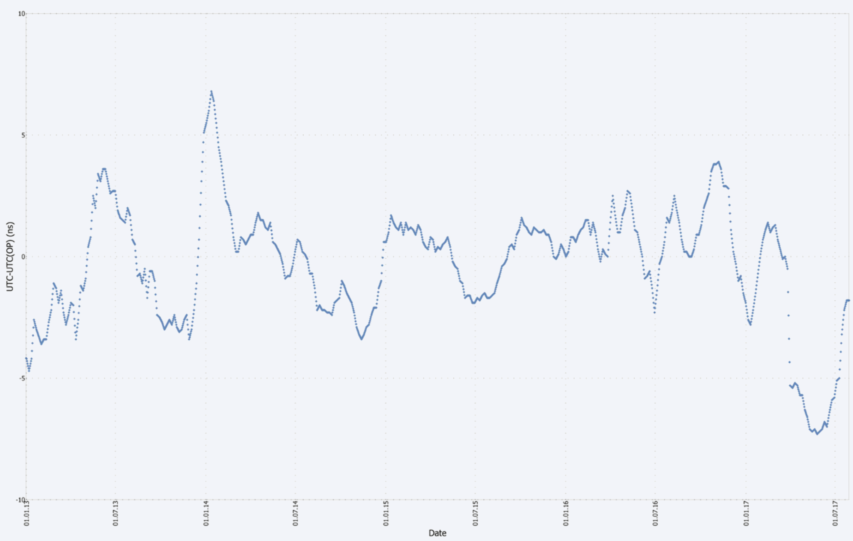
7.1 Coordinated Universal Time (UTC) Timescale and UTC (k)

Coordinated Universal Time (UTC), maintained by the Bureau International des Poids et Mesures (BIPM), is the time scale that forms the basis for the coordinated dissemination of standard frequencies and time signals

UTC is computed by the BIPM by processing clock data collected over a global network of atomic clocks operated by national metrology institutes and observatories. Each of these national institutes generates locally a physical realisation of the UTC which is commonly called UTC (k).

Unlike ENT and GPST, which are realised as continuous timescales consistent with the SI definition of the second,

Figure 7-1 Circular T UTC-UTC(OP) long-term evolution (January 2013 – July 2017)



UTC includes regular one-second magnitude discontinuities. These "leap seconds" are introduced artificially in UTC in order to keep its time of day aligned to mean solar time, which is based on the Earth's rotation period.

Ideally, EGNOS should provide traceability in real time to UTC as computed by BIPM. This is however not possible due to constraints which are difficult to overcome, such as the fact that the UTC time scale is available only 6 weeks afterwards (UTC is disseminated monthly through the BIPM publication "Circular T" with a latency of 6 weeks).

Instead of that, EGNOS provides access to the local UTC realisation at Observatoire de Paris, UTC(OP). A physical link between UTC(OP) and the EGNOS system has been established so that the ENT – UTC(OP) time offset can be monitored and predicted by the EGNOS system.

Figure 7-1 shows the evolution of the UTC – UTC (OP) offset from January 2013 to July 2017.

7.2 UTC (OP) Dissemination via EGNOS SIS

ENT is disseminated through the SBAS corrections embedded in the EGNOS Signal In Space. The accuracy of the local realization of ENT computed by an EGNOS receiver depends on the user ranging accuracy (affected by the errors described in Appendix B).

In order to access the EGNOS time service at a given instant, the EGNOS timing receiver first has to estimate the local ENT time by applying the EGNOS corrections to the GPS measurements. It is assumed that EGNOS timing users will use static receivers whose precise coordinates are known with an uncertainty of a few centimetres. In this case, the uncertainty of the local ENT time estimate can be modelled as:

$$\sigma(ENT_{local}) = \frac{UERE_{EGNOS}}{c\sqrt{N}} \text{ [sec]}$$

where

c is the speed of light

N is the number of measurements

Mobile EGNOS users can also have access to a local ENT realisation since it is estimated within the receiver navigation processing. However, in this case the accuracy of the ENT estimate is degraded with respect to the static case since it is amplified by the Time DOP[10].

$$\sigma(ENT_{local}) = \frac{UERE_{EGNOS}}{c} \cdot TDOP \text{ [sec]}$$

In order to relate the local realisation of ENT to UTC (OP), the EGNOS receiver has to decode the EGNOS message 12 (MT-12) which provides the time offset between the two timescales and apply it to the ENT estimate. The difference between ENT and UTC (OP) is modelled in MT-12 as an integer number of leap seconds plus a linear offset model (including the following parameters: bias, drift and time of applicability).

The accuracy of the offset between ENT and the UTC (OP) recovered using the message type 12 parameters is specified as 20 nanoseconds (3σ).

10 Time DOP (TDOP) is a factor due to satellite geometry and characterises how the range errors translate into time determination errors at user receiver level. More information about DOP-related terms can be found in Appendix B.

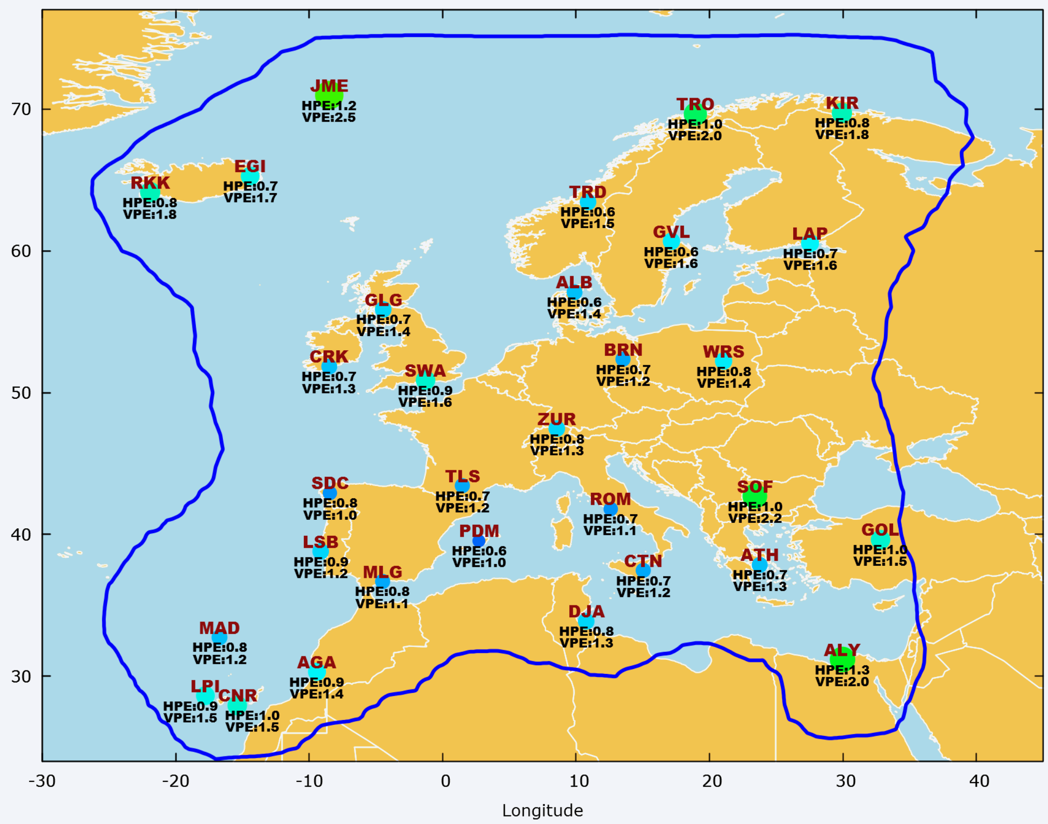
APPENDIX A:
EGNOS OS observed performance

This appendix to the EGNOS OS SDD provides the actual EGNOS OS accuracy performance that has been measured at 29 EGNOS RIMS sites (the ones inside the EGNOS OS positioning compliance area – see section 6.2.2) in the period March – August 2017.

Appendix A.1 Position Accuracy

The position accuracy is monitored using the EGNOS RIMS receivers. Figure 7-2 gives the HNSE (95%) and VNSE (95%) values measured during the last 6 months (March - August 2017) at 29 RIMS sites. The colour scheme for accuracy values varies from green (lower position accuracy) to blue (higher position accuracy).

Figure 7-2 EGNOS Open Service accuracy (95%)



The next figures show the histogram and cumulative distribution function of HNSE (Horizontal Navigation System Error) and VNSE (Vertical Navigation System Error), which are computed at the previous stations for each second.

Further updated information on EGNOS OS observed performance can be found/requested via the EGNOS Service Provider website (see section 3.2.2).

Figure 7-3 EGNOS Open Service HNSE Histogram and Cumulative Probability

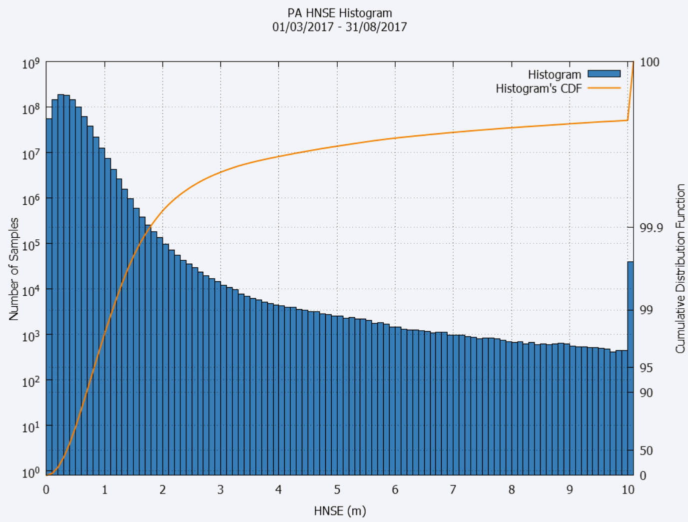
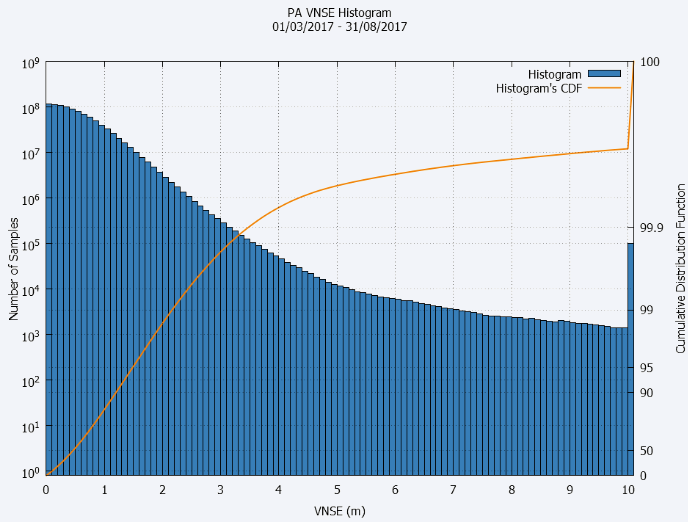


Figure 7-4 EGNOS Open Service VNSE Histogram and Cumulative Probability

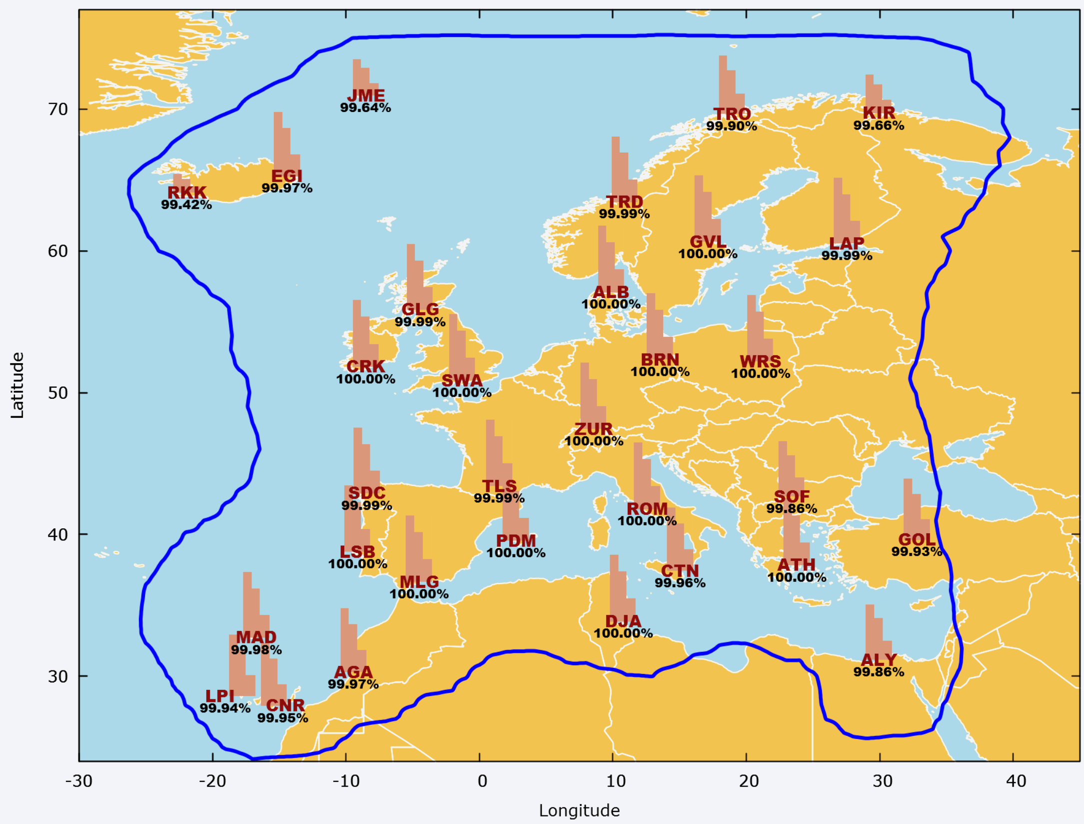


Appendix A.2 Open Service Availability

Figure 7-5 presents the Open Service Availability measured in the monitoring stations during the last 6 months (March – August 2017). EGNOS OS Availability is defined in the present document as the percentage of time when the instantaneous HNSE is lower than 3 meters and the instantaneous VNSE is lower than 4 meters.

The blue line of this figure indicates the OS Compliance Area, as was previously explained in section 6.2.2). The size of each icon represents the degree of compliance between the real performance measured and the reference value (99%).

Figure 7-5 EGNOS Open Service availability at reference stations



APPENDIX B: Satellite Navigation Concept

Satellite Navigation (GNSS) is a technique whereby mobile and static users can determine their position based on the measurement of the distance (range) between a number of orbiting satellites and the user receiver. Each satellite of the constellation broadcasts periodic signals that can be used by the user equipment to precisely determine the propagation time between the satellite signal transmission and the satellite signal reception by the receiver. This propagation time can easily be converted into a distance since, at a first approximation, the signals travel in space at a constant speed (the speed of light). Each satellite also continuously broadcasts all information (so-called ephemeris) necessary to determine the exact position of the satellite at any point in time.

Knowing the spacecraft position and the distance from that particular satellite, the user position is known to be somewhere on the surface of an imaginary sphere with a radius equal to that distance. If the position of and distance to a second satellite is known, the user/aircraft must be located somewhere on the circumference of the circle of where the two spheres intersect. With a third and fourth satellite, the location of the user can be inferred[11].

A GNSS receiver processes the individual satellite range measurements and combines them to compute an estimate of the user position (latitude, longitude, altitude, and user clock bias) in a given geographical coordinate reference frame.

The estimation of the satellite-to-user range is based on the measurement of the propagation time of the signal. A number of error sources affect the accuracy of these measurements:

- **Satellite clocks:** any error in the synchronisation of the different satellite clocks will have a direct effect on the range measurement accuracy. These errors are similar for all users able to view a given satellite.
- **Signal distortions:** any failure affecting the shape of the broadcast signal may have an impact on the propagation time determination in the user receiver.
- **Satellite position errors:** if the spacecraft orbits are not properly determined by the system's ground segment, the user will not be able to precisely establish the spacecraft location at any given point in time. This will introduce an error when computing the user position. The size of the error affecting the range measurements depends on the user's location.
- **Ionospheric effects:** The Ionosphere is an ionized layer of the atmosphere located a few hundred kilometres above the surface of the Earth. When transiting through the ionosphere, the satellite navigation signals are perturbed, resulting in range measurement errors. The size of the error will depend on the level of solar activity (peaks in the solar activity occur on approximately an 11-year cycle) and on the satellite elevation above the horizon. For a low elevation satellite (5° above the horizon), the error affecting the measurement is about 3 times larger than the error affecting a satellite seen at the zenith.
- **Tropospheric effects:** The troposphere is the lower part of the atmosphere where most weather phenomena take place. The signal propagation in this region will be affected by specific atmospheric conditions (e.g. temperature, humidity…) and will result in range measurement errors. The size of the error will also depend on the satellite elevation above the horizon. For a low elevation satellite (5° above the horizon), the error affecting the measurement is about 10 times larger than the error affecting a satellite seen at the zenith.
- **Reflections:** When propagating towards the user receiver, navigation signals are prone to reflections

11 Based on this principle (called triangulation), the location of a receiver could theoretically be determined using the distances from only 3 points (satellites). However, in reality, the determination of a location requires in addition an estimate of the "unknown" receiver clock bias. This necessitates an additional (4th) range measurement.

from the ground or nearby objects (buildings, vehicles...). These reflected signals combine with the direct signals and introduce a bias in the range measurements made by the user receiver, denoted as multipath error.

- **Thermal noise**, Interference and User receiver design: the navigation signals have an extremely low power level when they reach the user receiver. The range measurements made by the receiver will therefore be affected by ambient noise and interfering signals, and among other sources of disturbances, the accuracy of such measurements will also depend on the quality of the user receiver design.

When trying to characterise the overall range measurement errors, all error sources described above are aggregated and a unique parameter is used called the User Equivalent Range Error (UERE). The UERE is an estimate of the uncertainty affecting the range measurements for a given satellite.

When computing its position the user receiver combines the range measurements from the different satellites in view. Through this process, the individual errors affecting each range measurement are combined which results in an aggregate error in the position domain. The statistical relationship between the average range domain error and the position error is given by a factor that depends on the satellite geometry; this factor is named DOP (Dilution Of Precision).

One of the GNSS constellations is named Global Positioning System (GPS). The GPS is a space-based radio-navigation system owned by the United States Government (USG) and operated by the United States Air Force (USAF). GPS provides positioning and timing services to military and civilian users on a continuous worldwide basis. Two GPS services are provided: the Precise Positioning Service (PPS), available primarily to the armed forces of the United States and its allies, and the Standard Positioning Service (SPS) open to civil users (further information on SPS SIS or PPS SIS can be found on the web site of the National Executive Committee for Space-Based Positioning Navigation and Timing (PNT), http://pnt.gov/public/docs). The GPS Signal In Space characteristics are defined in the GPS ICD [RD-4].

The GPS SPS performance characteristics are defined in the GPS SPS Performance Standards (GPS SPS PS) [RD-3].

Other satellite navigation constellations are being deployed that are currently not augmented by EGNOS. In particular, the European Galileo constellation is meant to be augmented by subsequent versions of EGNOS.

The GPS architecture

In order to provide its services, the GPS system comprises three segments: the Control, Space, and User Segment. The Space and Control segments are briefly described below.

The Space Segment comprises a satellite constellation. The GPS baseline constellation comprises 24 slots in 6 orbital planes with four slots in each plane. The baseline satellites occupy these slots. Any surplus GPS satellites that exist in orbit occupy other locations in the orbital planes. The nominal semi-major axis of the orbital plane is 26,559.7 Km. The signals broadcast by the GPS satellites are in the L-band carriers: L1 (1575.42 MHz) and L2 (1227.6 MHz). Each Satellite broadcasts a pseudo-random noise (PRN) ranging signal on the L1 carrier.

The Operational Control System (OCS) includes four major subsystems: a Master Control Station, a backup Master Control Station, a network of four Ground Antennas, and a network of globally distributed Monitoring Stations. The Master Control Station is located at Schriver Air Force Base, Colorado, and is operated on a continuous basis (i.e. 24h, 7 days a week, all year); it is the central control node for the GPS satellite constellation and is responsible for all aspects of the constellation command and control.

APPENDIX C: Definitions

Terms	Definition
Accuracy	The position error is the difference between the estimated position and the actual position. The EGNOS OS minimum accuracy is specified in Table 6-1 Statistical values of the measured OS accuracy over Europe. For an estimated position at a specific location, the probability that the position error is within the EGNOS OS minimum accuracy requirements should be at least 95%.
Availability	EGNOS OS Availability is defined as the percentage of time when the instantaneous HNSE (Horizontal Navigation System Error) is lower than 3 meters and the instantaneous VNSE (Vertical Navigation System Error) is lower than 4 meters.
ECAC	Consists of the envelope of all FIRs of ECAC96 member States (including Canary Islands FIR) and the oceanic control areas of Reykjavik, Swanwick and Santa Maria. The ECAC landmass comprises the landmass region of ECAC member states, including ECAC islands (e.g. Canary Islands). EGNOS service coverage is limited in the North by 70 degrees latitude (70º N), in the South by 20 degrees latitude (20º N), in the East by 40 degrees longitude (40º E), and in the West by 40 degrees longitude (40º W).
EGNOS OS Compliance Area	Minimum area where at least 99% of the time any user is able to calculate its position with an instantaneous HNSE (Horizontal Navigation System Error) lower than 3 meters and an instantaneous VNSE (Vertical Navigation System Error) lower than 4 meters.
EGNOS Service Area	Geographic region defined in the EGNOS Service Message MT27 which comprises latitudes from 20º to 70º and longitudes from -40º to 40º. As part of the EGNOS Service Area, the concept of EGNOS OS Compliance Area is defined by the OS availability map.
End/ Final OS user	Every member of EGNOS OS user community interested in obtaining better positioning accuracy in those applications where safety is not critical (i.e. where a failure in availability, integrity, continuity and/or accuracy of the EGNOS SIS could not cause any kind of direct or indirect personal damage, including bodily injuries or death).

APPENDIX D: Ionospheric activity and impact on GNSS

Ionosphere and GNSS

Ionosphere is one of the main error sources in Global Navigation Satellite Systems (GNSS) error budget. The ionosphere is a highly variable and complex region of the upper atmosphere ionized by solar radiations and therefore containing ions and free electrons. The negatively charged free electrons and ions affect the propagation of radio signals and in particular, the electromagnetic satellite signals. Its dispersive nature makes the ionospheric refractive index different from unity. The structure of the ionosphere is continually varying in response to changes in the intensities of solar radiations: as solar radiation increases, the electron density in the ionosphere also increases. The ionosphere structure is also affected and disturbed by changes in the magnetic field of the Earth resulting from its interaction with the solar wind and by infrequent high-energy particles ejected into space during powerful solar eruptions such as coronal mass ejections and solar flares.

The ionospheric effects on satellite signals must be properly accounted for in the GNSS positioning process in order to obtain reliable and accurate position solutions. A large number of models and methods for estimating the ionospheric signal delay have been developed. The most widely used model is probably the Klobuchar model. Coefficients for the Klobuchar model are determined by the GPS control segment and distributed with the GPS navigation message to GPS receivers where the coefficients are inserted into the model equation and used by receivers for estimation of the signal delay caused by the ionosphere.

In the case of SBAS systems, the SBAS receivers inside the corresponding service area use the SBAS ionospheric corrections, which are derived from real-time ionospheric delay measurements. The SBAS ground system obtains these measurements from a network of reference stations and uses them to estimate the vertical delays and associated integrity bounds at the ionospheric grid points (IGPs), of a standardized ionospheric grid located 350 km above the surface of the Earth (ICAO SARPs for SBAS [RD-1].). The user equipment uses the SBAS grid information to compute a vertical delay and vertical integrity bound for each line of sight to a satellite; then applies a standardized "obliquity factor" to account for the angle at which the line of sight pierces the ionospheric grid.

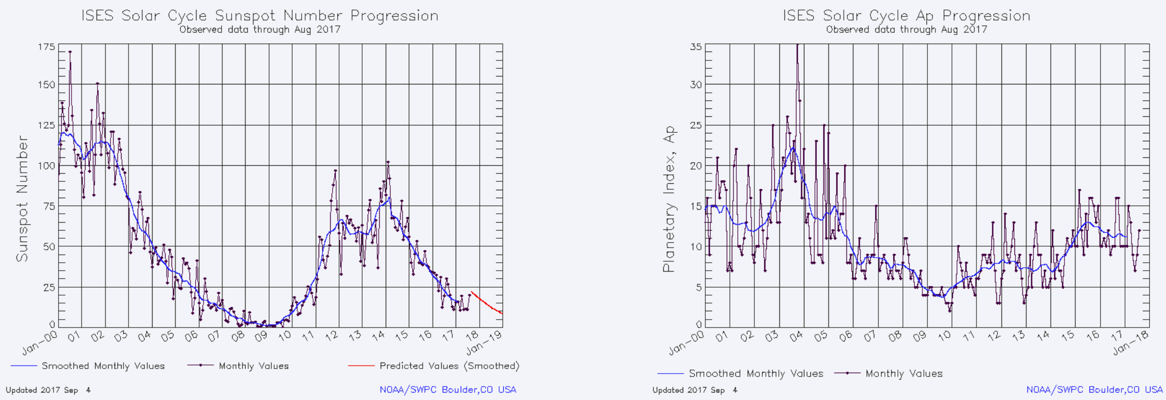
Impact of the ionospheric activity on GNSS

The GNSS signal delay, as direct effect of ionosphere, is always present and varies in size however it is generally well modelled and can be estimated to an extent that makes GNSS/SBAS usable. During periods with increased ionospheric activity or geomagnetic storm (caused by sudden eruptions of the Sun), GNSS/SBAS users can experience residual ionospheric effects owing to a high ionosphere variability impossible to be effectively modelled and corrected, which can reduce positioning, navigation, and timing performance.

Currently we are in the second half of solar cycle #24 which started in 2008. The solar cycle is the periodic change in the Sun's activity (including changes in the levels of solar radiation and ejection of solar material) and appearance (visible in changes in the number of sunspots, flares, and other visible manifestations) with a typical duration of eleven years. The number of sunspots (SSN) and the planetary geomagnetic indicator (Ap) are two of the main parameters to monitor the ionosphere behaviour (Figure 7-6). A first maximum of number of sunspots was reached in 2012 and a second relative maximum, higher than the first one, was reached in 2014. During 2015 the activity presented values similar to those observed in year 2011 and during 2017 the activity has continued decreasing.

The dependence of SBAS system performance on the ionosphere variations was especially noticeable during the period of solar activity increase in 2014 when EGNOS and other GNSS/SBAS systems were affected. SBAS systems estimate ionospheric delays assuming a bi-dimensional behaviour of the ionosphere (no height), which is valid in a nominal situation, but which is not accurate in case of high geomagnetic activity or ionospheric storms when

Figure 7-6 **SSN (left) and Ap (right) progression from NOAA/SWPC**



the ionosphere behaves as a 3-dimensional body (whose properties change with the height). This is considered as an intrinsic limitation of single frequency SBAS systems.

This link between EGNOS performance and solar activity is particularly clear in the case of performance degradations observed in the North of Europe during periods with very high geomagnetic activity.

Improvement and communication to users

For EGNOS, an improved level of stability concerning ionosphere effects estimation was achieved after the deployment of the EGNOS 2.3.1i in August 2012. EGNOS system release 2.3.2, deployed in October 2013, increased the robustness of EGNOS against this kind of events. However, even if ESR 2.3.2 provided a high stability to ionospheric disturbances, some degradation was still being expected during periods with very high ionospheric activity or under geomagnetic storm conditions. Since the deployment of the EGNOS system release ESR 2.4.1M in August 2015, the EGNOS system provides even further robustness to these ionospheric events.

It must be noted that this behaviour is limited to periods in which the ionosphere presents an important activity, what is specially high during the spring and autumn periods, presenting a better stability during the summer and winter periods.

ESSP SAS jointly with GSA and ESA are advancing towards a deeper understanding of the effects of ionosphere at user performance level in order to improve the EGNOS system behaviour towards ionospheric disturbances, make it more robust and provide a better service to the EGNOS users. ESSP SAS, as the EGNOS Service Provider, is continuously analysing the impact which could be faced by the different EGNOS users' communities. Whenever there is any relevant information (complementary to the different SDDs) related to this matter that could be of interest for the users, an EGNOS Service Notice is published in the EGNOS user support webpage (https://egnos-user-support.essp-sas.eu/new_egnos_ops/content/service-notices) and distributed.

APPENDIX E:
List of acronyms

The following table provides the definition of the acronyms used in this document.

Acronym	Definition
AENA	Aeropuertos Españoles y Navegación Aérea
ANSP	Air Navigation Service Provider
AOR	Atlantic Ocean Region
ASQF	Application Specific Qualification Facility
BIPM	Bureau International des Poids et Mesures
C/A	Coarse/Acquisition
CCF	Central Control Facility
CNES	Centre National d'Études Spatiales
CPF	Central Processing Facility
DAB	Digital Audio Broadcast
dBi	deciBel isotropic
dBW	deciBel Watt
DFS	Deutsche Flugsicherung
DGAC	Direction Générale de l´Aviation Civile
DOP	Dilution Of Precision
DSNA	Direction des Services de la Navigation Aérienne
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
ENAV	Ente Nazionale Di Assistenza Al Volo
ENT	EGNOS Network Time
ESA	European Space Agency
ESR	EGNOS System Release
ESSP	European Satellite Services Provider
ETRF	EGNOS Terrestrial Reference Frame
EU	European Union
EWAN	EGNOS Wide Area Network
FAA	Federal Aviation Administration
FDE	Fault Detection and Exclusion
FIR	Flight Information Region
FTP	File Transfer Protocol
GAGAN	GPS Aided GEO Augmented Navigation
GEO	Geostationary Satellite
GIVD	Grid Ionospheric Vertical Delay
GIVE	Grid Ionospheric Vertical Error

Acronym	Definition
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPST	GPS Time
GSA	European GNSS Agency
HDOP	Horizontal Dilution of Precision
HMI	Hazardous Misleading Information
HNSE	Horizontal Navigation System Error
HPE	Horizontal Position Error
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IERS	International Earth Rotation and Reference Systems Service
IGP	Ionospheric Grid Point
IGS	International GNSS Service
IOR	Indian Ocean Region
IP	Internet Protocol
IS	Interface Specification
ISRO	Indian Space Research Organisation
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunications Union
LPV	Localizer Performance with Vertical guidance
MCC	Mission Control Centre
MI	Misleading Information
MLIT	Ministry of Land, Infrastructure, Transport and Turism (Japan)
MOPS	Minimum Operational Performance Standards
MSAS	MTSAT Satellite-based Augmentation System
MT	Message Type
MTSAT	Multi-Function Transport Satellite
NATS	National Air Traffic Services
NAV-EP	Navegaçao Aerea de Portugal
NLES	Navigation Land Earth Station
OCS	Operational Control System
OS	Open Service
PACF	Performance and Check-out Facility
PDOP	Position Dilution Of Precision
PL	Protection Level
PNT	Precise Navigation and Timing
PPS	Precise Positioning Service

Acronym	Definition
PRN	Pseudo-Random Number
PS	Performance Standard
RAIM	Receiver Autonomous Integrity Monitoring
RD	Reference Document
RHCP	Right Hand Circularly Polarised
RIMS	Range and Integrity Monitoring Station
RTCM	Real Time Correction Message
SARPs	Standards and Recommended Practices
SAS	Société par Actions Simplifiée
SBAS	Satellite-Based Augmentation System
SDCM	System of Differential Correction and Monitoring
SDD	Service Definition Document
SES	Single European Sky
SI	International System of Units
SIS	Signal-In-Space
SoL	Safety of Life
SOLAS	Safety Of Life At Sea
SPS	Standard Positioning Service
SPU	Service Provision Unit
SREW	Satellite Residual Error for the Worst user location
SW	Software
TDOP	Time Dilution Of Precision
TEC	Total Electron Content
TF	Technical File
TN	Technical Note
TTA	Time-To-Alert
TWAN	Transport Wide Area Network
UDRE	User Differential Range Error
UERE	User Equivalent Range Error
UIVD	User Ionospheric Vertical Delay
US	United States
UTC	Coordinated Universal Time
UTC(OP)	Coordinated Universal Time (Observatoire de Paris)
VDOP	Vertical Dilution of Precision
VNSE	Vertical Navigation System Error
VPE	Vertical Position Error
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 84 (GPS Terrestrial Reference Frame)
WUL	Worst User Location

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European
Global Navigation
Satellite Systems
Agency