EGNOS Safety of Life (SoL)

Service Definition Document

DOCUMENT CHANGE RECORD

Revision	Date	Summary of changes
1.0	02/03/2011	First release of the document
2.0	28/06/2013	Update of the document including the improvements derived from the latest EGNOS system releases. Alignment with the latest versions of the EGNOS Open Service SDD and the EDAS SDD.
2.1	19/12/2014	EGNOS system information updated Update with new commitment maps for ESR2.3.2. Observed performance figures updated EGNOS NOTAM proposals updated with current service level provided New appendix D on the impacts of ionospheric activity on GNSS
2.2	07/04/2015	Figure 4-1 corrected

EGNOS

EGNOS, it's there. Use it.

EGNOS Safety of Life (SoL)

Service Definition Document

European
Global Navigation
Satellite Systems
Agency

Precise navigation,
powered by Europe

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

Table of Content

TABLE OF FIGURES

TABLE OF TABLES

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.

The EGNOS Safety of Life (SoL) Service is provided openly and is freely accessible without any direct charge, and is tailored to safety-critical transport applications in various domains, in particular for aviation applications. The service is thus compliant with the aviation APV-I (Approach with Vertical Guidance) requirements, as defined by ICAO in Annex 10 [RD-1], but may support also applications in other SoL domains. The operational use of the EGNOS SoL Service may require specific authorisation by the relevant authorities in the application sectors concerned.

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

The document describes the EGNOS system architecture and Signal-In-Space (SIS) characteristics, the SoL 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 Air Navigation Service Providers (ANSPs), receiver manufacturers, equipment integrators, airlines, operators, GNSS application developers and the final users of the EGNOS SoL Service.

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

This document is not intended to address EGNOS Open Service (OS) nor EDAS performance. Information about the EGNOS OS is available in a separate document called the "EGNOS Open Service - Service Definition Document" (EGNOS SDD OS - [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 SoL Service.

2 Introduction

2.1 Purpose and Scope of the Document

The EGNOS Safety of Life SDD (EGNOS SoL SDD) presents the characteristics of the service offered to users by EGNOS Safety of Life (SoL) Service highlighting the positioning performance currently available to suitably equipped users using both the GPS SPS broadcast signal and the EGNOS SoL augmentation signals.

The minimum level of performance of the EGNOS SoL Service as specified in the EGNOS SoL 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] and;
- The receiver characteristics as described in sections 3 and 4.

The EGNOS SoL SDD comprises 6 main sections and 5 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 SoL Service use, including liability, and its intended lifetime.
- Section 3 ("Description of the EGNOS System and EGNOS SoL Service Provision Environment") gives a brief overview of the EGNOS system, as well as its technical and organisational framework for EGNOS SoL service provision.
- Section 4 ("EGNOS SIS") introduces the EGNOS Signal In Space characteristics and performance in the range domain.
- Section 5 ("EGNOS Receivers") briefly presents the certification context for aviation receivers.
- Section 6 ("EGNOS SoL Service Performance") describes the positioning Service offered to users by the EGNOS SoL Service and the minimum performance in the positioning domain.
- Appendix A contains fundamental information of the satellite navigation (GNSS) as complementary concepts for the rest of the documents.
- Appendix B describes the integrity concept used in EGNOS.
- Appendix C presents relevant definitions.
- Appendix D assesses the impact of the ionospheric activity on GNSS and in particular on SBAS systems.
- Appendix E provides the list of acronyms used in the document.

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

2.2 EGNOS SoL Service Description

The EGNOS SoL Service consists of signals for timing and positioning intended for most transport applications in different domains. Nevertheless, navigation operations based on the EGNOS SoL Service may require a specific authorisation, issued by the relevant authority, unless the authority, or applicable regulation, establishes that no such authorisation is required.

The SoL service is based on integrity data provided through the EGNOS satellite signals.

The main objective of the EGNOS SoL service is to support civil aviation operations down to LPV (Localiser Performance with Vertical guidance) minima. However, the SoL Service is also intended to support applications in a wide range of other domains such as maritime, rail and road.

2.3 Terms and Conditions of Use of EGNOS Safety of Life Service, Including Liability

2.3.1 SCOPE OF THE EGNOS SAFETY OF LIFE SERVICE COMMITMENT

The EGNOS Safety of Life service (further **"EGNOS SoL Service"**) 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 SoL Service Definition Document (further **"EGNOS SoL 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.

2.3.2 WHO CAN USE THE EGNOS SoL SERVICE?

In general, the EGNOS SoL Service is intended for most transport applications in different domains where lives could be endangered if the performance of the navigation system is degraded below specific accuracy limits without giving notice in the specified time to alert. This requires that the relevant authority of the particular transport domain determines specific requirements for the navigation service based on the needs of that domain, as well as certification procedures if necessary. In addition, the navigation operations based on the EGNOS SoL Service may require a specific authorisation, issued by the relevant authority, unless the authority, or applicable regulation, establishes that no such authorisation is required.

At the date of EGNOS SoL SDD publication, only the aviation domain has specific service requirements, as well as certification and individual authorisation procedures developed and implemented.

Therefore, from the date of EGNOS SoL SDD publication the EGNOS SoL Service is tailored for use in aviation, for all phases of flight within the corresponding EGNOS SoL Service area, to aviation users (further **"Aviation Users"**) namely:

- *Airspace users*, as defined in the Single European Sky (SES) framework Regulation[1], equipped with an EGNOS certified receiver and located within the appropriate EGNOS SoL Service area corresponding to the phase of flight in which the EGNOS SoL Service is used (as described in the EGNOS SoL SDD);
- *Certified Air Navigation Service Providers* (ANSP) having signed an EGNOS Working Agreement with the European Satellite Services Provider (ESSP SAS), the certified EGNOS Services Provider, that is valid at the moment of the use of the EGNOS SoL Service.

2.3.3 OBLIGATIONS OF THE USERS TO EXERCISE DUE CARE

EGNOS is a complex technical system and the users also have certain obligations to exercise due care in using the EGNOS SoL Service. Before any use of the EGNOS SoL Service, all users should study this document in order to understand whether and how they can use the service,

1. Regulation (EC) No 1070/2009 (revision and extension of Regulation No 549/2004) of the European Parliament and of the Council of October 21 2009 aiming at increasing the overall performance of the air traffic management system in Europe (SES II Package).

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) to any party, other than Aviation Users specified under 2.3.2 above, and/or for any other use of the EGNOS SoL 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 SoL 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 SoL Service.

Furthermore, no party shall be entitled to any claim against ESSP SAS and/or the European Union and/or the GSA if the damage is the result, or the consequence, of one of the following events:

- Use of EGNOS SoL Service beyond the conditions and limitations of use set forth in the EGNOS SoL SDD, or
- Use of equipment or receivers which are
  - not fully compliant to MOPS (Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment) or
  - not certified or approved by the relevant competent authority or
  - malfunctioning, or
- Use of the EGNOS SoL Service when a test message is broadcast (a Message Type 0 or a Message Type 0/2), or
- Use of the EGNOS SoL Service without required authorisation, or
- In case of a Force Majeure event.

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). Aviation Users may also contact their National Supervisory Authority (NSA).

2.4 EGNOS SoL 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 or D)
[RD-3]	GPS Standard Positioning Service Performance Standard – 30th September 2008 4th Edition
[RD-4]	IS GPS 200 Revision H – NAVSTAR GPS Space Segment / Navigation User Interface – 24th September 2013
[RD-5]	EGNOS Service Definition Document – Open Service (OS SDD) http://egnos-portal.gsa.europa.eu/library/technical-documents
[RD-6]	EGNOS Data Access Service – Service Definition Document (EDAS SDD) http://egnos-portal.gsa.europa.eu/library/technical-documents
[RD-7]	REGULATION (EU) No 1285/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013on 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]	Single European Sky (SES) regulatory requirement RE (CE) 1070/2009 (revision and extension of EC 550/2004)
[RD-9]	Single European Sky (SES) regulatory requirement RE (CE) 691/2010 (amendment of EC 2096/2005)
[RD-10]	EC/ESA/CNES User Guide for EGNOS Application Developers Ed. 2.0 – 15th December 2011
[RD-11]	ICAO SARPs, Annex 15 Aeronautical Information Services, Amendment 77, 28th November 2002
[RD-12]	The European Concept for GNSS NOTAM, V2.7, 29th November 2011

3 Description of the EGNOS System and EGNOS SoL Service 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 safety critical applications, they may directly impact the safety 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 GPS 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.

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 A 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 global 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 in Europe 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 and the corresponding SDD is [RD-5].

Safety of Life Service (SoL)

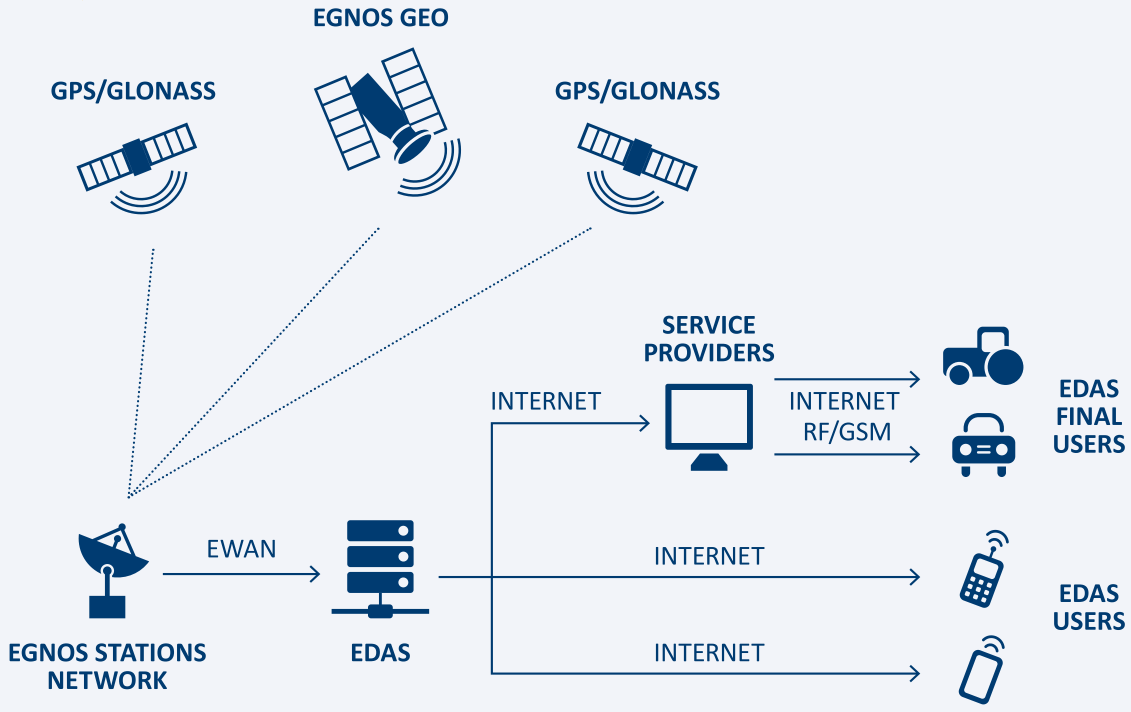
The main objective of the EGNOS SoL service is to support civil aviation operations down to Localiser Performance with Vertical Guidance (LPV) minima. At this stage, a detailed performance characterisation has been conducted only against the requirements expressed by civil aviation but the EGNOS SoL 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].

The EGNOS SoL Service has been available since March 2nd 2011 being this document the applicable SDD.

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[2] to final customers.

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

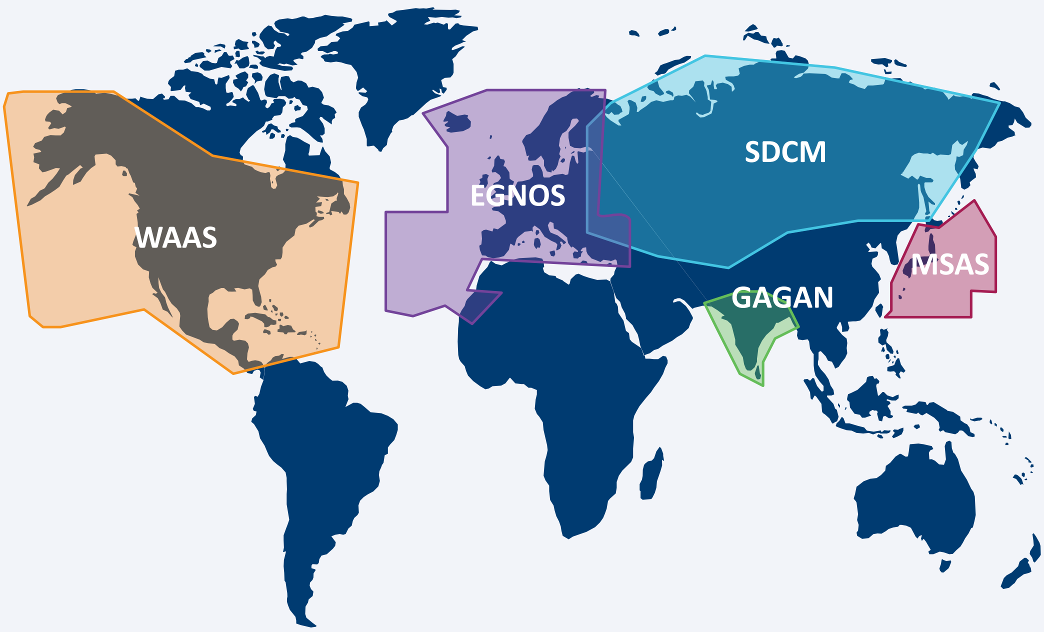
3.1.2.2 EGNOS: The European SBAS

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) and Japan (MTSAT Satellite based Augmentation System – MSAS). Implementation of analogous systems is being investigated in other regions of the world (e.g. GPS Aided GEO Augmented Navigation – GAGAN in India and System of Differential Correction and Monitoring – SDCM in Russia). 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): http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/
- SDCM, Federal Space Agency ("Roscosmos"): http://www.sdcm.ru/index_eng.html

Figure 3 2 **Existing and planned SBAS systems**



2. 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 RIMS data; provision of performance data (e.g. XPL availability maps, GIVE maps, etc.); provision of EGNOS message files.

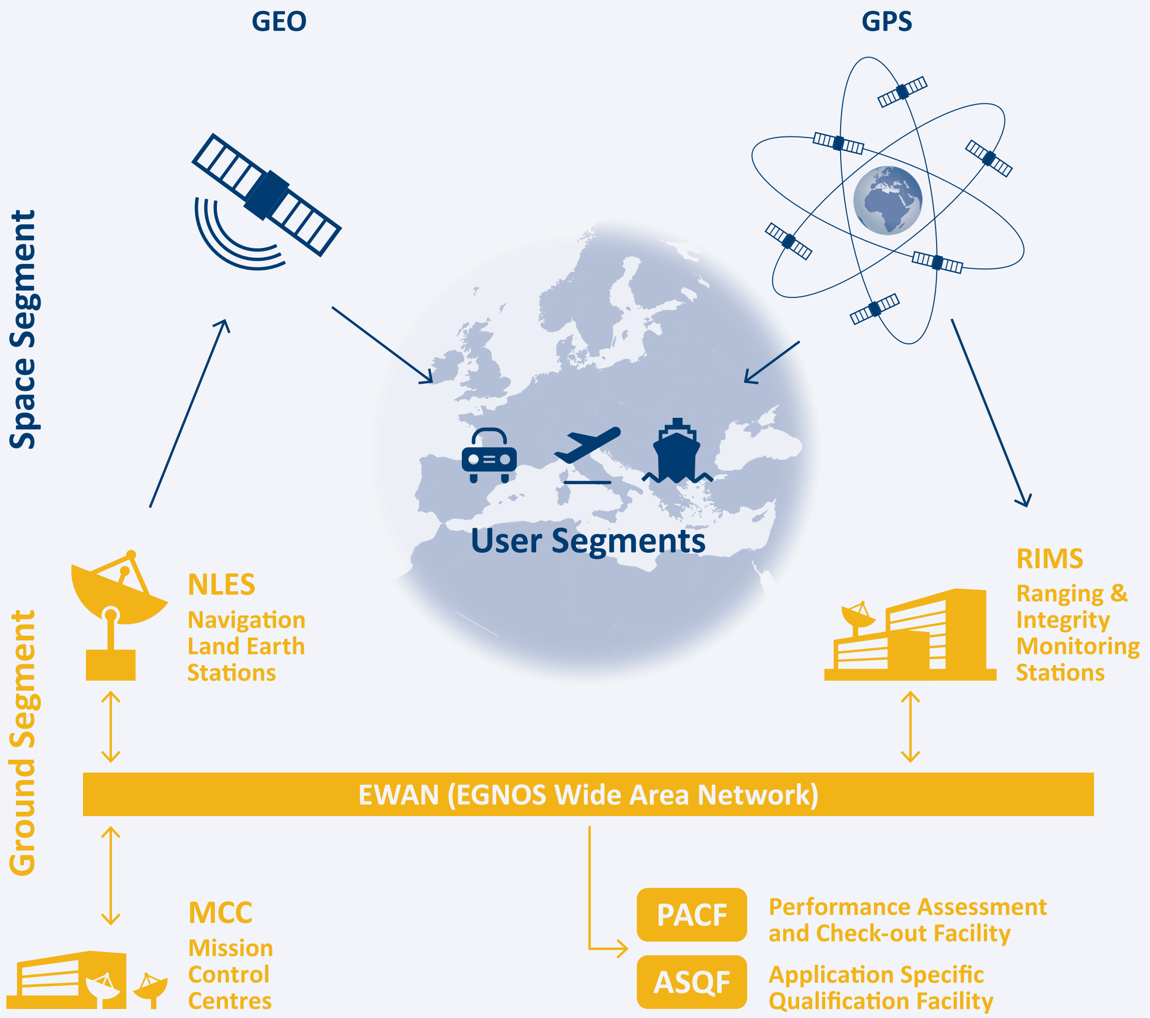
- MSAS, Japanese Ministry of Land, Infrastructure, Transport and Turism (MLIT): http://www.mlit.go.jp/
- GAGAN, Indian Space Research Organisation (ISRO): http://www.isro.org/scripts/futureprogramme.aspx?Search=gagan#Satellite

In addition, most of these systems 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 3 geostationary (GEO) satellites broadcasting corrections and integrity information for GPS satellites in the L1 frequency band (1,575.42 MHz). At the date of publication the 3 GEOs used by EGNOS are (see *table 3 1*).

EGNOS GEO satellites INMARSAT 3F2 AOR-E (PRN 120) and 4F2 EMEA (PRN 126) are currently part of the EGNOS operational platform and are transmitting the operational Signal-In-Space (SIS) to be used by EGNOS users. SES-5 (PRN 136) is part of the EGNOS TEST Platform broadcasting the TEST SIS.

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 of the three GEOs broadcast an operational 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.

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. However, all SBAS user receivers are designed to automatically detect and use any code in a pre-allocated set reserved for SBAS. Such evolutions will therefore be transparent for end users and will not necessitate any human intervention or change of receiving equipment. For this purpose, and whenever there could be any relevant information complementing the SDD, an EGNOS Service Notice is published (http://www.essp-sas.eu/service_notices) and distributed.

Table 3 1 GEOs used by EGNOS

GEO Name	PRN Number	Orbital Slot
INMARSAT 3F2 AOR-E	PRN 120	15.5 W
INMARSAT 4F2 EMEA	PRN 126	25.0 E
SES-5	PRN 136	5 E

EGNOS Ground Segment

The EGNOS Ground Segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), four Mission Control Centres (MCC), six Navigation Land Earth Stations (NLES), 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 39 RIMS sites located over a wide geographical area.

Figure 3 4 shows the geographical distribution of the RIMS already in operation and the RIMS currently under deployment.

• 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.
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 (less than Time To Alert (TTA)) 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.

Figure 3 4 EGNOS RIMS sites

• 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 agreements 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 play the role of a design and procurement agent for system evolutions.

The European Satellite Services Provider (ESSP) SAS is the 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, including the operation and technical management of EGNOS.

ESSP SAS has been awarded the operations and service provision contract by GSA for EGNOS until the end of 2021.

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* below lists the main sources of information about EGNOS.

EGNOS SoL SDD readers are also invited to refer to the GPS SPS PS [RD-3] and European Aviation Safety Agency (EASA) European Technical Standard Order (ETSO)-145/146 for details of both the fundamental GPS SPS service and EGNOS receiver equipment respectively. 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], except for the continuity requirements where some waivers exist as detailed in section 6.3.1.4 for NPA and in section 6.3.2.5 for APV-I.

3.2.3 EGNOS NOTAM PROPOSALS GENERATION

A NOTAM (Notice to Airmen) is a notice issued to alert pilots of potential hazards along a flight route that could affect the safety of the flight.

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/enterprise/policies/satnav/index_en.htm
EGNOS general information and EGNOS applications	GSA	http://www.egnos-portal.eu
EGNOS Status and Performance ESSP official reporting of the system status, performances, services, news, applicable documentation, service notices etc.	ESSP	http://www.essp-sas.eu
EGNOS User Support ESSP dedicated service to users on EGNOS status, system description, real time services performances, forecasts, FAQs, etc. A specific EDAS section is also available.	ESSP	http://egnos-user-support.essp-sas.eu/
EGNOS Helpdesk Direct point of contact for any question related with the EGNOS system, its performances and applications.	ESSP	egnos-helpdesk@essp-sas.eu +34 911 236 555
EGNOS System ESA dedicated services and detailed technical information on EGNOS.	EASA	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

The objective of the EGNOS NOTAM proposal generation is to:

- Predict APV-I service outages at given airports.
- Create and format the corresponding NOTAM proposals into an ICAO format [RD-11] and according to the European Concept for GNSS NOTAM [RD-12] to ease the validation process to be performed by the NOF (NOTAM Offices).
- Distribute the NOTAM proposals to the concerned NOFs through the AFTN network.

The need for a NOTAM service when implementing SBAS based approach procedures is clearly stated by the ICAO SARPs ([RD-11]). Apart from establishing the NOTAM service as a key element in the implementation of SBAS based approach procedures, the ICAO SARPs also lay down the applicable recommendations for this kind of service, in terms of notification timeliness.

Since the 2nd of March 2011 (EGNOS SoL Service Declaration date), the ESSP, as the EGNOS Services Provider, is providing the EGNOS NOTAM proposals service, through the corresponding national AIS provider, to any airport having an EGNOS based approach procedure published. Hence, the ESSP acts as data originator in the EGNOS NOTAM generation chain. In particular, ESSP provides NOTAM proposals to the corresponding national NOTAM Offices (AIS provider) of the concerned States, which are responsible for the validation and publication of NOTAMs for end users.

Please note that, apart from the EGNOS NOTAM proposals, there is no other EGNOS operational status information provided in line with the EGNOS based approaches applicable concept of operations; specifically there is no EGNOS operational status information provided to aerodrome control towers and units providing approach control services as of ICAO Annex 10 Volume I, 3.7.

Figure 3 5 **ESSP NOTAM proposal service within the NOTAMs life cycle**

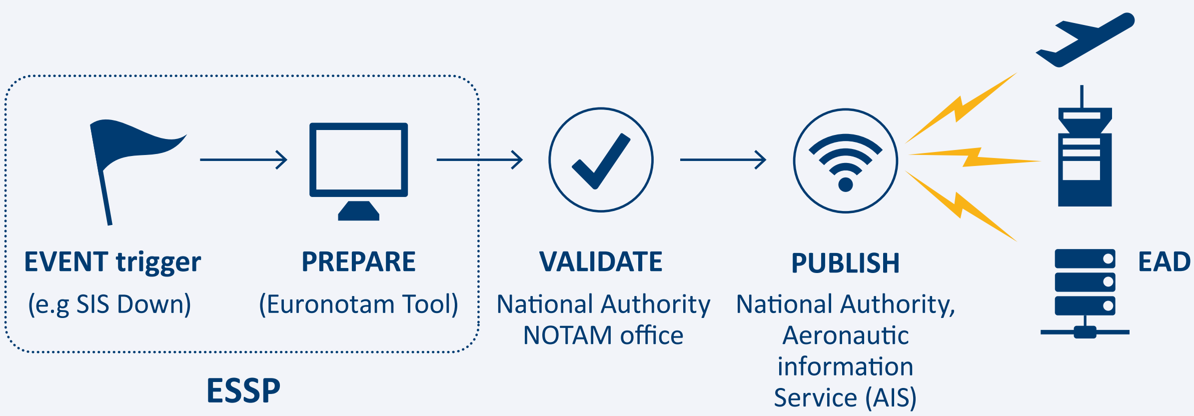
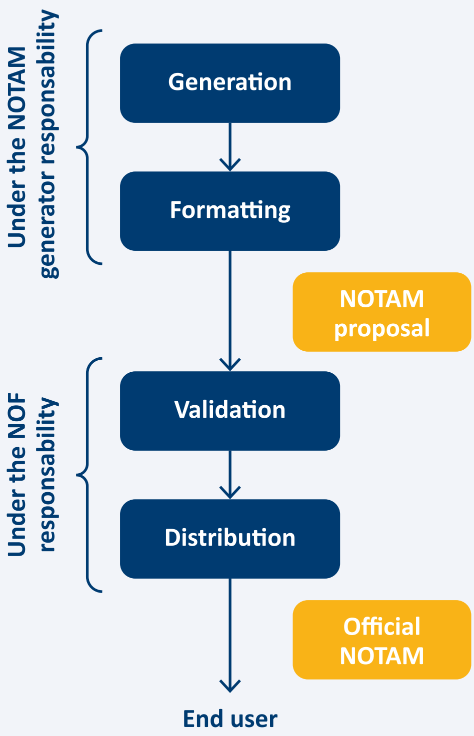


Figure 3 6 **The NOTAM process**



Next Figures show the ESSP NOTAM proposal service in the overall NOTAM lifecycle and depict the NOTAM process until the reception to the end users.

The terms and conditions under which the ESSP SAS provides EGNOS NOTAM proposals to any national NOTAM Offices (NOFs) of ANSPs providing Aeronautical Information Services (national AIS provider) are detailed within the corresponding EGNOS Working Agreement (EWA) signed between ESSP SAS and the particular ANSP implementing EGNOS based operations. Even more, the publication of SBAS based approach procedures is only possible after the signature of an EGNOS Working Agreement between the ESSP and the ANSP (see section 3.2.4). The agreement includes the EGNOS NOTAM proposals services as one of the main enablers for the EGNOS based approach procedures implementation.

Since January 1st 2014, the EGNOS NOTAM Proposals service is (so called Service Level 4) based on:

- NOTAMs resulting from:
  - GNSS scheduled events notified minimum 72 hours in advance.
  - GNSS (EGNOS and GPS) unscheduled events notified within 2 hours (7D/H24).

It is expected that the NOTAM Proposals Service will be based on Service Level 4 for a minimum period of 24 months from that date. Hence, the current service is compliant with the ICAO recommendation for notification of scheduled events (72 hours notice) but is not yet in line with the recommendation for unscheduled events.

The EGNOS NOTAM Proposals Service is foreseen to be ICAO fully compliant in 2016 by the reduction of the reaction time for unscheduled events at EGNOS and GPS systems level applicable every day of the week on an H24 basis

3.2.4 EGNOS WORKING AGREEMENT

As foreseen in the Single European Sky (SES) regulatory requirements (see [RD-8] and [RD-9]), an EGNOS Working Agreement (EWA) is required to be signed between the ESSP SAS and the ANSP implementing EGNOS based operations.

It is each National Supervisory Authority (NSA) who has the competence and authority to require it within the approval process of the corresponding operation.

The overall objective of an EGNOS Working Agreement is to formalize the operational and technical modalities between ESSP SAS and a specific ANSP, in order to support in particular the operational introduction and use of EGNOS LPV (Localizer Performance with Vertical guidance) approaches within the airspace where this particular ANSP is providing its services.

The EWA includes:

- EWA contractual document: The agreement itself containing contractual liability with two annexes:
- EWA Annex 1: Including the "ESSP SAS SoL Service Commitment" as stated in this EGNOS SoL SDD. It also includes reference to contingency coordination between ESSP and the ANSP.
- Annex 2: Including the "Service Arrangements" defined between the ESSP and the ANSP with the purpose to enable the ANSP to implement Performance Based Navigation (PBN) procedures based on EGNOS, covering all identified applicable requirements, namely:
  - NOTAM Proposal Origination: Outlining the terms and conditions under which the ESSP SAS will provide EGNOS NOTAM proposals to the NOFs of the ANSP providing Aeronautical Information Services (AIS) under the scope of a signed EWA (see section 3.2.3).
  - EGNOS Data Recording: Describing the proposal of the ESSP SAS in order to provide GNSS data to ANSP. To this purpose, the detailed data, format, storing time, time to provide these data and procedures are described.
  - Collaborative Decision Making (CDM): Defining clear working relationships between ESSP SAS and ANSP describing ANSP involvement in the ESSP SAS decision making process whenever any decision could lead to a material impact on the service provided.

The EGNOS SoL users of other than aviation domains should refer to their sectorial laws and regulations.

All EWA related information / discussions will be managed by ESSP SAS through the dedicated focal points (see section 3.2.2 for contact information).

The updated information concerning the EGNOS implementation status at European airports can be found in the EGNOS user support website (including up-to-date number of EGNOS Working Agreements signed between ESSP and ANSPs and the number of EGNOS based operations for civil use already published): http://egnos-user-support.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.

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[3]) which is a geocentric system of coordinates tied to the surface of the Earth and in which the unit

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

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 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 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 SBAS Network time with UTC
17	GEO satellite almanacs	GEO 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

4. 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.

distance is consistent with the International System of Units (SI[5]) definition of the metre. The ITRF system is maintained by the International Earth Rotation and Reference Systems Service (IERS[6]) and is the standard terrestrial reference system used in geodesy and Earth research. Realizations of ITRS are produced by the IERS under the name International Terrestrial Reference Frames (ITRF). Several realizations of the ITRS exist, being ITRF2008 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[7]) 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.

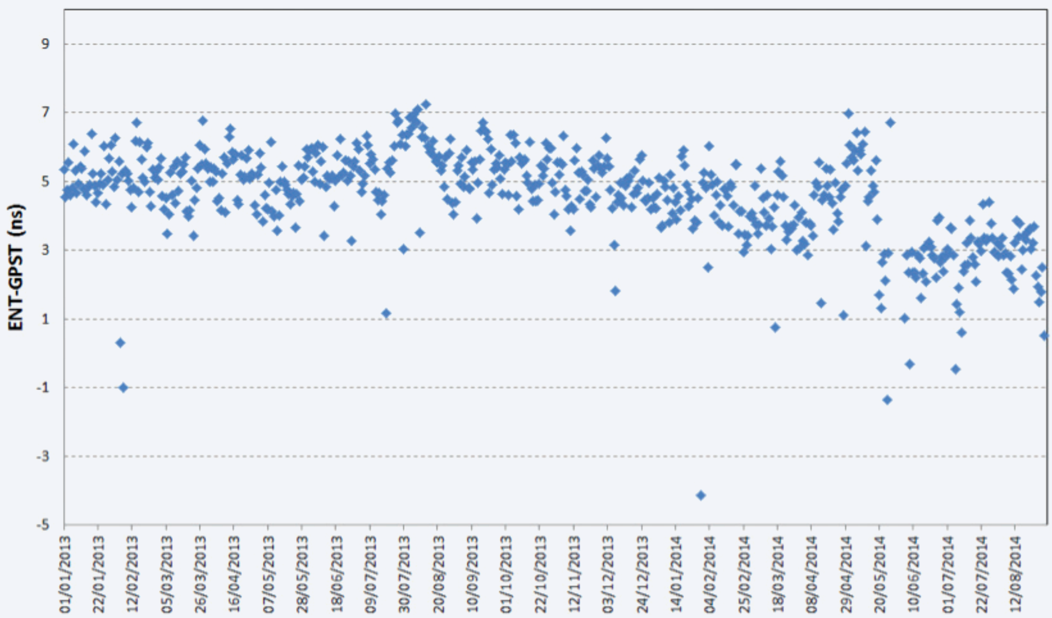
The ENT is continuously steered towards GPS Time (GPST) by the EGNOS Ground Control Segment and the relative consistency between the two timescales is maintained at the level of tens of nanoseconds as observed in *Figure 4 1*:

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.

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

5. Information on the International System of Units (SI) can be obtained from http://www.bipm.org/en/si/
6. Information on IERS can be obtained from http://www.iers.org/
7. Information on IGS can be obtained from http://igscb.jpl.nasa.gov/

Figure 4 1 **ENT GPS time offset evolution (Period January 13 - September 14)**



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.

4.3 EGNOS SIS Performance in the Range Domain

4.3.1 ACCURACY IN THE RANGE DOMAIN

This section focuses on the EGNOS SIS accuracy performances 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[8], 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 iono-

8. The “relevant service area” is defined as the ECAC area, which comprises latitudes from 20º to 70º and longitudes from -40º to 40º.

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**

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[9] 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.

spheric 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.

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.

9. *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.

4.3.1 INTEGRITY IN THE RANGE DOMAIN

As the SREW and GIVD range accuracy parameters cannot be monitored in real time, the EGNOS system provides an estimation of the statistical distribution (i.e. standard deviation) which bounds the real SREW and GIVD. The two integrity parameters provided by EGNOS are the User Differential Range Error (UDRE) and the Grid Ionospheric Vertical Error (GIVE). The UDRE characterises the SREW parameter while the GIVE characterises the GIVD.

For the integrity in the range domain, the range error is bounded by a threshold based on the UDRE and GIVE parameters. For each pseudorange, the range error shall be less than 5.33 times the estimated standard deviation ($\varepsilon \leq 5.33\sigma$ where ε is Range error and σ is the computed SBAS Range error estimate standard deviation).

The metrics used for analysis in the range domain aim at demonstrating that the UDRE and the GIVE parameters bound respectively the pseudorange errors at the Worst User Location (SREW) and the Grid Ionospheric vertical delay (GIVD). In other words, in order for UDRE and GIVE to bound properly the true range error in the measurements, it should be ensured that *5.33xUDRE > SREW* and *5.33xGIVE > GIVD* with the adequate level of probability.

EGNOS is designed in such a way that the SoL service ensures that the satellite correction error and Ionospheric error are bounded with a probability of 99.99999%. The observed maximum values for SREW/UDRE and GIVD / GIVE are both around 3.

More details on the EGNOS integrity concept can be found in Appendix B.

5 EGNOS Receivers

5.1 EGNOS Receivers For Aviation

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.

This standard identifies different classes of user receivers depending on the intended operations. *Table 5 1* summarises the main characteristics of the EGNOS equipment operational classes.

For EGNOS, the minimum performance levels are defined for two specific types of operations and assume equipage with a class 1 receiver (for operations down to Non Precision Approach, NPA) or class 3 receiver for LPV operations.

For non-aviation SoL users, alternative EGNOS message processing may be implemented, deviating from the DO-229 MOPS standard ([RD-2]). However, the EGNOS system performance has not been characterised for such a receiver configuration and therefore the performance experienced by such receivers is likely to deviate from that described in the EGNOS SoL SDD.

More information about EGNOS receivers for aviation can be found in the official EGNOS portal website (see section 3.2.2).

Table 5 1 EGNOS equipment operational classes

Operational Class	Phases of Flight
Class 1	Oceanic and domestic en route, terminal, approach (LNAV), and departure operation
Class 2	Oceanic and domestic en route, terminal, approach (LNAV, LNAV/VNAV), and departure operation
Class 3	Oceanic and domestic en route, terminal, approach (LNAV, LNAV/VNAV, LP, LPV), and departure operation
Class 4	Equipment that supports only the final approach segment operation

5.2 Receiver & Avionics Certification

According to the intended operation, EASA material providing implementing guidance and Accepted Means of Compliance (AMCs) is available. The AMCs include airworthiness criteria such as equipment qualification and functional criteria, airworthiness compliance for installation, as well as operational criteria.

The equipment qualification recommended in the AMCs refers to ETSO certified equipment. An ETSO certified piece of hardware (receiver, antenna, etc) has been demonstrated to have been designed, tested and manufactured in compliance with the applicable standards. It is recalled that the ETSO approval process is just a way that the equipment manufacturer chooses to demonstrate compliance with the standards; it is not the unique method. Therefore, it is possible to find non-ETSO certified equipment that is fully compliant with the standards and that is certified for use by the competent NSA.

It should also be considered that ETSO certificates refer only to the equipment itself (avionics and related hardware) and not the installation within the aircraft. The user/operator should follow the guidance provided in the applicable AMC in order to seek approval for the avionics installation.

Given an airworthy installation and functions compliant with the requirements in the applicable AMC, an operational approval has to be obtained from the National Supervisory Authority.

Table 5 2 lists the existing ETSOs related to the hardware required for SBAS operations:

Table 5 2 **Existing ETSOs and hardware requirements for SBAS operations**

Operational Class	Phases of Flight
ETSO-C144a	Passive Airborne Global Navigation Satellite System (GNSS) Antenna
ETSO-C145c	Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System
ETSO-C146c	Stand Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Satellite Based Augmentation System
ETSO-C190	Active Airborne Global Navigation Satellite System (GNSS) Antenna

6 EGNOS SoL Service Performance

6.1 EGNOS SoL Service Description and Characteristics

The EGNOS SoL Service is available from March 2nd 2011. It consists of signals for timing and positioning, provided openly which are freely accessible and without any direct charge. In the case of aviation, the use of EGNOS SoL Service is subject to the subscription of specific Working Agreements between ESSP and ANSPs as required by the EC Single European Sky regulation. The EGNOS Working Agreement (EWA) is intended to cover and formalize both operational and technical coordination requirements between ESSP and each ANSP to support the operational introduction and use of EGNOS based procedures (see section 3.2.4).

The EGNOS SoL Service is accessible to any user equipped with an EGNOS receiver as described in Section 5 within the EGNOS SoL Service area as defined in Section 6.3. The minimum performance reported in this section is the performance that can be experienced when using receiving equipment compliant with RTCA MOPS DO229 Class 3 specifications as described in section 5.1. It also assumes GPS characteristics/performance as mentioned in section 2.1 and a clear sky environment with no obstacle masking satellite visibility at angles greater than 5° above the local horizontal plane.

At the time of publication of this document, there are two GEOs in operational mode, while the third is in test mode, therefore broadcasting Message Type 0. The configuration of the GEOs in operation does not change frequently but possible updates are nevertheless reported to users by the EGNOS Service Provider. Current space segment configuration was detailed in section 3.1.2.3.

The EGNOS SoL Service is compliant with the aviation NPA (Non Precision Approach) and APV-I (Approach with Vertical Guidance) requirements, except for specific deviations noted within Section 6.3 but is also intended to support applications in other SoL domains.

The "minimum" performance figures shown in this section 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. 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 SoL Service.

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 SoL Service Performance Requirements

The EGNOS system has been designed to support different types of civil aviation operations. Requirements for each type of operation have been issued by [RD-6][RD-1] and are summarised in *Table 6 1*.

6.3 EGNOS SoL Minimum Service Performance Characteristics

The EGNOS SoL minimum performance characteristics are described below for accuracy, integrity, availability and continuity. This minimum performance is conservative since it has been derived to take account of a number of degraded conditions or abnormal environmental conditions that could be experienced throughout the lifetime of the system.

EGNOS SoL Service performance is detailed in *Table 6 2*.

Table 6 1 SoL service performance requirements (ICAO)

	Accuracy		Integrity				Continuity	Availability
Typical operation	Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-To-Alert (TTA)	Horizontal Alert Limit (HAL)	Vertical Alert Limit (VAL)		
En-route (oceanic/ continental low density)	3.7 km (2.0 NM)	N/A	1 – 1x10–7/h	5 min	7.4 km (4 NM)	N/A	1 – 1x10–4/h to 1 – 1x10–8/h	0.99 to 0.99999
En-route (continental)					3.7 km (2 NM)	N/A		
En-route, Terminal	0.74 km (0.4 NM)	N/A	1 – 1x10–7/h	15 s	1.85 km (1 NM)	N/A	1 – 1x10–4/h to 1 – 1x10–8/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	1 – 1x10–7/h	10 s	556 m (0.3 NM)	N/A	1 – 1x10–4/h to 1 – 1x10–8/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	1 – 2x10–7 in any approach	10 s	40 m (130 ft)	50 m (164 ft)	1 – 8x10–6 per 15 s	0.99 to 0.99999

Table 6 2 **EGNOS SoL Service performance values**

	Accuracy		Integrity		Continuity	Availability
	Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-To-Alert (TTA)		
Performance	3 m	4 m	1 - 2x10-7 / approach	Less than 6 seconds	For NPA: <1 – 2.5x10-4 per hour in most of ECAC <1 – 2.5x10-3 per hour in other areas of ECAC For APV-I: <1 – 1x10-4 per 15 seconds in the core ECAC 1 – 5x10-4 per 15 seconds in most ECAC 1 – 1x10-3 per 15 seconds in other areas of ECAC	0.999 for NPA in all the ECAC 0.99 for APV-I in most ECAC
APV-I requirement	16.0 m (52 ft)	20 m (66 ft)	1 – 2x10–7 in any approach	10 s	1 – 8x10–6 per 15 s	0.99 to 0.99999
Comment	Accuracy values at given locations are available at: http://egnos-user-support.essp-sas.eu/	N/A			See sections 6.3.1.3 and 6.3.2.4 for availability See sections 6.3.1.4 and 6.3.2.5 for continuity.	

6.3.1 NPA - PON PRECISION APPROACH[10]

The performance commitment for NPA covers other less stringent phases of flight (en route, terminal or other RNPs) using EGNOS only for lateral guidance.

6.3.1.1 Accuracy

The EGNOS accuracy is compliant with the accuracy requirements specified in *Table 6 1* for NPA inside the availability service area defined in Section 6.3.1.3.

6.3.1.2 Integrity

The EGNOS integrity is compliant with the integrity requirements specified in *Table 6 1* for NPA.

6.3.1.3 Availability

Figure 6 1 provides the minimum availability performance that can be expected from EGNOS for NPA. The area in red is where the 99.9% availability requirement, specified in *Table 6 1*, is met. These values correspond to the expected average performance measured by a fault-free receiver using all GPS satellites in view over a period of one month, using all the operational EGNOS GEOs.

6.3.1.4 Continuity

Figure 6 2 provides the commitment on the continuity that can be expected from EGNOS for NPA (not considering RAIM). These values correspond to the expected average performance measured by a fault-free receiver using all GPS satellites in view over a period of one month, using all the operational EGNOS GEOs.

The minimum continuity risk performance is less than 2.5×10^{-4} per hour in large parts of ECAC 96 Flight Information Regions (FIRs). It should be noted that the regions of continuity risk smaller than 5x10-4/hour are relatively sensitive to the scenario and models used to compute the minimum service area. This explains the variability observed for the most stringent contour over different releases of EGNOS. There are however some regions in the ECAC 96 FIRs where the risk rises up to 2.5x10-3 per hour. Such a minimum performance is not strictly compliant to ICAO requirements for NPA as described in *Table 6 1*. These values are however considered as sufficient to start the EGNOS use in civil aviation. Indeed, ICAO SARPs include interpretative material stating that when the continuity performance objective is not achieved by a given system, it is still possible to allow approaches based on the given system. In this case, local air navigation authorities shall define, if necessary, measures to mitigate the risks of an operational nature[11].

6.3.2 APV-I - APPROACH WITH VERTICAL GUIDANCE

6.3.2.1 Assumptions for the Definition of the Commitment Maps

The APV-I commitment maps presented in the following sections have been elaborated on the basis of the results observed during several months of observation of EGNOS performances. These maps represent the minimum level of performances which can be expected under similar conditions to those under which these performance maps have 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 constellations status, environmental conditions, etc), are detailed hereafter:

10. Even if it is recommended by RTCA MOPS 229 to use ionospheric corrections if they are available, the NPA performance results provided in this document consider that the ionospheric correction applied for this navigation mode is the GPS model, which represents a conservative approach.
11. Annex 10, Volume 1 of the Chicago Convention, Attachment D, 3.4.3.4: "For those areas where the system design does not meet the average continuity risk specified in the SARPs, it is still possible to publish procedures. However, specific operational mitigations should be put in place to cope with the reduced continuity expected. For example, flight planning may not be authorised based on GNSS navigation means with such a high average continuity risk".

Figure 6 1 EGNOS NPA availability

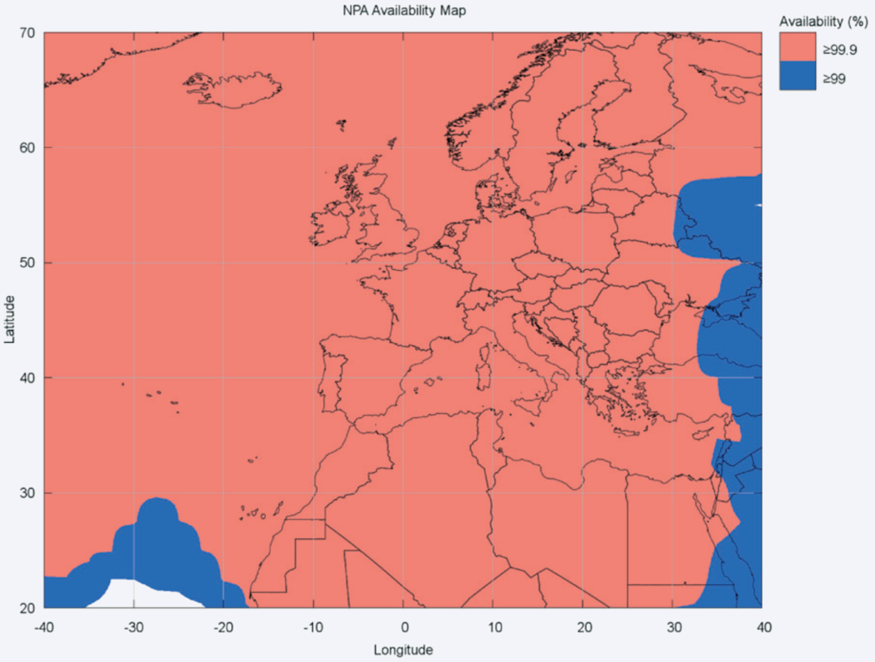
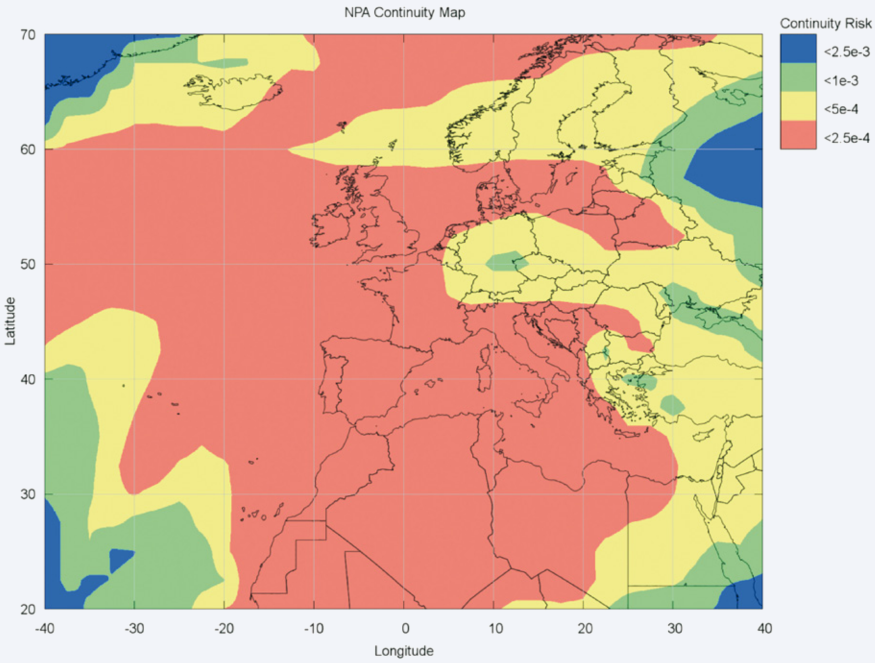


Figure 6 2 EGNOS NPA continuity [12]



12. In order to observe the minimum NPA continuity performance shown in the map (2.5x10-4), at least 6 months of data needs to be evaluated due to the discrete nature of discontinuity events.

- EGNOS RIMS configuration: the number and location of the EGNOS RIMS corresponds to those presented in *Figure 3 4*, in section 3.1.2.3. Those stations which appear as part of the TEST platform or under deployment have not been considered for the definition of the commitments.
- EGNOS GEOs configuration: The EGNOS space segment assumed for the preparation of the maps consists of two operational GEOs. The use of at least two GEOs by the SBAS receiver secures a switching capability in case of interruption and ensures a high level of continuity of service.
- GPS satellite constellation (PRN mask): The number of usable GPS satellites assumed for the definition of the commitment maps corresponds to all the satellites identified in the EGNOS PRN mask, as broadcasted in the SBAS Message Type 1. During the observation period the number of GPS PRNs identified in the EGNOS mask has been 31 GPS satellites.
- Environmental conditions: The observations used for the generation of the commitment maps cover a period of particularly severe ionospheric activity (February-March 2014). Under such high ionospheric activity or geomagnetic storm periods (caused by sudden eruptions of the Sun), GNSS/SBAS users, in particular EGNOS SoL users, can experience residual ionospheric effects owing to increased ionospheric variability impossible to be effectively modelled and corrected, which can cause reduced navigation performance (see Appendix D for further details). The methodology used for the definition of the commitment maps filters out data coming from days with abnormally high ionosphere activity; this is achieved by discarding days with a planetary A index (Ap) higher

Table 6 3 **Approach with vertical guidance accuracy**

Operational Class	Definition	Value	APV-I requirement
Horizontal	Corresponds to a 95% confidence bound of the 2-dimensional position error[13] in the horizontal local plane for the Worst User Location[14]	3m	16m
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	20m

13. 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.
14. The definition of Worst User Location can be found in Appendix C

Figure 6 3 EGNOS APV-1 availability

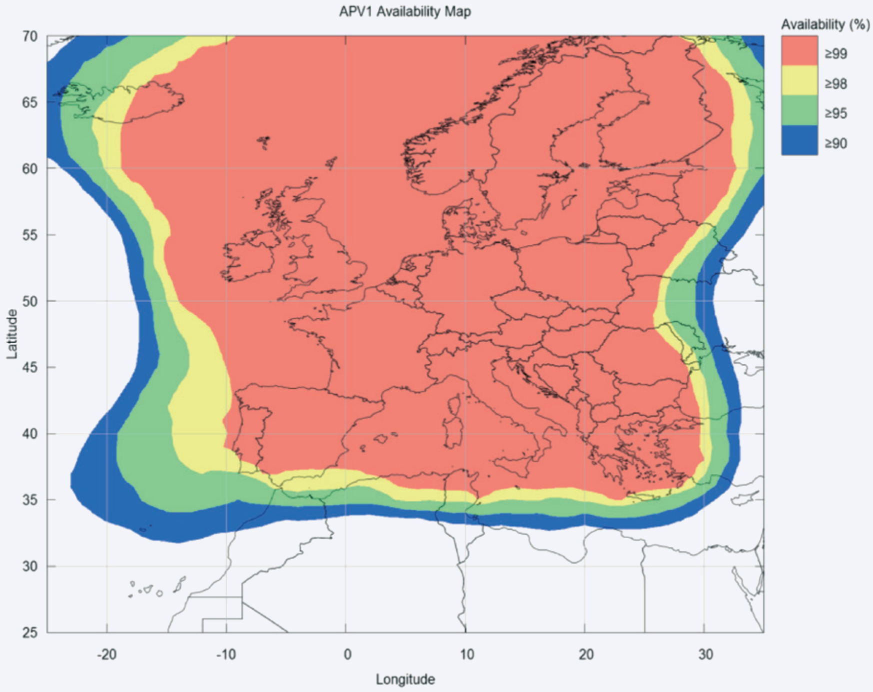
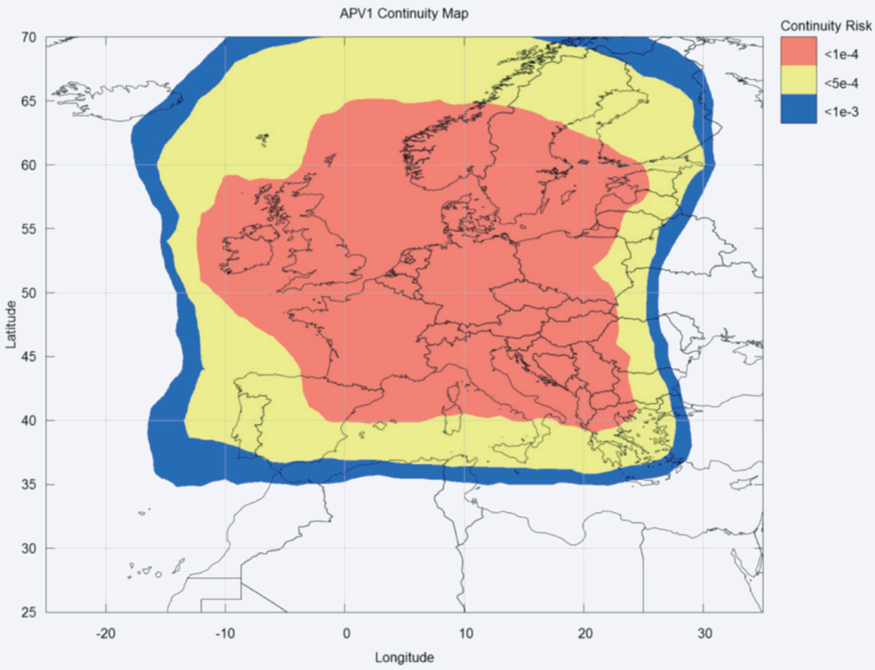


Figure 6 4 EGNOS APV-1 continuity



than 30 and by discarding the outliers of the analysed data. The Ap index is one of the most commonly used indicator to quantify and classify the ionospheric and geomagnetic conditions during a time period. An Ap index of 30 or greater indicates unusually high local geomagnetic storm conditions.

The consequence of the presented assumptions and methodology is that the actual performance experienced by a user at a particular moment may differ from the one presented in the following sections, owing in particular to the uncontrollable variability of environmental conditions (see Appendix D for further details).

6.3.2.2 Accuracy

The definitions of horizontal and vertical accuracy and the associated requirement are detailed in *Table 6 3*.

The EGNOS system is therefore compliant with the accuracy requirements specified in *Table 6 1* for APV-I inside the availability service area defined in Section 6.3.2.4.

6.3.2.3 Integrity

The EGNOS integrity is compliant with the integrity requirements specified in *Table 6 1* for APV-I.

6.3.2.4 Availability

Figure 6 3 provides the minimum availability performance that can be expected from EGNOS for APV-I. The area in red represents the area where the 99 % availability requirement, specified in *Table 6 1*, is met and other colours represent other availability requirements (yellow - 98 %, green - 95 % and blue - 90 %). These values correspond to the expected minimum performance measured by a fault-free receiver using all satellites in view over a period of one month, using all the operational EGNOS GEOs.

For the sake of a proper interpretation of the APV-I availability map, please see the details in section 6.3.2.1 concerning the methodology used for the map generation.

6.3.2.5 Continuity

Figure 6 4 provides the minimum continuity performance that can be expected from EGNOS for APV-I. These values correspond to the expected minimum performance measured by a fault-free receiver using all satellites in view, when averaging over a period of one month, using all the operational EGNOS GEOs.

For the sake of a proper interpretation of the APV-I continuity map, please see the details in section 6.3.2.1 concerning the methodology used for the map generation.

The minimum continuity risk performance is less than 10^{-4} per 15 seconds in core part of ECAC landmasses, and less than $5x10^{-4}$ per 15 seconds in most of ECAC landmasses. There are however some regions with a risk of over 10^{-3} per 15 seconds. Such a minimum performance is not strictly compliant to ICAO requirements for APV-I as described in *Table 6 1* ($8x10^{-6}$ per 15 seconds). These values are however considered as sufficient to start the EGNOS use in civil aviation. Indeed, ICAO SARPs include interpretative material stating that when the continuity performance objective is not achieved by a given system, it is still possible to allow approaches based on the given system. In this case, local air navigation authorities shall define, if necessary, measures to mitigate the risks of an operational nature[15].

15. Annex 10 of the Chicago Convention, Attachment D, 3.4.3.4: "For those areas where the system design does not meet the average continuity risk specified in the SARPs, it is still possible to publish procedures. However, specific operational mitigations should be put in place to cope with the reduced continuity expected. For example, flight planning may not be authorised based on GNSS navigation means with such a high average continuity risk".

6.4 EGNOS SOL Service Limitations

In the vast majority of cases, the EGNOS SoL Service will be available and will provide performance in line with or beyond the minimum performance levels described in the previous sections of this document (section 6.3.1 for NPA and section 6.3.2 for APV-I). However, in a limited number of situations, users may experience non-nominal navigation performance levels. In all these cases, the integrity is always warranted. The most common causes for such abnormal behaviour are listed below in *Table 6 4*.

Table 6 4 **EGNOS SoL 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.
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.

Root Cause	Most Likely Symptoms
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. Such events are usually localised for ground users but this may affect a wider area for airborne users. 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 performances) is under the responsibility of local authorities.
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 when satellite tracking is 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 the EGNOS signal is lost, the impact will be similar to the one described for "EGNOS signal blockage" above.
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 SoL performance can be degraded. The performance experienced by the receiver may be worse than the minimum performance indicated in section 6.3.1 for NPA and section 6.3.2 for APV-I.

Appendix A – 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[16].

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

16. 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 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 B – EGNOS integrity concept

Integrity is a measure of the trust which can be placed in the correctness of the information supplied by a given system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight).

The integrity service of ICAO compliant GNSS systems may currently be provided by the three normalised augmentations known under the terms ABAS (Airborne Based Augmentation System), GBAS (Ground Based Augmentation System) and SBAS (Satellite Based Augmentation System). There are several SBAS systems deployed around the world (WAAS in North America, MSAS in Japan and EGNOS in Europe) and others under development. EGNOS (and the other SBAS) augments GPS by providing integrity information and corrections through geostationary satellites.

The EGNOS integrity concept relies on the use of a network of ground reference stations which receive data from the GPS satellites and compute integrity and correction data. This information is uploaded to the EGNOS geostationary satellites which then relay this information to EGNOS receivers through the EGNOS SIS. The EGNOS receivers acquire and apply this data to determine the integrity and improve the accuracy of the computed navigation solution. Therefore, the SBAS integrity service should protect the user from both:

- Failures of GPS satellites (drifting or biased pseudoranges) by detecting and excluding faulty satellites through the measurement of GPS signals with the network of reference ground stations
- Transmission of erroneous or inaccurate differential corrections. These erroneous corrections may in turn be induced from either:
  - undetected failures in the ground segment,
  - processing of reference data corrupted by the noise induced by the measurement and algorithmic process.

The EGNOS ground system, using the measures taken from the observation of the GPS constellation through its dedicated network of reference ground stations provides separate corrections and bounds to the satellite ephemeris errors, clock errors and ionospheric errors.

The SBAS integrity concept is based on the following definitions:

- **Integrity risk:** the probability that the position error is larger than the alert limit defined for the intended operation and the user is not warned within the time to alert (TTA).
- **Integrity Event:** Occurs when the Navigation System Error is greater or equal to the corresponding Protection Level for the corresponding service level (e.g. APV-I) and the receiver does not trigger an alert within the Time To Alert (TTA).
- **Alert Limit:** the error tolerance not to be exceeded without issuing an alert (SARPS definition). There is a Horizontal Alert Limit (HAL) and a Vertical Alert Limit (VAL) for each operation (i.e.: alert limits for APV-I are more demanding than for NPA).
- **Protection levels [RD-2]:**
  - The **Horizontal Protection Level (HPL)** is the radius of a circle in the horizontal plane, with its centre being at the true position, which describes the region which is assured to contain the indicated horizontal position (RTCA MOPS).
  - The **Vertical Protection Level (VPL)** is the half length of a segment on the vertical axis with its centre being at the true position, which describes the region which is assured to contain the indicated vertical position (RTCA MOPS).

In other words, the HPL bounds the horizontal position error with a confidence level derived from the integrity risk requirement. Similarly, the VPL bounds the Vertical Position Error.

- **Time To Alert (TTA):** The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the user equipment enunciates the alert.
- **"Out of tolerance":** The out of tolerance condition is defined as a horizontal error exceeding the HPL or a vertical error exceeding the VPL.
  - The horizontal error is referred to as HPE (Horizontal Position Error),
  - The vertical error is referred to as VPE (Vertical Position Error).

  Therefore, an out of tolerance event occurs when one of both following events occurs:
  - HPE > HPL or,
  - VPE > VPL (in absolute value)

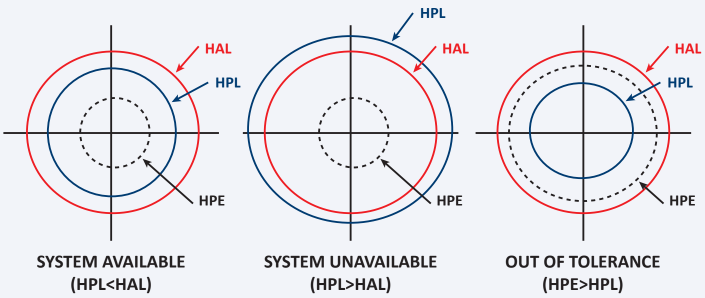
The EGNOS integrity concept can be summarised as follows, from a user point of view:

- The user calculates the navigation solution and its associated protection levels. The protection levels should be understood as a conservative estimate of the user position error (typically for a confidence level of 10-7) that is assumed to be a Gaussian function. As the user is unable to measure the real position error, the user will rely on this conservative estimate of the real error to determine the system integrity.
- Then, the computed protection levels are compared to the alert limits defined for the intended operation, and if the protection levels are larger than the corresponding alert limits, the system becomes unavailable (the performance level provided by the system at that time is not sufficient to ensure the safety of the intended operation). On the contrary, if the computed protection levels are smaller than the alert limits defined for the intended operation, the system is declared available as the safety of the operation is ensured.

Figure 6 5 clarifies the concepts above and their physical interpretation. The figure depicts the situations that a SBAS user may experience; in this case, the horizontal plane has been chosen for the diagram but the reasoning would be equivalent for the vertical one.

Please notice that in the first two situations shown above, the system is working properly, as EGNOS provides a correct bound to the position error, and the safety of the user is ensured. Note that the system is expected to be declared available most of the time. In the third case, the error is not properly bounded by EGNOS (HPE>HPL), and safety issues could arise if the error is larger than the alert limits defined for the intended operation. The probability of this situation is minimal by design, enabling EGNOS to meet the integrity requirements of APV-I and NPA operations. A detailed description of how the Protection Levels are computed by EGNOS can be found on Appendix J of the RTCA SBAS MOPS [RD-2].

Figure 6 5 Possible situations when navigating with EGNOS



Appendix C – Definitions

Accuracy: GNSS position error is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement. (ICAO SARPS)

Approach Procedure with Vertical guidance (APV): An instrument approach procedure which utilises lateral and vertical guidance but does not meet the requirements established for precision approach and landing operations. Depending on the type of APV procedure, vertical guidance can be provided from GNSS augmentation system such as SBAS (or possibly Galileo in the future) or a barometric reference.

- **APV Baro:** An approach with barometric vertical guidance flown to the LNAV/VNAV Decision Altitude/Height. A vertically guided approach can be flown by modern aircraft with VNAV functionality using barometric inputs. Most Boeing and Airbus aircraft already have this capability meaning that a large part of the fleet is already equipped. Airworthiness approval material is available from EASA (AMC 20-27 – *"Airworthiness Approval and Operational Criteria for RNP APPROACH (RNP APCH) Operations Including APV BARO-VNAV Operations").*
- **APV SBAS:** An approach with geometric vertical and lateral guidance flown to the LPV Decision Altitude/Height. It is supported by satellite based augmentation systems such as WAAS in the US and EGNOS in Europe to provide lateral and vertical guidance. The lateral guidance is equivalent to an ILS localizer and the vertical guidance is provided against a geometrical path in space rather than a barometric altitude. Airworthiness approval material is available from EASA in 2011 (AMC 20-28 – *"Airworthiness Approval and Operational Criteria for LPV APPROACH (LPV APCH)")*.

Area navigation (RNAV): A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

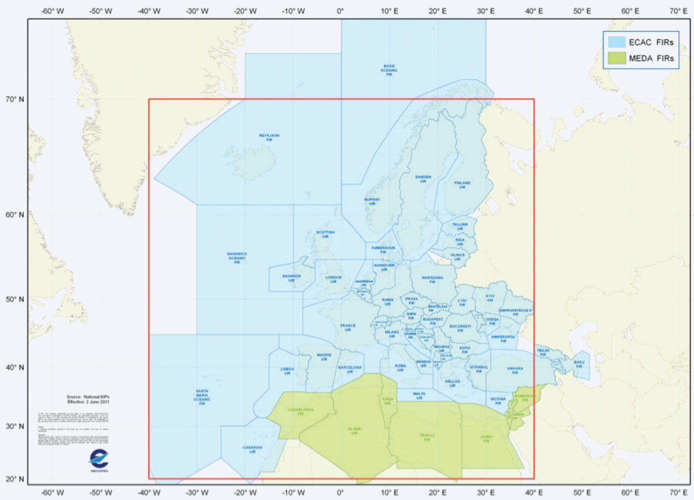
Availability: The availability of GNSS is characterised by the proportion of time during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft. (ICAO SARPS)

Continuity: Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation. It relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity during the approach, assuming that it was available at the start of the operation. (ICAO SARPS).

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), and is indicated in *Figure 13*. 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).

End/Final User: The aviation user in possession of the certified receiver using the EGNOS Signal-In-Space for flying a previously approved operation based on EGNOS and more generally for other domains any user with an EGNOS-compatible receiver. On the contrary, the term "User" is typically used alone to refer to ANSPs in the context of this document.

Figure 6 6 ECAC 96 FIRs and EGNOS service coverage (in red)



Fault-free receiver: The fault-free receiver is assumed to be a receiver with nominal accuracy and time-to-alert performance. Such a receiver is assumed to have no failure affecting the integrity, availability and continuity performance. (ICAO SARPS)

Fault Detection and Exclusion (FDE): FDE is a receiver processing scheme that autonomously provides integrity monitoring for the position solution, using redundant range measurements. The FDE consists of two distinct parts: fault detection and fault exclusion. The fault detection part detects the presence of an unacceptably large position error for a given mode of flight. Upon the detection, fault exclusion follows and excludes the source of the unacceptably large position error, thereby allowing navigation to return to normal performance without an interruption in service.

Integrity: Integrity is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight). (ICAO SARPS).

Hazardously Misleading Information (HMI): Information that persists beyond the allowable TTA causing the errors in the position solution output by an EGNOS receiver to exceed the user's particular tolerance for error in the current application.

Misleading Information (MI): Information causing the errors in the position solution output by an EGNOS receiver to exceed the protection levels.

Navigation mode: According to RTCA MOPS [RD-2], the navigation mode refers to the equipment operating to meet the requirements for a specific phase of flight. The navigation modes for MOPS C are: oceanic/remote, en route, terminal, non-precision approach, and precision approach (including LNAV/VNAV, APV-II and GLS). The navigation modes for MOPS D are: oceanic/remote, en route,

Table 6 5 RTCA MOPS C&D terminology differences for navigation mode

Navigation Mode	Service	MOPS C	MOPS D
En route and terminal		Section 2.1.2	Section 2.1.2
Non Precision Approach		Section 2.1.3	Does not exit (see LNAV)
Precision Approach	LNAV	Does not exit (see NPA)	Section 2.1.3
	LNAV/VNAV	Section 2.1.4 (This mode covers APV-I service)	Section 2.1.4
	LPV and LP	Does not exist	Section 2.1.5
	APV-II	Section 2.1.5	Does not exist

terminal, and approach (including LNAV, LNAV/VNAV, LP and LPV levels of service). The main differences and equivalences in terminology are summarised in *Figure 6 5*.

Notice to Airmen (NOTAM): A notice containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations. NOTAM are issued by Aeronautical Information Services (AIS) when there is not sufficient time to publish information and incorporate it into the Aeronautical Information Publication (AIP) or for changes of short duration.

Receiver Autonomous Integrity Monitoring (RAIM): RAIM is an algorithm used in a GPS receiver to autonomously monitor the integrity of the output position/time solution data. There are many different RAIM algorithms. All RAIM algorithms operate by evaluating the consistency of redundant measurements.

Service Volume: The service volume is defined to be those regions which receive the navigation service with the required level of availability.

Time-to-Alert (TTA): See Appendix B.

Worst User Location (WUL): The WUL is a key parameter in the estimation of the EGNOS integrity data. Since a satellite clock error is the same for all users whereas the orbital error is different depending on the location of users, the WUL depends on the satellite orbit errors which can be estimated using the measurements from the RIMS. The WUL is the position for which the projection of UERE vector is maximum. If the location of the WUL is determined to be outside the ECAC area, it is transferred to the nearby boundary point.

Appendix D – Ionospheric activity and impact on GNSS

Appendix D.1 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.

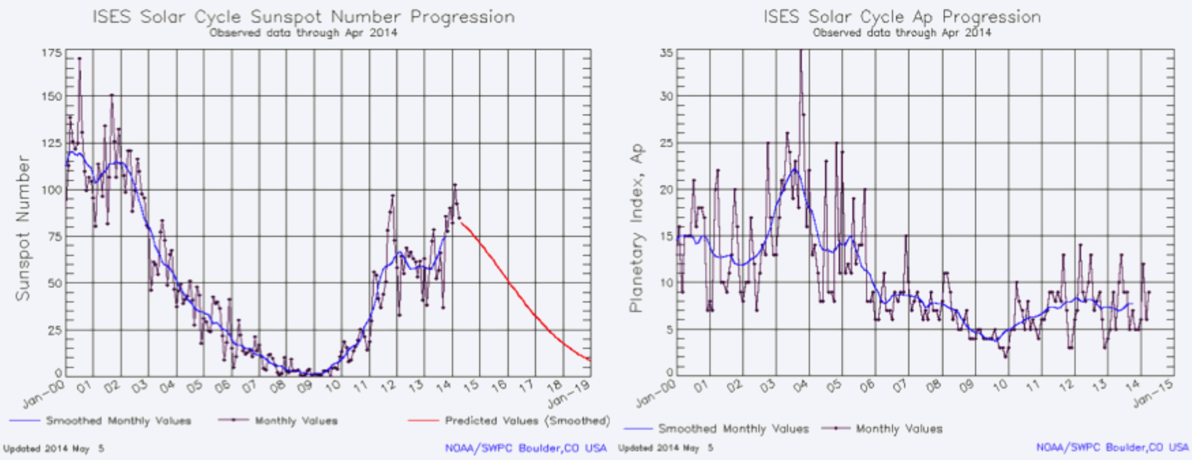
In the case of SBAS systems, the SBAS receivers inside the corresponding service area use the SBAS ionospheric corrections, which are derived from real-time ionospheric delay measurements. The SBAS ground system obtains these measurements from a network of reference stations and uses them to estimate 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 ([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.

Appendix D.2 Impact of the ionospheric activity on GNSS

Although the GNSS signal delay, as direct effect of ionosphere, is always present and varies in size, it is generally well modelled and can be estimated to an extent that makes GNSS/SBAS usable. During period with increased ionospheric activity or geomagnetic storm (caused by sudden eruptions of the Sun), GNSS/SBAS users can experience residual ionospheric effects owing to increased ionospheric variability impossible to be effectively modelled and corrected, which can cause reduced navigation performance at user level.: The increase in the residual ionospheric effects implies a higher error over-bounding (this is, higher protection level) and in case this higher over-bounding exceeds the maximum value for the intended operation (this is, alert limit) the service availability for such operation is impacted.

From the beginning of 2008, we are facing a period of high solar activity linked to solar cycle #24. 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).Taking into account a typical duration of eleven years, solar cycle #24 would have just reached halfway point. The number of sunspots (SSN) and the planetary geomagnetic indicator (Ap), as two of the main parameters to monitor the ionosphere behaviour, reflects the existence of a high activity in the ionosphere (*Figure 6 7*). A first maximum of number of sunspots was reached in

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



February 2012 and a second relative maximum, higher than the first one, was reached in August 2013.

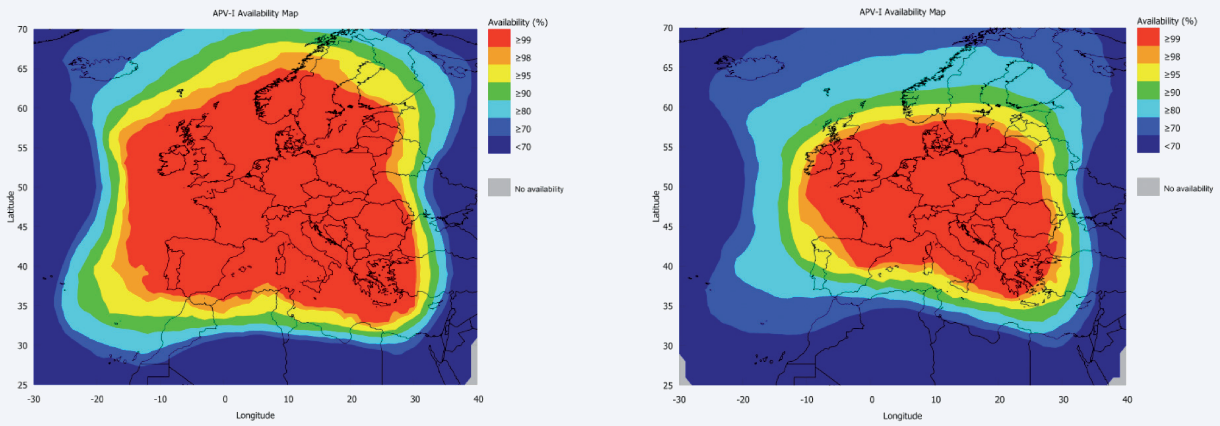
Concerning EGNOS in Europe, the dependence of the ionospheric corrections provided by the system and consequently of the system performance with the variations observed in the ionospheric behaviour has been especially relevant since the beginning of the solar activity increase linked to the current solar cycle. This kind of events affects not only EGNOS but also other GNSS/SBAS systems under geomagnetic storm conditions. The reason for this is that SBAS systems estimate ionospheric delays assuming a bidimensional behaviour of the ionosphere (no height), which valid in a nominal situation, but is not accurate in case of high geomagnetic activity or ionospheric storms when the ionosphere behaves as a 3-dimensional body, which properties change with height. This is considered as an intrinsic limitation in 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. In fact, this issue and its impact in the performance are well known from the beginning of the solar cycle for EGNOS and other SBAS systems. In parallel, other performance degradations mainly focused in the South of Europe and coming from the high variability of the ionosphere behaviour (TEC variations) have been also detected.

The month of February 2014 represents a very clear case of a period with a high number of ionospheric events impacting the performance of EGNOS and other SBAS systems. As an example, *Figure 15* presents the daily LPV performance[17] achieved by EGNOS two particular degraded days, February 19th (nominal degraded case) and 27th (highly degraded case).

17. EGNOS LPV availability is measured as the percentage of time the Horizontal Protection Level (HPL) and VPL (Vertical Protection Level) is below the Horizontal Alarm Limit (HAL) and Vertical Alarm Limit (VAL). HAL is 40m and VAL is 50m for LPV. The International Civil Aviation Organization (ICAO) requirement specifies that availability must be over 99%.

Figure 6 8 EGNOS LPV performance results on 19th (left) and 27th (right) February 2014



As it can be observed, several regions in the North of Europe were affected during February 19th. The case of February 27th is especially relevant owing to the size of the area impacted (this is, with SoL service availability below 99%) by the degradations. From the users´ perspective, the impact of these performance degradations originated by ionospheric events resulted in unavailability of the corresponding service level at specific areas and during limited periods of time.

Nonetheless it is worth noting that, even in such degraded scenario, during these periods of time the SoL Service Availability in the most impacted areas (North and South-West) within the SoL SDD commitment area was close to 94% (from the 1st February to the 31st March 2014);

Additionally it should be highlighted that the ionospheric events in case of impact on GNSS/SBAS-based operations cannot be currently notified to users in advance. Even if the possibility of predicting that kind of phenomenon, using space weather forecasts, to potentially alert users is still under investigation, the high impact for the SBAS users shows the clear need of understanding the mechanisms involved in this process.

It is of high importance to emphasize that independently of the presence of some EGNOS performance degradations linked to ionosphere in terms of Availability, Accuracy or Continuity, no associated integrity event (this is, navigation position error exceeds alarm limit for a given operation and the system does not alert the pilot in a time less than the time to alert) has been detected in the whole service area.

Appendix D.3 Improvement and robustness achieved by EGNOS

GSA, ESA and ESSP SAS 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. 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 provides a high stability to ionospheric disturbances, some degradation can still be expected during periods with very high ionospheric activity or under geomagnetic storm conditions.

The EGNOS system release that is currently under test and will be operational in a few months, ESR 2.4.1M, provides even further robustness to these ionospheric events. As an example, see the following figures *(Figure 6 9 and Figure 6 10)*.

Figure 6 9 **EGNOS APV-I availability on 12th September 2014 with ESR 2.3.2 (left) ESR 2.4.1M (right)**

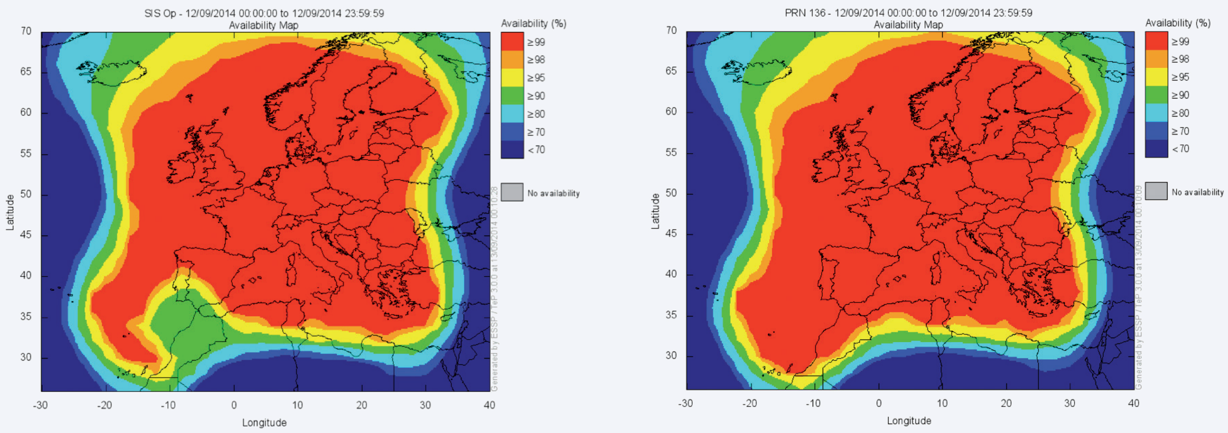
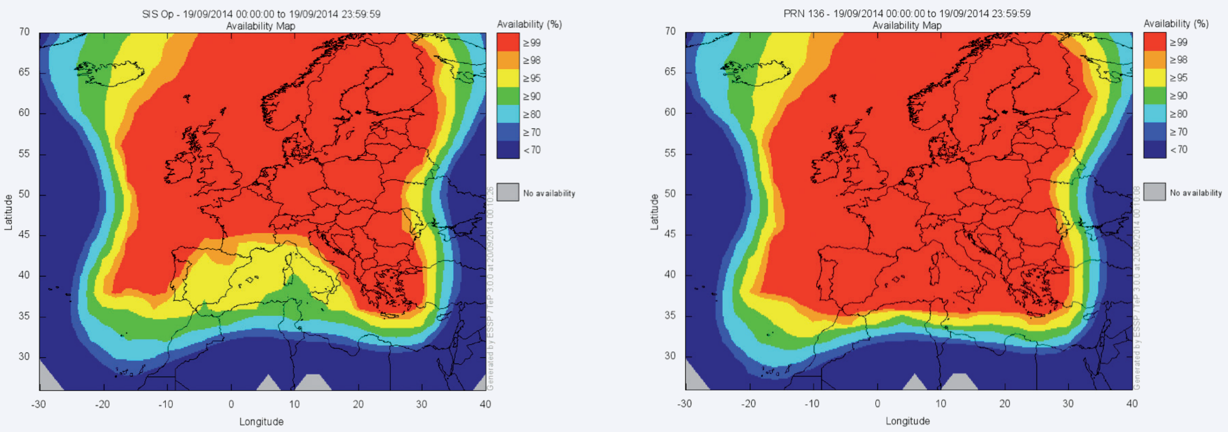


Figure 6 10 **EGNOS APV-I availability on 19th September 2014 with ESR 2.3.2 (left) ESR 2.4.1M (right)**



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. To illustrate this, the following maps (*Figure 18* and *Figure 19*) show, respectively, the measured APV-I Availability during the period from February to mid-May 2014 (“spring period”) and from mid-may until the first week of September (“summer period”).

Figure 6 11 **EGNOS LPV availability during “spring” (left) and “summer” (right) periods**

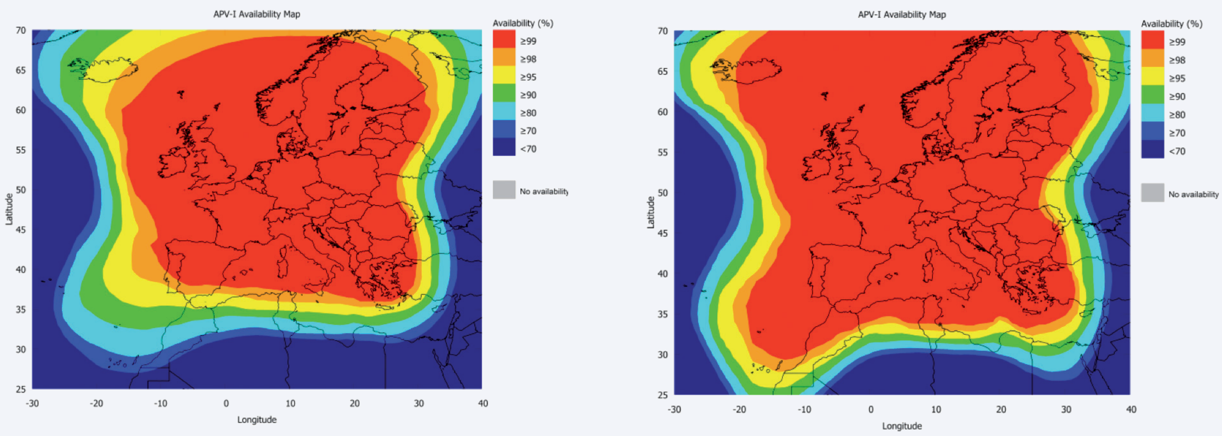
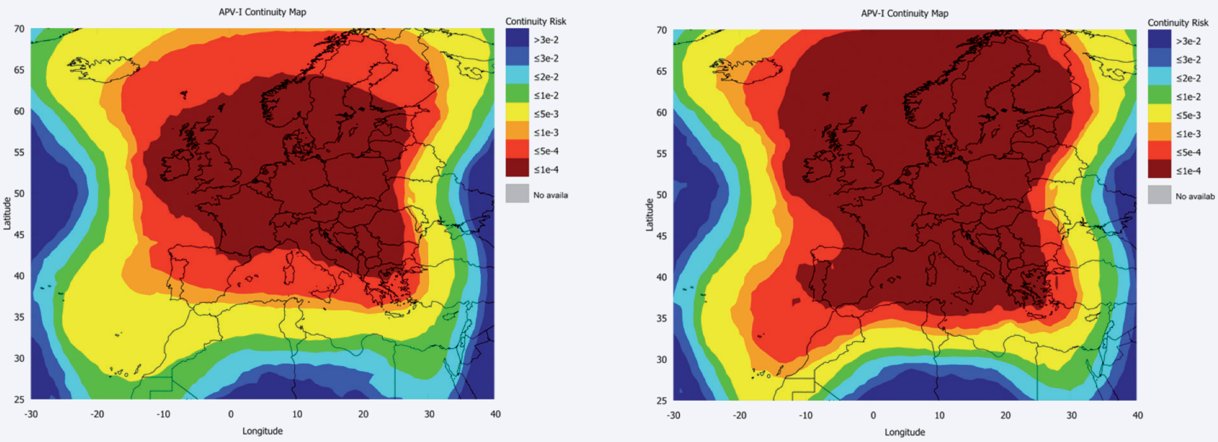


Figure 6 12 **EGNOS LPV continuity during “spring” (left) and “summer” (right) periods**



As observed, during the summer period, the coverage, in terms of LPV performance, presents better results, in particular in the North and Southwest of Europe.

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 (http://www.essp-sas.eu/service_notices) and distributed.

Particularly, the EGNOS Working Agreements (EWA) signed between ESSP and the different Air Navigation Services Provider includes commitment with regards to contingency communications. Whenever any degraded situation, which cause is expected to be maintained or that could potentially be reproduced (causing a similar impact) in the short term, is identified the corresponding contingency communications will be distributed by ESSP SAS to the impacted ANSPs, providing the corresponding performance reports and distributing the corresponding NOTAM proposals when required.

Appendix E – List of acronyms

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

ACRONYM	DEFINITION
ABAS	Airborne Based Augmentation System
AD	Applicable Document
AENA	Aeropuertos Españoles y Navegación Aérea
AFTN	Aeronautical Fix Telecommunication Network
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
AMC	Accepted Means of Compliance
ANSP	Air Navigation Service Provider
APV	APproach with Vertical guidance
ASQF	Application Specific Qualification Facility
C/A	Coarse/Acquisition
CCF	Central Control Facility
CDM	Collaborative Decision Making
CNES	Centre National d'Études Spatiales
CPF	Central Processing Facility
DAB	Digital Audio Broadcast
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
ENT	EGNOS Network Time
ESA	European Space Agency
ESR	EGNOS System Release
ESSP	European Satellite Services Provider
ETRF	EGNOS Terrestrial Reference Frame
ETSO	European Technical Standard Orders
EU	European Union
EWA	EGNOS Working Agreement
EWAN	EGNOS Wide Area Network
FAA	Federal Aviation Administration
FDE	Fault Detection and Exclusion
FIR	Flight Information Region

GAGAN	GPS Aided GEO Augmented Navigation
GBAS	Ground Based Augmentation System
GEO	Geostationary Satellite
GIVD	Grid Ionospheric Vertical Delay
GIVE	Grid Ionospheric Vertical Error
GLONASS	Global Navigation Satellite System
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPST	GPS Time
GSA	European GNSS Agency
HAL	Horizontal Alert Limit
HMI	Hazardous Misleading Information
HNSE	Horizontal Navigation System Error
HPE	Horizontal Position Error
HPL	Horizontal Protection Level
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IERS	International Earth Rotation and Reference Systems Service
IGS	International GNSS Service
IS	Interface Specification
ISRO	Indian Space Research Organisation
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunications Union
LNAV	Lateral NAVigation
LP	Localiser Performance
LPV	Localizer Performance with Vertical guidance
MCC	Mission Control Centre
MI	Misleading Information
MOPS	Minimum Operational Performance Standards
MRD	Mission Requirements Document
MSAS	MTSAT Satellite-based Augmentation System
MT	Message Type
NLES	Navigation Land Earth Station
NM	Nautical Mile

NOF	NOTAM Office
NOTAM	Notice To Airmen
NPA	Non-Precision Approach
NSA	National Supervisory Authority
OCS	Operational Control System
OS	Open Service
PACF	Performance and Check-out Facility
PBN	Performance Based Navigation
PNT	Precise Navigation and Timing
PRN	Pseudo-Random Number
PS	Performance Standard
RAIM	Receiver Autonomous Integrity Monitoring
RD	Reference Document
RDS	Radio Data System
RF	Radio Frequency
RHCP	Right Hand Circularly Polarised
RIMS	Range and Integrity Monitoring Station
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCA	Radio Technical Commission for Aeronautics
RTCM	Real Time Correction Message
SARPs	Standards and Recommended Practices
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
SPS	Standard Positioning Service
SPU	Service Provision Unit
SREW	Satellite Residual Error for the Worst user location
TEC	Total Electron Content
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
USAF	United States Air Force
USG	United States Government
VAL	Vertical Alert Limit
VNAV	Vertical NAVigation
VPE	Vertical Position Error
VPL	Vertical Protection Level
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 84 (GPS Terrestrial Reference Frame)
WUL	Worst User Location

More information on the European Union is available on the Internet (http://europa.eu).
Luxembourg: Publications Office of the European Union, 2015

ISBN: 978-92-9206-021-3
doi: 10.2878/493199

Document subject to terms of use and disclaimers p. 6 – 8
EGNOS Safety of Life Service (SoL) SDD, Issue 2.2

EGNOS

EGNOS, it's there. Use it.

TS-04-15-225-EN-N

European
Global Navigation
Satellite Systems
Agency