EGNOS System Test Bed Status and Achievements

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ABSTRACT

EGNOS is now becoming a reality as ESTB (EGNOS System Test Bed) - a simplified version of the fully-fledged system has been readied in January. An EGNOS-like signal has since mid-February 2000 been transmitted from the Inmarsat AOR-E satellite, providing users with a GPS augmentation signal (with ranging and GIC/WAD messages) enabling them to compute their positions to an accuracy of a few metres.

ESA is responsible for the overall operations of the EGNOS System Test Bed and, in performing this role, is working in close co-operation with the French space agency CNES and the Norwegian Mapping Authority (NMA). Development of the EGNOS System Test Bed was managed by Alcatel Space Industries (F), ESA prime contractor for EGNOS and by the subcontractors GMV (E), Racal (UK), Seatex (N), Dornier SatellitenSysteme (D), DLR (D) and Sextant (F).

This paper presents the current ESTB architecture, a description of the main algorithms, the performances achieved and the on-going development.

1 EGNOS ESTB OBJECTIVES

Within the EGNOS program, ESA is providing a pre-operational signal in space with several objectives:

- Assessment of overall system and mission performance in such a way that confidence in the EGNOS system design and in that the mission requirements can be reached in the final system.
- Analysis of specific critical design issues and trade-offs that are difficult to solve without very realistic system models.
- Data gathering. The data are being widely used in particular to validate developed algorithms and components to be integrated in the frame of EGNOS program.
- Demonstration of the operational benefits of EGNOS to the different user communities.
- Preparation for the future operational introduction of EGNOS

With a phasing advance over the EGNOS AOC, which will be turned into operation in 2004, the ESTB is today's available tool to prepare the potential EGNOS users for the integration of GNSS technology into real-life applications. Among them, companies and institutions providing transport services can prepare for the use of EGNOS. Using the ESTB signal, it is possible to perform real-time operational demonstrations of GNSS navigation.

The current ESA pre-operation programme includes the continuous operations of the ESTB system continuously, that is the delivery of ESTB signal in space, and a set of pre-planned trials sessions, so-called Early System Design Verification experiments (ESDV), some of them involving user platforms in connection with European Civil Aviation Authorities.

In the near future, satellite navigation trials outside Europe will be promoted, with fielding of additional Reference Stations using the current ESTB configuration as a backbone.

2 GROUND SEGMENT ARCHITECTURE

The ESTB architecture is presented in figure 1; it has been driven by high performance objectives in order to be able to assess the operational capabilities of EGNOS.

Also, in order to reduce the development time of the ESTB and to optimize the overall ESTB effort, a number of existing assets have been taken into account to build up the ESTB:

- from NMA in Norway, based on the existing SATREF system,
- from ESA, based on the EURIDIS ranging system (EURIDIS was implemented in 1999 by THOMSON CSF under a CNES contract in order to provide the GPS ranging capability on the INMARSAT III AOR-E navigation payload),

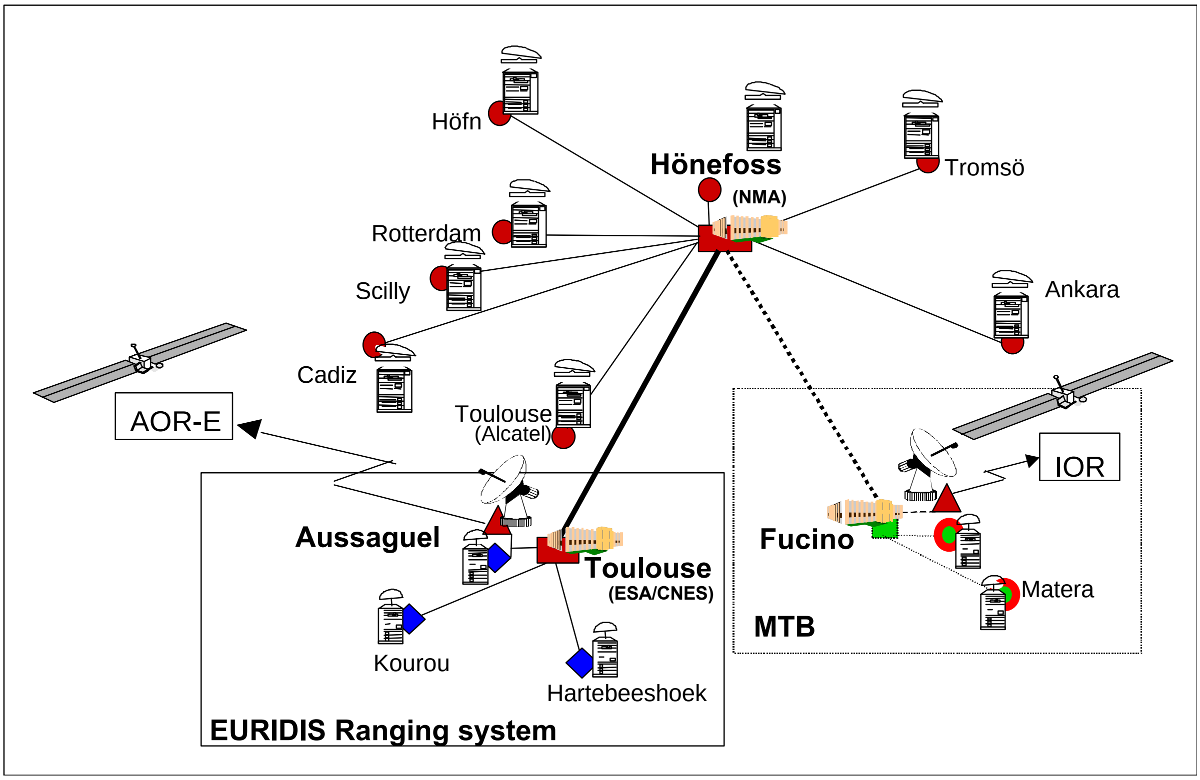

Figure 1 : ESTB Architecture

Alcatel Space Industries has managed the ESTB development, integrating the contributions of the various providers and the existing assets:

- a network of Reference Stations, sized to a number of 8 in a first step, expandable in the future, and which are permanently collecting GPS/GEO/GLONASS data,
- a Control and Processing Facility (CPF) designed and developed by GMV (Spain), generating the WAD user messages. The CPF is located in Hönefoss (Norway), and supported by SATREF® platform provided by the NMA,
- one Navigation Land Earth Stations (NLES) also part of the EURIDIS Ranging system, located in Aussaguel (France), allowing the access to the INMARSAT III AOR-E satellite,
- three EURIDIS Reference Stations for the purpose of the Ranging function. These RS are located on an intercontinental basis in order to provide a wide observation base for the GEO. They are also collecting GPS/GEO data.
- a EURIDIS processing centre located in Toulouse (France), devoted to the generation of the GEO ranging data, and which also act as a node for the transmission of the user message,
- a real-time communication network, allowing the transfer of the reference stations data to the processing centres, and of the navigation messages from Hönefoss to the NLES.

The eight ESTB reference stations and the three EURIDIS reference stations have been produced by SEATEX (Norway) and SEXTANT (France), respectively; their locations are shown in figure 1. The connection to the IOR payload through the MTB (from ENAV) will be effective in the next future (see 5.1)

3 FUNCTIONAL DESCRIPTION

The real time chain for the WAD/Ranging data generation and of the MOPS message production is depicted in the figure 2.

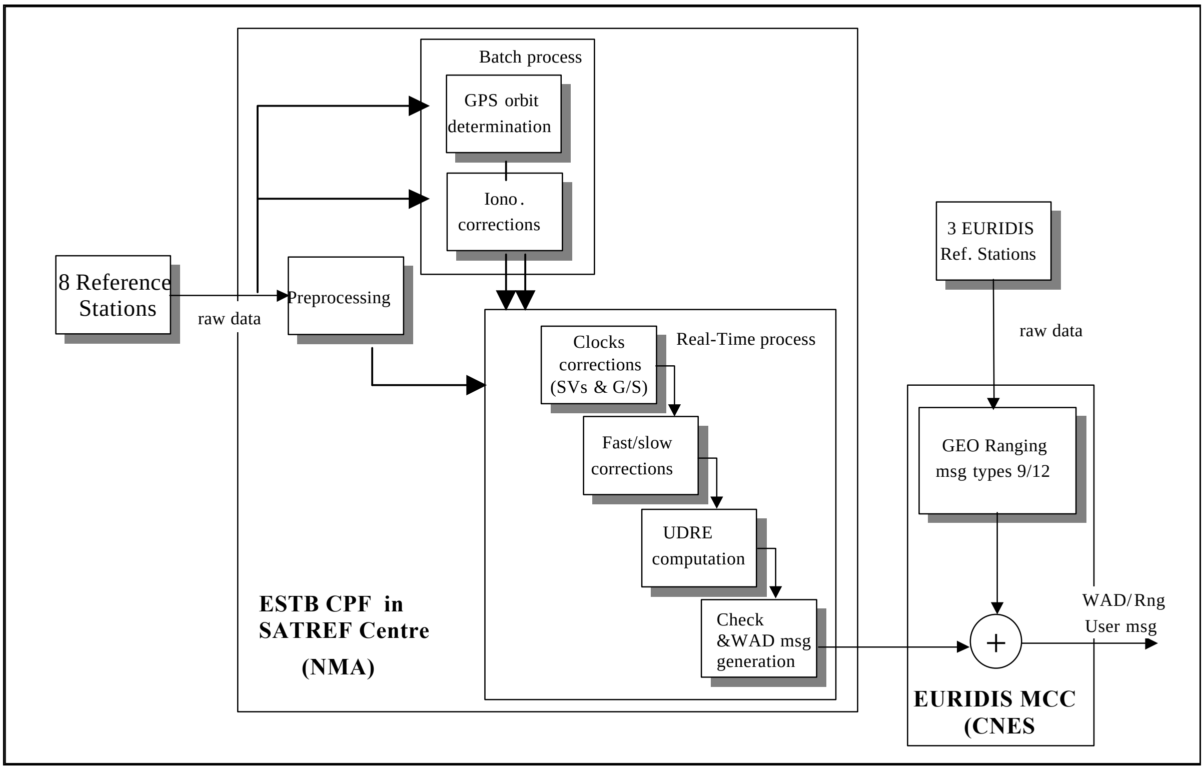

Figure 2 : WAD/Ranging message generation chain

3.1 Algorithms

The functions implemented in the ESTB CPF are selected as required for the generation of EGNOS WAD messages. All functions are addressed to provide WAD corrections to GPS (corrections to GLONASS are not to be provided).
Functions related to GEO are included in the EURIDIS MCC. Algorithms and performances of the GEO ranging are described in Ref (4), Ref(5) and Ref(7).
The most relevant functions in ESTB CPF are:

3.1.1 GPS Orbit determination

Estimates precise orbital information for the GPS satellites (including predictions for the future epochs) to be included as part of the information broadcast to the users. It is in charge of:

- Pre-process the input data (basically measurement data and GPS broadcast ephemeris data, both provided by ESTB stations).
- Compute for all monitored GPS satellites:
  - Precise state vectors (position and velocity) based on measurements collected during a certain arc of time (orbit determination).
  - Precise state vectors predictions for future epochs (orbit propagation).
- Generate an output file containing the GPS satellite state vectors and time information compliant with the SP3 NGS format.

3.1.2 Ionospheric Corrections Determination

Estimates the:

- Receiver and Satellite HW biases.
- Ionospheric delays and error bounds for a number of configurable grid points, which are part of the information broadcast to the user. The broadcast GIVE is a 99,9% value (roughly error*3.2).

3.1.3 Data pre-processing and Validation

Checks data reasonability, eliminates systematic errors (correct troposphere, detect cycle-slips, compute iono-free observables) and smooths the input GPS data (filter iono-free observables) which will feed the rest of the real time modules.

3.1.4 Clock corrections

The functionalities provided are:

- Ground Clock Synchronisation: estimation of the clock offsets between Reference Stations clocks and steering of the resulting ESTB Network Time to the GPS time scale.
- Satellite Clock Corrections Estimation: estimation of the satellite clock corrections which is part of the information broadcast to the user.
- Fast/Slow Characterisation: compute the final satellite related corrections (orbits and clocks) which are bound to be broadcast, according to the message description in the MOPS RTCA Ref(9)

3.1.5 UDRE Computation

Computation of upper bounds to the errors in the satellite related corrections (orbits and clocks), which will be part of the information broadcast to the user. The UDRE broadcast is a 99.9% value.

3.1.6 Modelised Navigation Overlay Frame Consistency Check

Checks the consistency and size of the computed outputs of the CPF functionalities to identify possible problems of integrity loss in the broadcast messages.

3.1.7 CPF Message Generation

Selects the type and contents of the next message to be generated. Formats the information to be broadcast according to the restrictions defined in § 3.2.

3.2 ESTB modes and SIS contents

A set of modes has been defined for the ESTB according to the status of some ESTB components. The main modes are listed in the ESTB User Interface document Ref(8) and the most useful are :

- "**only ranging**" mode : in this case, the broadcast messages make it possible to consider the navigation payload as a supplementary GPS-like resources. The receiver is able to deliver pseudoranges for the GEO PRN, and user positions mixing GPS and navigation resources. In this case, the RAIM is most efficient and the user position is smoother and a little more accurate than the GPS/SPS one.
- "**clock only corrections**" mode : in this case, the broadcast messages make it possible to correct GPS pseudoranges with differential corrections and integrity information compensating for a large part of the GPS Selective Availability. The receiver is able to use corrected pseudoranges and to deliver a user position more accurate than the GPS SPS one.
- " **clock corrections & ranging**" mode : the combination of the two above described modes.
- "**GIC/WAD corrections**" mode : in this case, the broadcast messages make it possible to correct GPS pseudoranges :
  - with differential corrections (slow and fast) and integrity information compensating for a large part of the GPS Selective Availability and a large part of the broadcast GPS ephemeris error
  - with a grid of "near real time" ionosphere delays (GIVD) and associated errors (GIVE) instead of the Klobuchar algorithm with the last broadcast set of the associated parameters. The

receiver is able to deliver corrected pseudoranges concerning the PRN and the user position is more accurate than using the GPS SPS (an 8m HNSE (Horizontal Navigation System Error) and a 10m VNSE (Vertical Navigation System Error) are specified. The integrity of the user position is largely enhanced.

- “ **GIC/WAD corrections & ranging**” mode : this mode is really the demonstration of the future EGNOS service. It is the combination of the only ranging mode and the GIC/WAD correction mode applied on the GPS signals and the GPS like signal.

The different types of broadcast messages according to ESTB mode are summarised in the following table. Content and use of each type of message is described in the RTCA DO 229 document Ref(9).

ESTB mode	Types of broadcast messages (see also note 1)	Availability through	
		AORE (PRN 120)	IOR (PRN 131)
internal test	0	Yes	*TBD*
only ranging	1, 9, 12, 17, 24, 63, (0)*	Yes	No
clock only corrections	0, 1, 2, 3, 4, 7, 25***, (63)**	Yes	Yes
clock corrections & ranging	0, 1, 2, 3, 4, 7, 9, 12, 25***, (63)**	Yes	No****
GIC/WAD corrections	0, 1, 2, 3, 4, 7, 18, 25, 26, (63)**	Yes	Yes
GIC/WAD corrections & ranging	0, 1, 2, 3, 4, 7, 9, 12, 18, 25, 26, (63)**	Yes	No****

* : depending on internal MCC status, not often used

** : depending on unavailability of ESTB message at the NLES for the current epoch, not often used, just in case of network disturbances concerning links CPF/MCC or MCC/NLES

*** : fields “slow correction” filled with 0 except clock.

**** : in case of reception of ranging messages through IOR, they will be filled with 0 and the slot for PRN 131 in message type 1 will be set to 0.

Note 1 : There is no standard ESTB sequence(s) of messages except for the “only ranging” mode. The ESTB messages are only constrained to the maximum update interval defined for each type of message in Ref(9).

Note 2 : The ESTB broadcast information (fast corrections) are not potentially free of bias, this bias affecting each pseudorange disappears when a user navigation solution is computed.

4 PERFORMANCE RESULTS

The performance below was obtained during the acceptance tests (January 2000).

4.1 Position accuracy results

Figure 5 shows horizontal and vertical errors from a static GNSS receiver located at Euridis MCC (Toulouse). The typical HNSE (95%) is less than 3m and VNSE (95%) less than 5m (see figures 3 and 4). The double distribution shown in Fig. 4 corresponds to a change in the GPS visibility (without applying a weighing factor on the SVi used by the receiver).

4.2 Integrity results

The results here after correspond to the day January 20th, 2000. The ESTB was configured in GIC/WAD corrections mode (i.e. the Ionospheric Corrections Module and the Orbit Determination Module were enabled).

4.2.1 UDRE

Figure 6 depicts the minimum, mean and maximum values computed for UDRE type 2 from 01h 43m up to 11h 47m. Mean UDRE value is around 2.3 m.

4.2.2 Protection levels

The Vertical and Horizontal Protection Levels have been computed for the Precision Approach flight phase. The results are shown on figures 7 and 8. As an example, at Honefoss the VPL is varying between 10m and 50m, and in Toulouse between 15m and 60m. The VPL is mainly affected by the high values of GIVE. It might be due to the fact that only 8 reference stations are available to day, and optimised in the future with additional references stations.

4.3 Ionosphere delays and errors (GIVE, GIVD)

With the current 8 ESTB Reference Stations, a large part of the ECAC zone is covered, only some points of the grid near the border of this area have "don't use" GIVD and GIVE values due to the small number of stations (see figure 9). Some comparisons were made between the 4 points of the grid around Toulouse and measurements obtained through EURIDIS data collection on the same location. Euridis ionospheric measurements are ionospheric delays towards the AORE satellites and represent roughly twice the vertical delay These comparisons show that the GIVD are in the expected range, except when transitions occur (night/day). In that case, the GIVE increase.

4.4 Time to alarm

The Time-to-Alarm performance is constrained by the ESTB architecture. An additional delay (approximately 3s) is introduced by the network link between the ESTB Processing Facility located in Honefoss and the EURIDIS Center located in Toulouse, and by the EURIDIS processing and message generation function.

In order to have an idea of this performance, two specific tests were performed by creating events causing a "Don’t Use" situation for several SVs_i. The alarm delay measured between the time tag for the event (stop of a specific Reference Station) and time tag for a "Don’t Use" received by a user receiver was between 8 and 12 seconds, with a mean value of 10.1s.

5 ON GOING EVOLUTIONS

5.1 ESTB-MTB connection

At the mid of the year 2000, the ESTB will be connected with the Italian Mediterranean Test Bed (MTB being provided by ENAV) in two ways (refer to figure 1):

* the WAD message will be sent from the SATREF® Control Centre to the Fucino NLES, and broadcast via the INMARSAT III IOR satellite.
* Two Reference Stations from the MTB (located in Fucino and Matera) will be connected to the ESTB SATREF® Control Centre. This will allow the improvement of the GPS satellites observations and the ionospheric measurement in the zone.

5.2 Addition of Reference stations

In the second half of year 2000, additional reference stations will be installed in various parts of Europe:

- Two from AENA, one on Canaries and one on Mallorca
- Two from DFS, one in Berlin and one in Moscow

The expansion will provide a network with a density of operational reference stations which are more representative for the EGNOS network, helping the future EGNOS service providers to prepare for the introduction of the operational service.

5.3 MOPS Standard

In the second half of the year 2000, the ESTB-CPF will be upgraded (in parallel with the expansion functions) in order to be compliant with the evolution of the MOPS standard RTCA DO229A dated 8 of June 98 . This evolution mainly consists of the generation of new message type 10 (with a priori values), involving GIVE, UDRE and RRC (Range Rate Correction) degradation parameters.

5.4 Expansion Outside Europe

Transportable reference stations are being developed for international trials under the European Commission’s International Test Bed initiative. In addition, a new message type is being introduced in the ESTB to reflect a recent RTCA MOPS change on this subject (Message Type 27). Also, ionospheric corrections will be provided in the expansion service area in order to achieve NPV-1 performances. An ESTB signal-in-space outside Europe is expected in the second half of 2000.

6 CONCLUSIONS

The ESTB is now providing a pre-operational signal in space, allowing a high level of positioning accuracy above Europe. It supports four main domains:

1. Industrial activities for the development of EGNOS: assessment of the overall system and the mission performances to establish confidence in the system design and that the final accomplishment of the mission requirements can be reached.
2. Validation of algorithms during EGNOS implementation phases, including subsystems testing with real data.
3. Preparation of the EGNOS operational phase: In the year 2000, the ESTB will be used for static and in-flight data collection activities.
4. Demonstrations: the ESTB will also continue to play an important role in demonstration activities not only for aviation but also to prove EGNOS functionality for other modes of transport. Multi-modal trials have already been planned for the year 2000 involving land, maritime, and rail users. A first Maritime demonstration was made during February 2000 in Genoa Harbour.

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8. ESTB/SIS - User Interface Description, N. Suard, H. Secretan, document E-TN-ITF-E31-0008-ESA available on request
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10. RTCA MOPS for GPS/WAAS Airborne Equipment, RTCA/DO-229, June 8, 1998

Acronyms :

AENA:	Aeropuertos Espanoles y Navegacion Aérea
AORE :	Atlantic Ocean Region - East
CNES :	Centre National d'Etudes Spatiales – French Space Center
CPF :	Central Processing Facility
DGAC :	Direction Générale de l'Aviation Civile - French Civil Aviation
DFS:	Deutsche Flugsicherung GmbH - (German Civil Aviation)
EGNOS :	European Geostationary Navigation Overlay Service
ENAV:	Ente Nazionale di Assistenza al Volo (Italian Civil Aviation)
ESTB	EGNOS System Test Bed
GEO :	INMARSAT III AORE satellite
GIVD	Grid Ionospheric Vertical Delay
GIVE	Grid Ionospheric Vertical Error
GLONASS :	GLObal NAvigation Satellite System (Russian system)
GMV:	Grupo de Mecanica del Vuelo (Spain)
GNSS :	Global Navigation Satellite System (Generic term)
GPS :	Global Positioning System
GRS :	Geostationary Ranging Station
HPL	Horizontal Protection Level
IGP	Ionosphere Grid Point
IOR :	Indian Ocean Region
MCC :	Mission Control Centre
NIC :	Critical Non Integrity (French acronym)
NLES :	Navigation Land Earth Station
NMA:	Norwegian Mapping Authority
NPV-1:	Non Precision Approach with vertical guidance (Alert limit of 50m)
SIS :	Signal In Space
UDRE	User Differential Range Error
VPL	Vertical Protection Level
WAD	Wide Area Differential

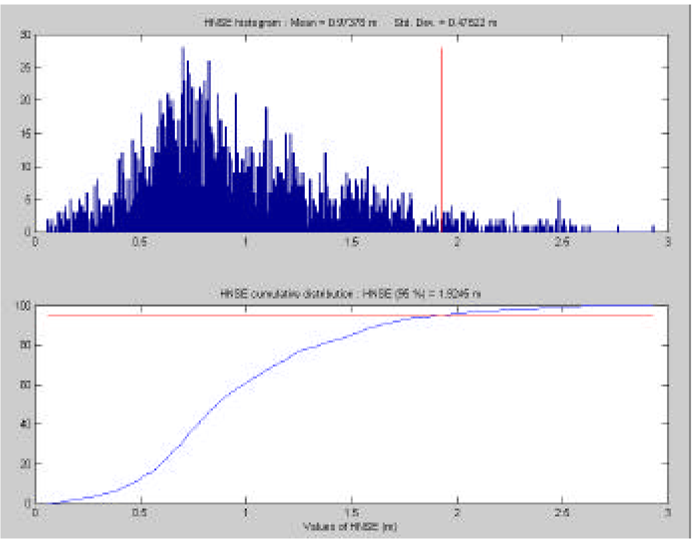

Fig.3: HNSE 95% (2m) in Toulouse the 18/01/00

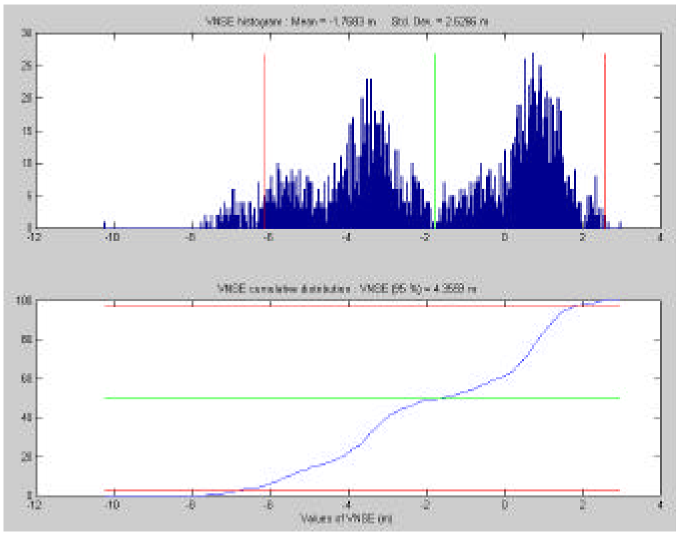

Fig.4: VNSE 95% (5m) in Toulouse the 18/01/00

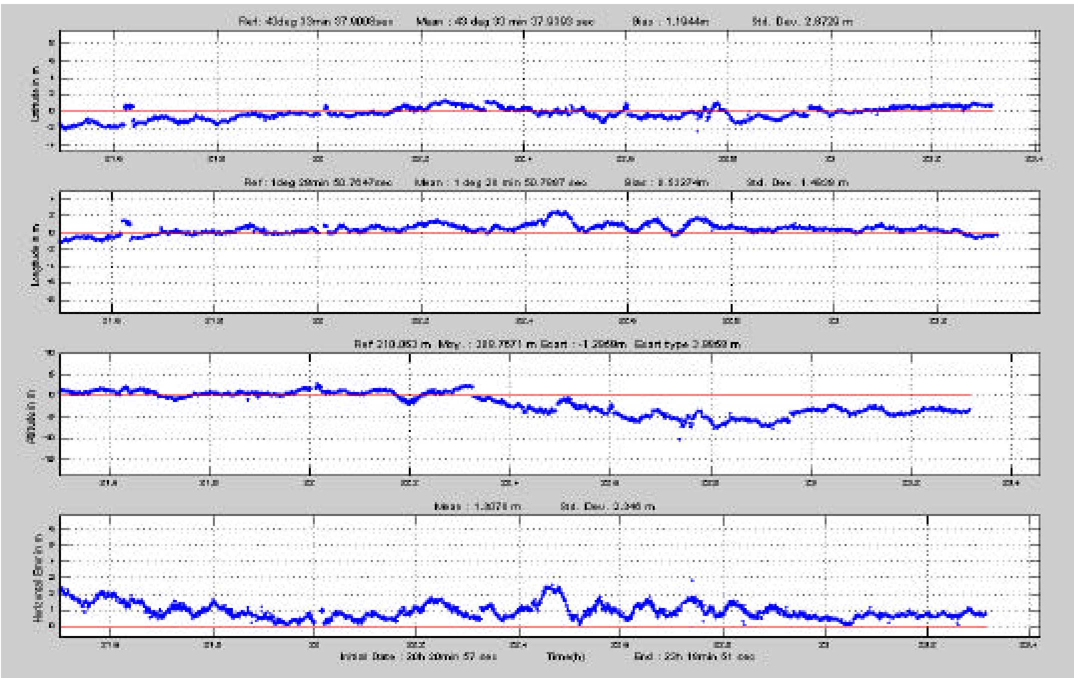

Figure 5:typical Horizontal and vertical errors (m)

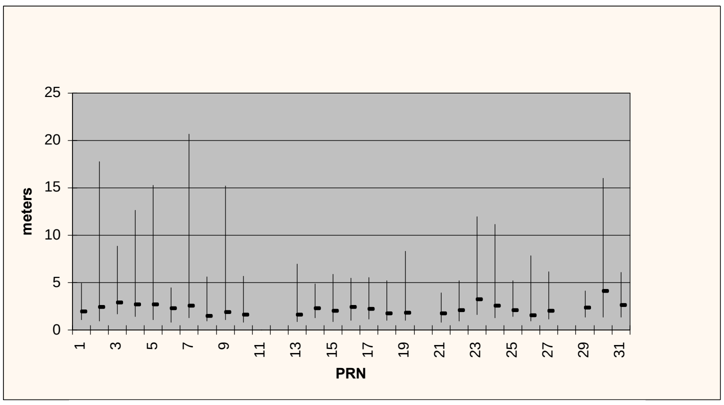

Figure 6: Min-mean-max UDRE values (m)

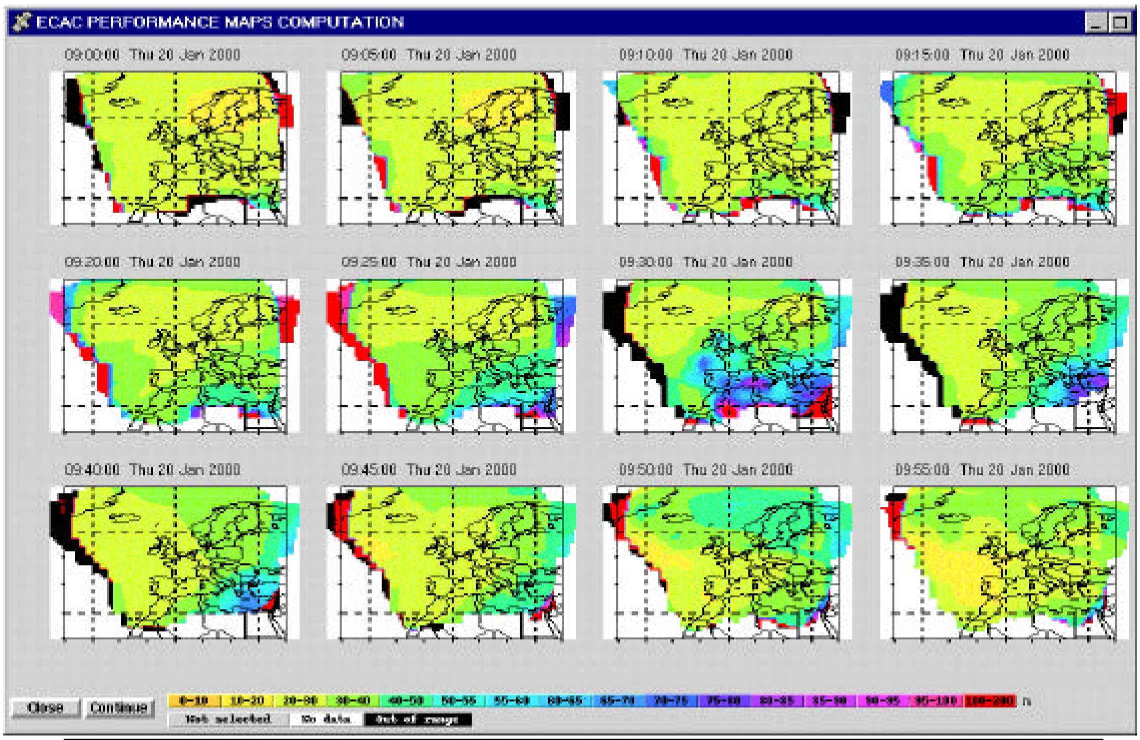

Figure 7. VPL (PA, All-Corrections) 20/01/00 from 09:00:00 till 09:55:00.

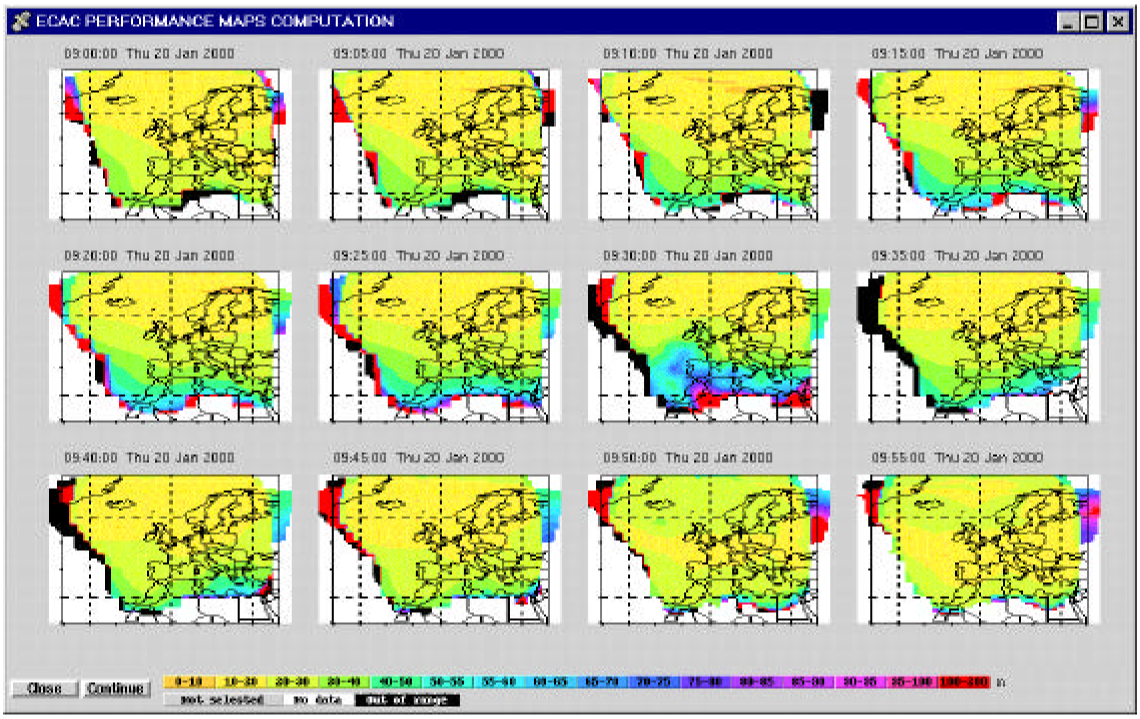

Figure 8. HPL (PA, All-Corrections) 20/01/00 from 09:00:00 till 09:55:00.

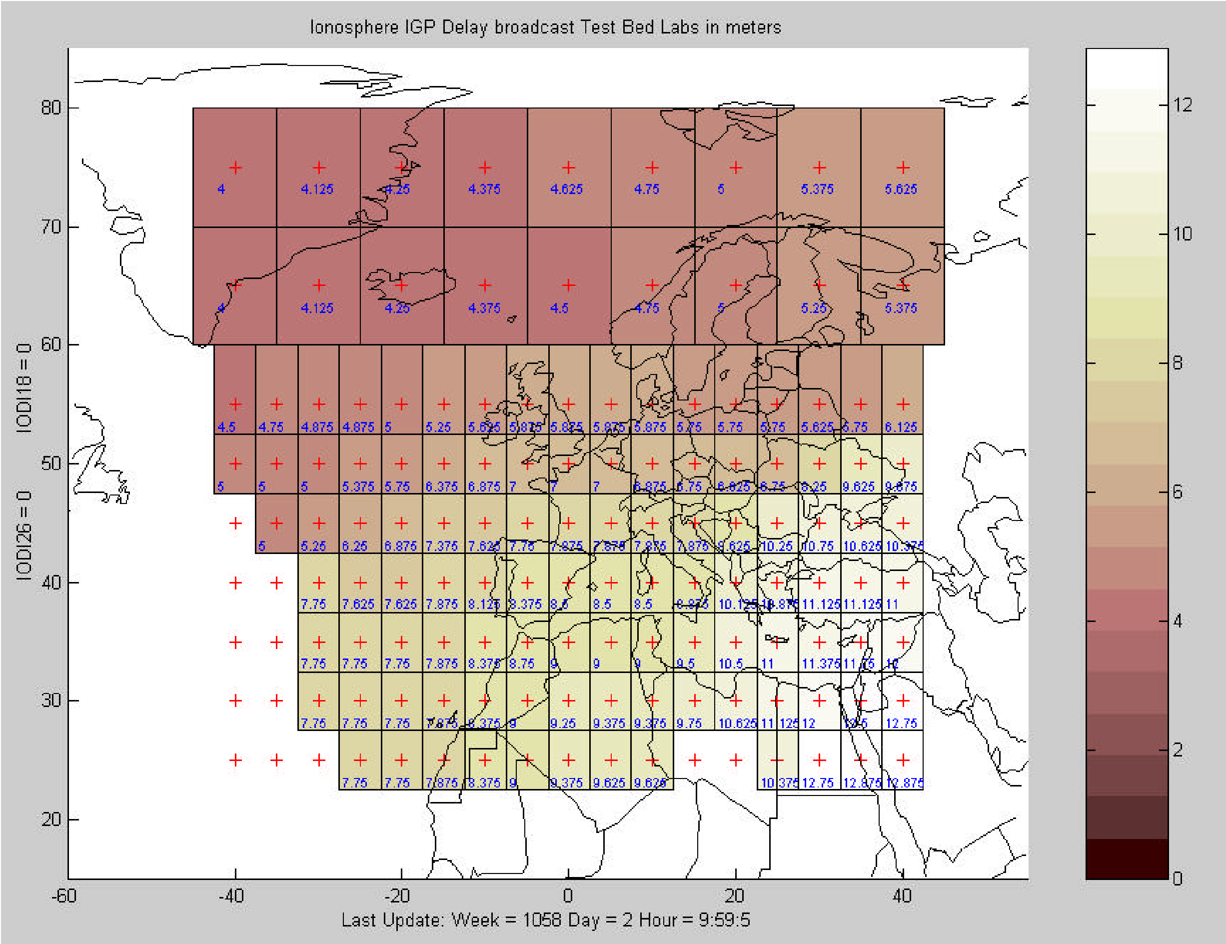

Fig.9: ESTB IONO GRID and GIVD broadcast

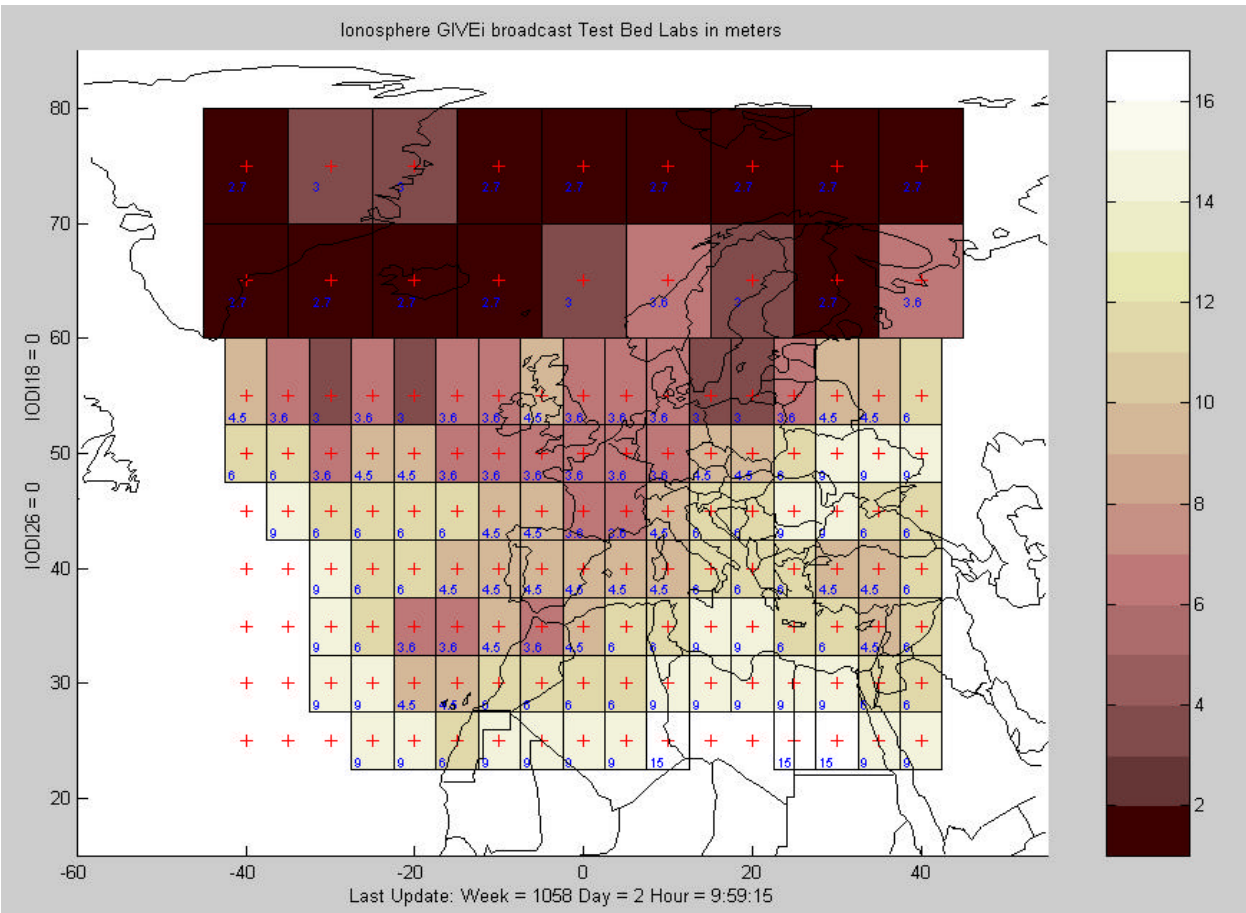

Fig. 10: GIVE broadcast

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