EGNOS: The first European implementation of GNSS - Project Status

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I. ABSTRACT

The European Tripartite Group (ETG), (ESA – EC – EUROCONTROL) is implementing, via the EGNOS project, the European contribution to the Global Navigation Satellite System (GNSS-1). The European Space Agency (ESA) is responsible for the design, development and technical validation of an Advanced Operational Capability (AOC) of the EGNOS system. The Technical validation is to be completed in early 2004, to enable operational use of the EGNOS Signal in 2004.

The EGNOS system will provide and guarantee navigation signals for aeronautical, maritime and land mobile users, that will significantly improve the GPS services, in term of accuracy, (from 20 meters to better than 5 meters), service guarantee (via Integrity signal) and availability (via additional ranging signals). It will operate on the GPS L1 frequency, and will thus be receivable with standard GPS front-ends. EGNOS is one of three Satellite-Based Augmentation Services (SBAS), the two others being the United States WAAS and the Japanese MSAS. The EGNOS coverage will first be the ECAC (European Civil Aviation Conference) area, and could be later extended to include other regions such as Africa, Eastern countries, and Russia. EGNOS is the first pillar of the European Satellite Navigation strategy, and a major stepping stone towards GALILEO, future European navigation satellite constellation.

This paper describes the EGNOS System requirements, the overall System design, as well as the current status of the on-going development activities, the EGNOS system test bed (ESTB), and the path from System development towards sustainable operations, in an integrated EGNOS/GALILEO Strategy.

II. EGNOS MISSION REQUIREMENTS

The current performance capabilities of GPS and GLONASS, although very adequate for many user communities, present some shortfalls. Firstly, the lack of civil international control presents a serious problem from the institutional point of view. Secondly, GPS or GLONASS cannot meet all civil aviation requirements for precision and non-precision approach phases of flight. Marine and land users will also require some sort of augmentation for improving GPS / GLONASS performances.

The Global Navigation Satellite System, GNSS-1, as defined by the experts of the ICAO/GNSS Panel, plans for some GPS/GLONASS Augmentation services to achieve the level of performance suitable for civil aviation applications.

The purpose of EGNOS program is to implement such an augmentation service, that fulfils a range of user service requirements, based on the broadcasting through GEO satellites of GPS-like navigation signals containing integrity and differential correction information. EGNOS will address the needs of all modes of transport, including Civil Aviation, Maritime and Land users.

The performance objectives for **aeronautical applications** (Table 1) are characterised by four main parameters: accuracy, integrity, availability and continuity of service. The values for these parameters are highly dependent on the phases of flight. Neither GPS nor GLONASS can meet the above integrity, availability and continuity of service objectives without a system augmentation, although their performance in terms of accuracy alone could meet the requirements of en-route, terminal area navigation and non-precision approaches. After more than 6 years of intensive standardisation efforts, these requirements are now finalised by the International Civil Aviation Organisation (ICAO) in the form of SARPS (Standards and Recommended Practices), as a part of Amendment 76 to Annex 10 of the Chicago Convention, with an applicability date of the 1st of Nov. 2001.

The performance objectives for **maritime applications** are broken down into ocean, coastal, in-land waters and harbour navigation, and have been quantified by the European Maritime Radionavigation Forum (Table 2).

A large number of **Land applications** under development world-wide relate to the use of satellite navigation. These include: vehicle positioning, fleet management, position tracking, emergency services, theft protection, farming, passenger information, control road, etc. The accuracy required ranges from hundreds of meters to a few meters, requiring the use of differential corrections. Integrity is also required for some of these applications.

Interest has been shown for other applications, such as the provision of a global time reference. EGNOS will provide a stable time reference within few ns of the Universal UTC time. Related applications include, time synchronisation of cellular phone networks, VSAT synchronisation, electric power synchronisation networks, Internet nodes synchronisation, etc.

III. EGNOS SERVICE AND PERFORMANCE

Amongst the three user communities, civil aviation requirements are the most stringent (in terms of integrity and continuity) and hence the EGNOS performance objectives are mostly driven by the needs of civil aviation, covering then, the needs of other user communities.

The coverage area serviced by EGNOS will be the European Civil Aviation Conference (ECAC) service area (fig 1) comprising the Flight Instrument Regions (FIR) under the responsibility of ECAC member states (most of European countries, Turkey, the North Sea and the eastern part of the Atlantic ocean). In addition, EGNOS has the capability to extend services beyond the ECAC region, within the Geostationary broadcast area.

The EGNOS AOC performance objectives are to provide a primary means service of navigation for all phases of flight from en-route through precision approach within this coverage, via the following services:

GEO Ranging (R-GEO): Transmission of GPS-like signals from 3 GEO satellites (INMARSAT-3 AOR-E, INMARSAT-3 IOR and the ESA ARTEMIS satellite) for the AOC phase. This will augment the number of navigation satellites available to the users.

GNSS Integrity Channel (GIC): Broadcasting of integrity information. This will increase the availability of GPS / GLONASS / EGNOS safe navigation service up to the level required for civil aviation non-precision.

Wide Area Differential (WAD): Broadcasting of differential corrections. This will increase the GPS / GLONASS / EGNOS navigation service performance, mainly its accuracy, up to the level required for precision approaches.

IV. EGNOS ARCHITECTURE

The EGNOS Reference architecture (Fig. 2) is composed of four segments: ground segment, space segment, user segment and support facilities.

The *EGNOS* Ground Segment consists of *Ranging and Integrity monitoring Stations* (RIMS) which are connected to a set of redundant control and processing facilities called *Mission Control Centre* (MCC). The AOC system will deploy 34 RIMS located in mainly in Europe and 4 MCCs located in Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). The MCC determines the integrity, differential corrections for each monitored satellite, ionospheric delays and generates GEO satellite ephemeris. This information is sent in a message to the *Navigation Land Earth Station* (NLES), to be uplinked along with the GEO Ranging Signal to GEO satellites. These GEO satellites broadcast this data on the GPS L1 frequency with a modulation and coding scheme similar to the GPS one. All ground Segment components are interconnected by the *EGNOS Wide Area Communications Network* (EWAN). The system will deploy 2 NLES per GEO navigation transponder, plus an NLES for Test and Validation purposes, located in Torrejon (E), Fucino (I), Aussaguel (F), Raisting (D), Goonhilly (UK), and Sintra (P) respectively. Planned sites for the different EGNOS G/S elements are shown in Fig. 3.

The *EGNOS* Space Segment is composed of Geostationary transponders with global Earth coverage. The EGNOS AOC system is based on the use of the INMARSAT-3 AOR-E and IOR, and the ESA ARTEMIS navigation transponders, with the Broadcast Areas as per Fig. 4.

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

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

V. THE EGNOS SYSTEM TEST BED (ESTB)

To support the development of the EGNOS system, an EGNOS System Test Bed (ESTB) has been developed and is now operational. It provides the first continuous GPS augmentation service within Europe. The ESTB has been developed under European Space Agency (ESA) contract by an industrial consortium, involving key European Satellite Navigation industries such as Alcatel Space Industries, Astrium, GMV, Racal, Seatex and DLR. This development was based on a number of pre-existing assets: These include the SATREF™ system from NMA (Norwegian Mapping Authority) and the EURIDIS ranging system from CNES. Since early 2001, the ESTB is also fully inter-connected with the Italian Mediterranean Test Bed (MTB), operated by ENAV (–Italian Civil Aviation Authority--).

The ESTB, operational since February 2000, constitutes a great step forward for the European strategy to develop the

European Satellite Navigation Systems, EGNOS and GALILEO. The ESTB has been developed to support to EGNOS detailed design, to analyse the future EGNOS upgrade and evolutions, but also to be a key tool to demonstrate the capabilities of Satellite Navigation systems to European users**.** In particular, ESTB signal allows Civil Aviation authorities to initiate development of infrastructure and operational procedures for future EGNOS use.

The ESTB architecture is a real-time full-scale prototype of EGNOS, as presented in Fig. 5. It is made up of a space segment (two transponders on board the Inmarsat-III AOR-E & IOR), a network of 10 RIMS, two Central Processing Facility (CPF), generating the user messages, (located in Hønefoss, Norway), one Operation control and processing centre (located in Toulouse, France), devoted to the generation of the GEO ranging data, and one Navigation Land Earth Station (NLES), located at Aussaguel (France). A real-time communication network interconnects these elements. In year 2001, thanks to additional supports from the European Commission, the ESTB will become operational 24 hours / 7 days a week, and will embrace capabilities for service expansion (outside of Europe) and interoperability analysis (with other augmentation systems such as WAAS). In addition, the ESTB will be permanently used in connection with the Italian Mediterranean Test Bed (MTB) and will incorporate additional reference stations provided in co-operation with AENA (Spanish CAA).

By using GPS and ESTB signals, European users can today determine their position with an error less than 3 meters (horizontal) and 5 meters (vertical), 95 percent of the time. A typical ESTB Vertical error distribution histogram is represented in Fig. 6. The area within which the test signal can be exploited, is determined primarily by the location of the reference stations. At the present time the accuracy performances are as per Fig. 7.

The ESTB is also providing an integrity service, represented by the Vertical and Horizontal protection levels computed by the User with the ESTB information data, which are to bound with a probability of 2x10-7/150 sec the Alert limits associated to a particular operation. Fig. 8 depicts typical Vertical Protection Level (Protection Level measures the guaranteed maximum error provided by the system ensuring the required level of safety) achieved throughout Europe through the ESTB. Values required for aircraft precision approach landing are already achieved in most of the European coverage. Results provide additional confidence in the current EGNOS design specially considering the reduced number of reference stations available in the ESTB and the current high solar activity.

Since early 2000, the EGNOS Test Bed has supported a number of application demonstrations in Europe. They have included landing planes at several airports, guiding ships into harbours but also navigating cars, such as:

Flight Trials:

- Approaches in Edinburgh (NATS, May 2000)
- Tests over Germany by (NLR/DFS, Nov. 2000)
- High Latitude tests (BNSC/DERA/NATS, March 2001)
- Helicopter approaches (Belgium Army, August 2001)
- Nice Airport Approaches (Eurocontrol/NLR, Sept 2001)

Land Mobile

- Fiat Road Trials (Turin, Nov 2000)
- APOLO demonstration (Czech Railways, March 2001)
- Precision Farming (UK, August 2001)

Maritime

- Italian Navy Trials in Genoa harbor (Feb. 2000)
- Greek Maritime demonstration in Aegean sea (March 2001)

More are planned, including in particular some demonstrations of EGNOS Extension capabilities in Middle East and in Africa. The European Commission, national agencies and ESA are supporting these demonstration initiatives of European industry and operators in a number of ways. To this aim, an ESTB Help Desk service can be reached through the E-mail address **ESTB@esa.int.** General information on ESTB scheduling, signal standards and the like can be found on **http://www.esa.int /navigation.** These user assistance services can provide a wide range of information for potential ESTB users, who can also attend the next ESTB user workshop planned in Nice, NAVSAT 2001.

VI. INTEROPERABILITY AND EXTENSIONS

Two other Satellite Based Augmentation Systems (SBAS) are under development, namely the Wide Area Augmentation System (WAAS) in USA, and the Multi-functional transport satellite (MTSAT) satellite-based augmentation system (MSAS), in Japan (see Fig. 9). Those SBAS are primarily defined as regional systems, and co-operation/co-ordination among the different systems will enable to provide a seamless world-wide navigation system.

To this aim, the three systems have set up common interoperability requirements, and this is monitored via regular "I*nteroperability Working Group (IWG)*" meetings between system development teams.

In addition to interoperability, EGNOS has built-in expansion capability to enable extension of the services over regions within the Geostationary Broadcast Area of GEO satellites used, such as Africa, Eastern countries, and Russia. The combination of SBAS Interoperability and expansion concepts will allow to provide a true global world-wide GNSS1 navigation seamless service, and actions are being pursued with international partners to exploit this capability, towards a full seamless service over wider areas.

VII. EGNOS PROGRAMME STATUS

The EGNOS System development is currently executed in the frame of the ESA ARTES 9 Programme. An "Initial phase" was concluded in November 1998 with the System Preliminary Design Review (PDR), and the "EGNOS AOC Implementation phase" is currently on-going since the end of 1998, towards system delivery in early 2004.

The industrial team in charge of this development is led by Alcatel Space Industries (France) with the participation of companies from all participating States, as illustrated in Fig. 10. The main development contract was signed in 1999, for a total contract value of 214 M€.

The EGNOS AOC Implementation Phase schedule is illustrated in Fig. 11. Current on-going major project milestones are the subsystems Critical Design Reviews, in 2001, towards the System Critical Design Review (CDR), planned in January 2002. The System Factory Qualification Review (FQR) is planned in early 2003, and the EGNOS AOC Operational Readiness Review (ORR), which concludes the Technical Validation Phase, is targeted for February 2004.

The ESA ARTES 9 Programme also includes significant contributions from the French Space Agency (CNES), the Norwegian Mapping Authority (NMA), and main European Air Traffic Management service providers like AENA (E), NAV-EP (P), DFS (D), ENAV (I), DGAC (F), NATS (UK) and Skyguide (CH). Those partners will in particular provide the infrastructure to host a number of the necessary EGNOS ground stations. Some other hosting sites are being provided via specific agreements with potential hosting entities. Site survey activities are currently being performed, to confirm adequacy of each site to host the EGNOS element, and to plan for necessary infrastructure upgrades.

VIII. FROM EGNOS SYSTEM DEVELOPMENT TO SUSTAINABLE OPERATIONS

The EGNOS System development currently carried out via the ESA ARTES-9 programme is the initial necessary step to the development of EGNOS services. Two other elements still need to be implemented before a sustainable business case for EGNOS operations could be achieved.

The first element is the EGNOS system operations during a transition period. It may take a considerable period of time before any significant revenues can be recovered from specific user communities. Consequently the public sector may have to subsidise the EGNOS operations during this transition period and probably beyond.

The second element is the development of technology and validation of specific user applications. Also here, public investments may be required, specifically in those fields where safety of life applications require a lengthy process of certification and regulatory approval, such as civil aviations.

To continue the European effort towards introduction of sustainable EGNOS Services, the ESA Member States have initiated the definition of this "post-ORR" operational framework. The key actors of this phase will be the EGNOS Owner Entity, the System Operator, and the Application Service Providers.

Up to the Operational Readiness Review (ORR), ESA remains the owner of the EGNOS system. A process of transfer of ownership of the EGNOS assets to a future EGNOS Owner Entity will have to be defined.

The System Operator will be responsible for the delivery of the Signal in Space (SIS) according to the specified requirements.

The Application Specific Service Providers for different modes of transport (e.g. Aviation, Maritime Rail, Road, etc.) will have to develop the necessary means for their specific field of application (e.g.

operational validation and certification process for aviation).

A new specific Regulatory Entity is actually not yet addressed, but may have to be set up in a global European GNSS context.

ESA Member States have set up a Working group, to define the legal framework and procedures under which these entities will be defined, created and/or selected. To this aim, the Civil Aviation Partners, assembled as EOIG, (EGNOS Operator and Investor Group) have expressed their willingness to play an important role within the future owner entity. They intend to become the future EGNOS System Operator / Service Provider, to develop the aviation services, and are open for further investors and interested parties for the provision of multimodal services.

IX. TOWARDS AN INTEGRATED EGNOS/GALILEO STRATEGY

The European strategy for sustained development of satellite navigation services in Europe needs to include the following principles:

i. The operational EGNOS Service over the European region needs to be initiated as soon as possible, to support the early development of European satellite navigation applications,

ii. Europe needs to engage as soon as possible in the implementation of GALILEO, to timely promote the wide use of satellite navigation technology, and to achieve a European autonomy in such a critical domain.

iii. Two satellite navigation systems (GPS augmented with WAAS / EGNOS / MSAS and GALILEO) in the future architecture of GNSS will be necessary to achieve the stringent reliability level required for security and safety of life services. This is a prerequisite to the long term introduction of satellite technology as the main means of navigation for all civil positioning and timing applications.

iv. These two satellite navigation systems (GPS augmented with WAAS / EGNOS / MSAS and GALILEO) need to be functionally independent with no common failure modes. Technical interfaces between EGNOS and GALILEO will be investigated, without compromising the overall objective of avoiding common failures or unavailability modes of EGNOS and GALILEO services, which cannot be tolerated either at system or operational levels.

v. The integration of EGNOS with GALILEO will be pursued in all areas where significant synergies and reuse of European investments could be expected. Maximum reuse of EGNOS experience will be pursued in the GALILEO programme.

vi. As a function of the future evolutions of the GPS system, up-grades of the EGNOS system will have to be assessed (e.g. to provide integrity to the new civil signals to be broadcast by GPS such as L5).

X. SUMMARY

EGNOS is the main European contribution to GNSS-1 to serve the needs of maritime, land transport, time and aeronautical applications in the European and neighbouring regions. For aviation, EGNOS AOC will be used in the ECAC Region as a primary means of navigation for all phases of flight down to CAT-I.

EGNOS will be interoperable with equivalent US (WAAS) and Japanese (MSAS) SBAS systems, aiming at contributing to a true world-wide global system.

The EGNOS Test Bed signal-in-space is available since early 2000, and is used to support demonstrations and trials in Europe, Africa, South America and interoperability trials with Japan and US. The ESTB provides a unique opportunity for validating new application developments in a realistic environment, in preparation not only for the EGNOS operations but also for future GALILEO services.

EGNOS AOC Development and Technical validation will be completed by early 2004, and will be followed by initial operation and operational validation activities. EGNOS is the first step of the European Satellite Navigation strategy and a major stepping stone towards GALILEO, Europe’s own global satellite navigation system for which ESA has a major role and responsibility.

Table 1: Aviation GNSS Signal-in-space performance requirements

Typical operation(s)	Accuracy lateral /vertical 95%	Alert limit lateral /vertical	Integrity	Time to alert	Continuity	Availabi - lity	Associated RNP type(s)
En-route	2.0NM/ N/A	4NM/ N/A	10^{-7}/h	5 mn	$1-10^{-4}$/h to $1-10^{-8}$/h	0.99 to 0.99999	20 to 10
En-route	0.4NM/ N/A	2NM/ N/A		15 s		0.999 to 0.99999	5 to 2
En-route, Terminal	0.4NM/ N/A	1NM/ N/A					1
Initial approach, NPA, Departure	220 m/ N/A	0.3NM/N/A		10 s		0.99 to 0.99999	0.5 to 0.3
APV-I	220 m/ 20 m	0.3NM/50 m	$2x10^{-7}$ per approach		$1-8x10^{-6}$ in any 15 s		0.3/125
APV-II	16 m/ 8 m	40 m/ 20 m		6 s			0.03/50
Category I	16 m/ 4-6 m	40m/10-15m					0.02/40

Table 2: Maritime GNSS typical performances

	GNSS System level parameters			
	Accuracy Horizontal	***Integrity Alert limit***	***Integrity Time to alarm***	***Integrity risk (per 3 hours)***
Ocean	10 m	25 m	10 sec	10^{-5}
Coastal	10 m	25 m	10 sec	10^{-5}
Port approach and restricted waters	10 m	25 m	10 sec	10^{-5}
Port	1 m	2.5 m	10 sec	10^{-5}
Inland waterways	10 m	25 m	10 sec	10^{-5}

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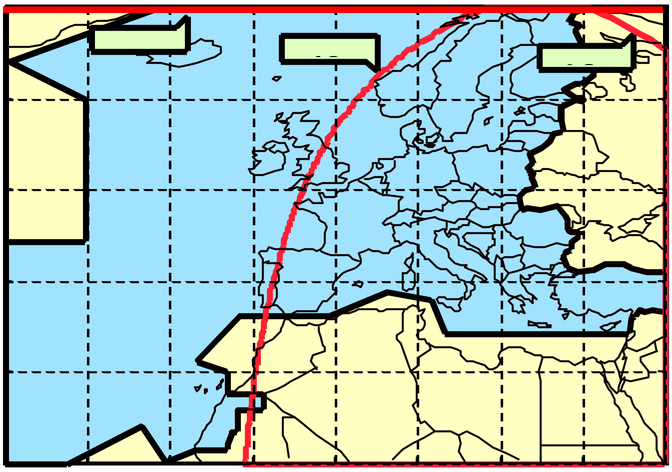

Figure 1 ECAC approximate coverage Area

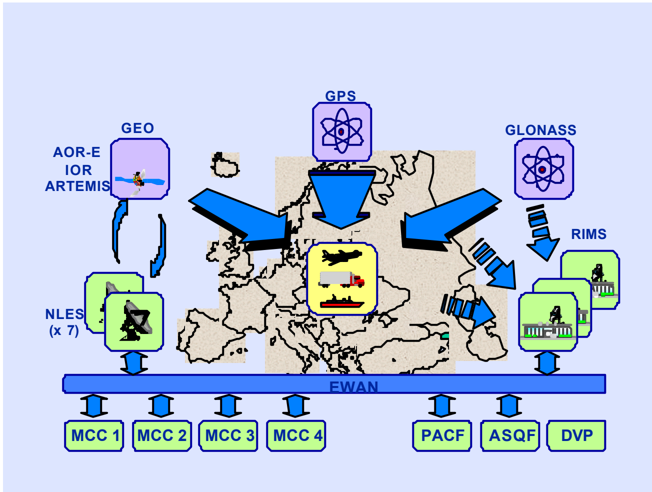

Figure 2: EGNOS AOC Architecture

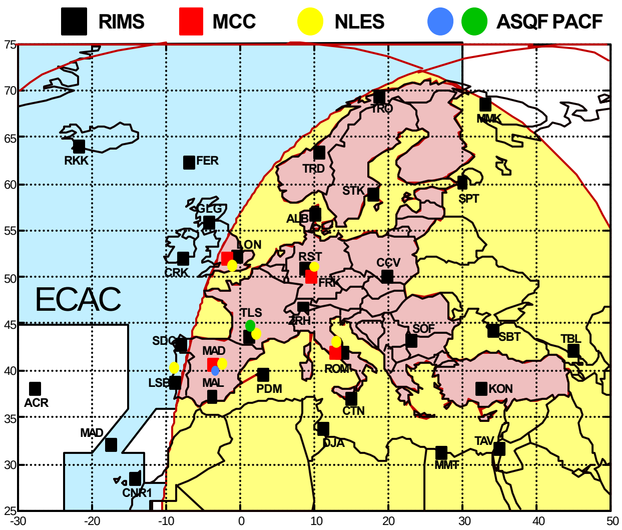

Figure 3: EGNOS Ground Segment Sites

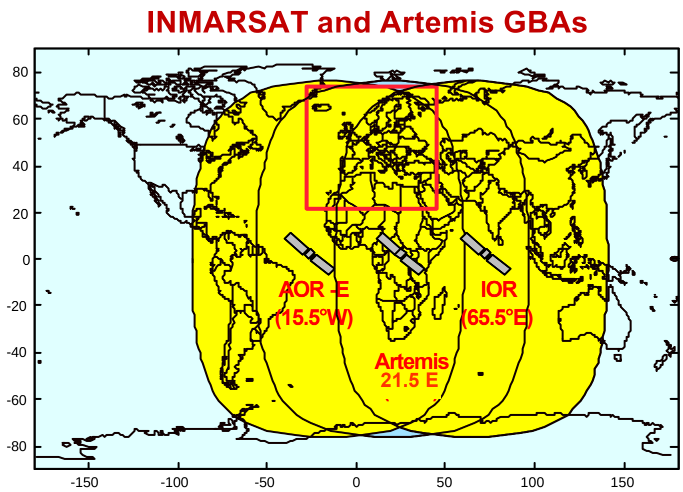

Figure 4: Inmarsat and Artemis Broadcast Areas

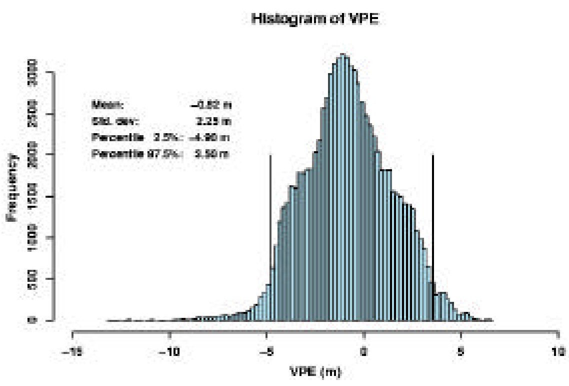

Figure 6: Typical ESTB Vertical error histogram

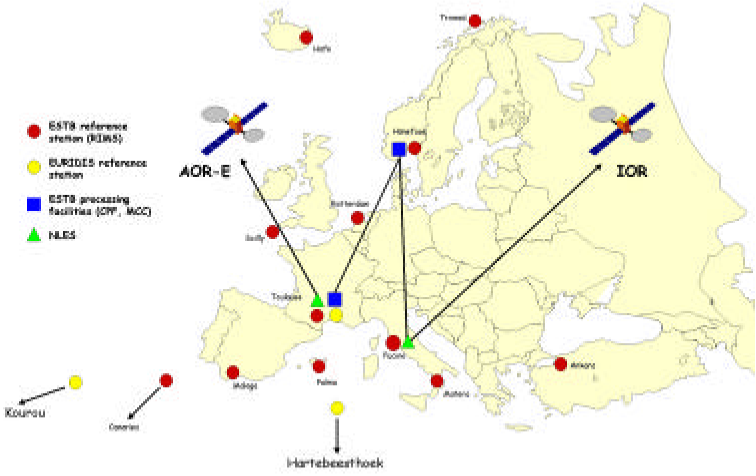

Figure 5: EGNOS System Test Bed (ESTB) architecture

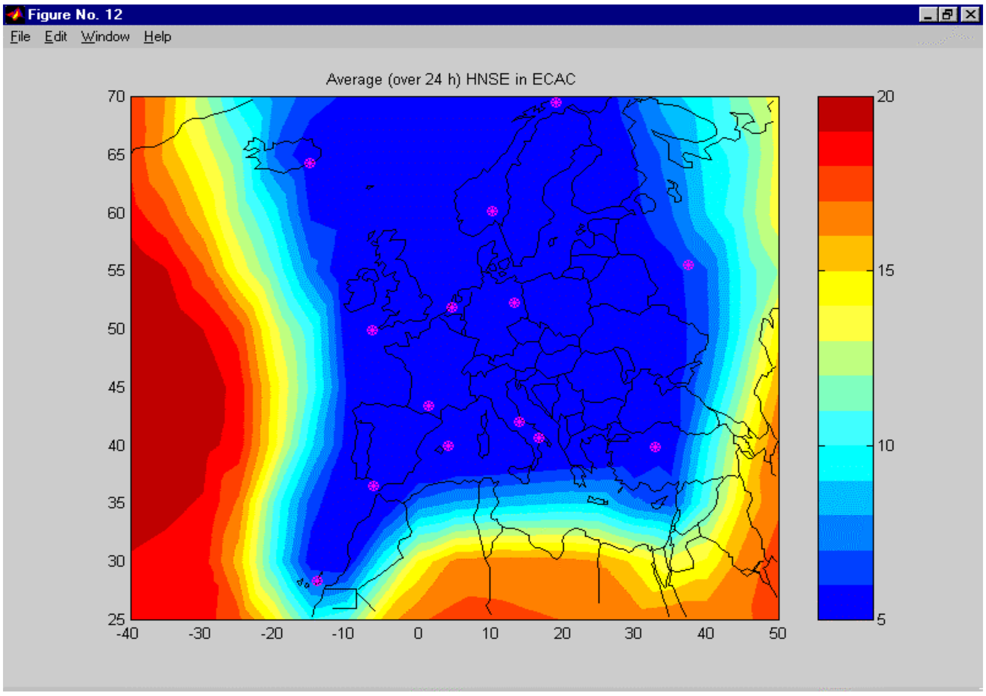

Figure 7: ESTB accuracy (2-sigma value) performances (including MTB)

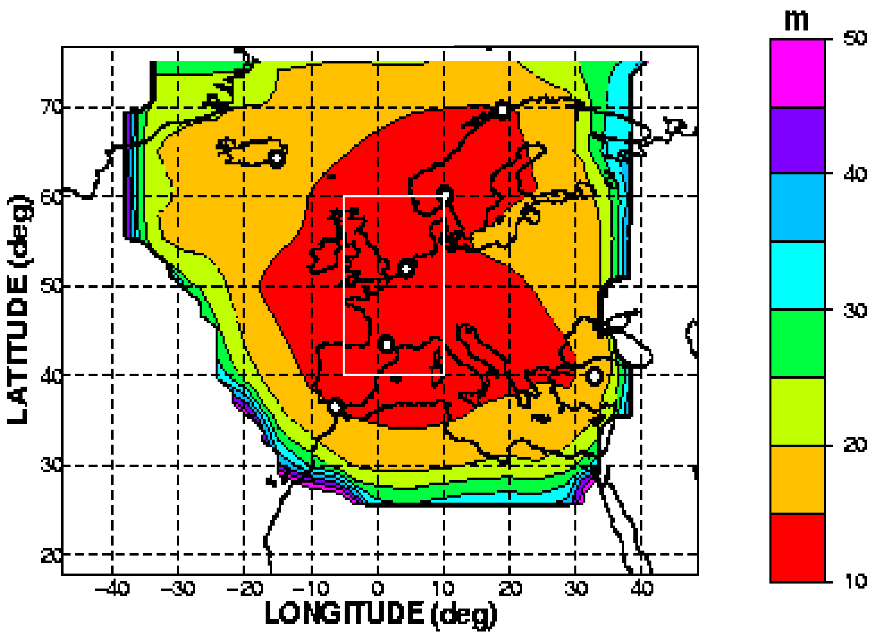

Figure 8: Typical Vertical Protection levels achieved by the ESTB

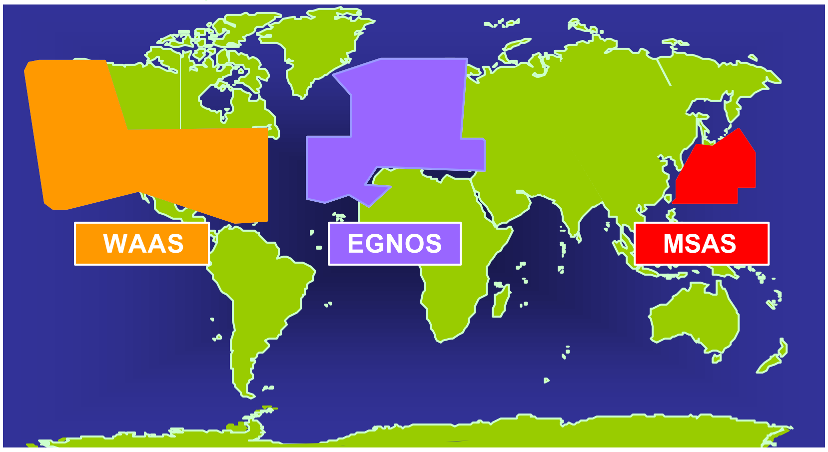

Figure 9: WAAS, EGNOS and MSAS nominal service volumes

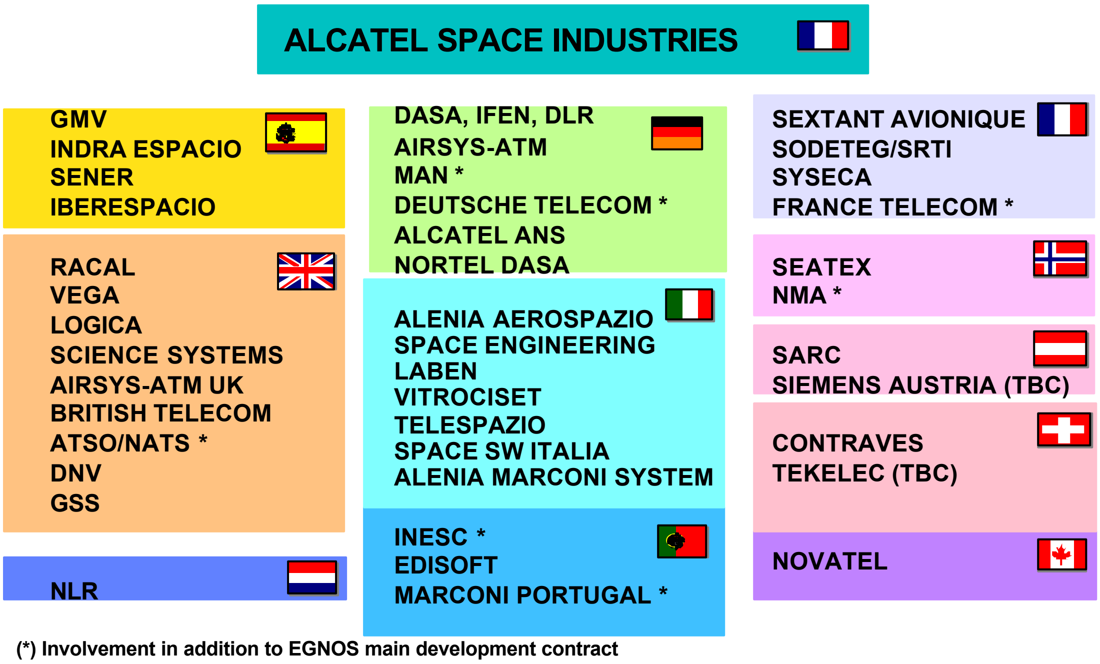

Figure 10: The industrial team in charge of EGNOS AOC

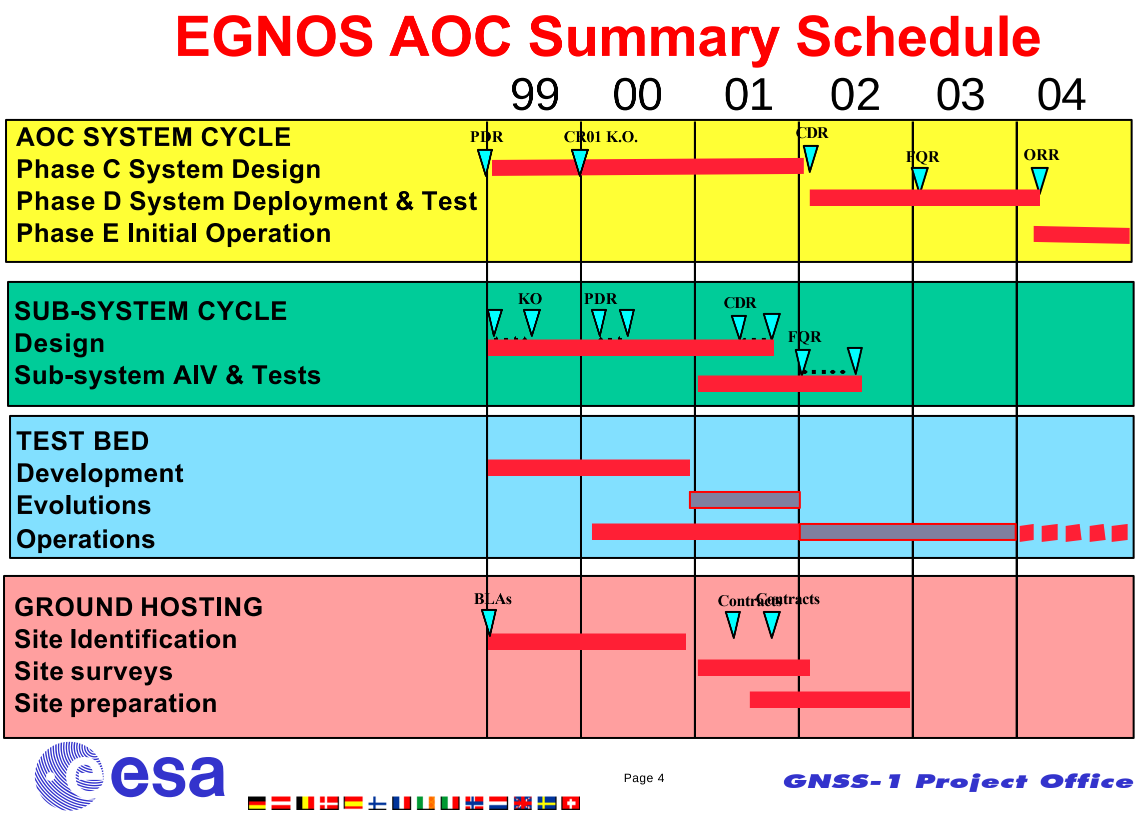

Figure 11: EGNOS AOC Summary Schedule