The Data Collection Network: EGNOS revealed

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BIOGRAPHY

Santiago Soley graduated with an MSc in Telecommunication Engineering from the *Universitat Politecnica de Catalunya* in 1998. He started to work on Satellite Navigation in 1997 with Indra-Espacio S.A. In 1999 he joined the ESA Galileo Team to work on the Definition Phase of Galileo. Since October 2000 he has been working, through his co-founded company PILDO Labs S.L., as a consultant for the EUROCONTROL Navigation Domain at their Experimental Centre premises, giving technical support in all related activities to GNSS-1 Operational Validation, and the introduction of GNSS systems for Civil Aviation.

ABSTRACT

In the frame of the activities in preparation for the future EGNOS Operational Validation, Eurocontrol has established a standardised data collection environment to perform regular EGNOS System Test Bed (ESTB) performance monitoring. Monitor stations have been set up at six different universities geographically distributed around Europe. Thanks to the weekly data collection and evaluation already performed since late 2001, a wide expertise has been built up on the tools that are currently being developed for the future EGNOS Operational Validation, as well as an understanding of how an SBAS system works and how its performance can be evaluated.

It is anticipated that the sites of the Data Collection Network in addition to the States contributions, will be the baseline for the validation monitoring activities that will be performed in the frame of the EGNOS Operational Validation to demonstrate that the user requirements defined in ICAO SARPS [3] in terms of Required Navigation Performance (RNP) parameters are met. Currently the data collection network is contributing by means of dedicated weekly campaigns, to the definition of the philosophy and processes to be applied for analysis and assessment of the SBAS system performances. The actual performance achieved at each location is computed and can be checked against the RNP requirements, and in addition any anomalies identified are analysed in detail to assess the cause, the probability of re-occurrence and possible mitigation techniques from the user side. All the lessons learned should contribute to the definition of standardised data processing and analysis techniques to be used in the operational validation process.

1. INTRODUCTION

EGNOS, the European Satellite-Based Augmentation System (SBAS) to GPS, is currently under development and is expected to be in operation in 2004. EUROCONTROL, as a part of its commitment to the European Tripartite Agreement with the Commission of the European Union and ESA, is responsible for the co-ordination of the operational validation of EGNOS for Civil Aviation.

Operational validation includes all activities that will demonstrate that EGNOS is ready to be used to support the flight operations for which it is intended. The operational validation activities are co-ordinated through a group known as the 'GNSS - 1 Operational Validation (GOV) Working Group, chaired by EUROCONTROL and primarily composed of European Air Traffic Service Providers (ATSP) intending to offer navigation services based on EGNOS.

In the frame of the GOV, two distinct areas of work have been identified today as required and complementary to support the implementation of EGNOS services for Civil Aviation in European airspace [2] [12]:

- The technical validation of the performance that can be achieved using the EGNOS system. This will include the demonstration that the implemented system is compliant with the requirements defined by civil aviation in the ICAO SARPS documents. Those requirements are expressed in terms of RNP parameters (Accuracy, Availability, Integrity and Continuity of service) for each phase of flight (from En-Route to Cat-I Precision Approach).
- Definition of operational rules and procedures for aircraft to use the system for a particular application.

Even if some work has already been initiated on the operational side, for example with the definition of an Operational Concept for EGNOS [6], still a number of issues have to be resolved and will have to be adapted as more is learned about the actual operations that EGNOS can be used to support.

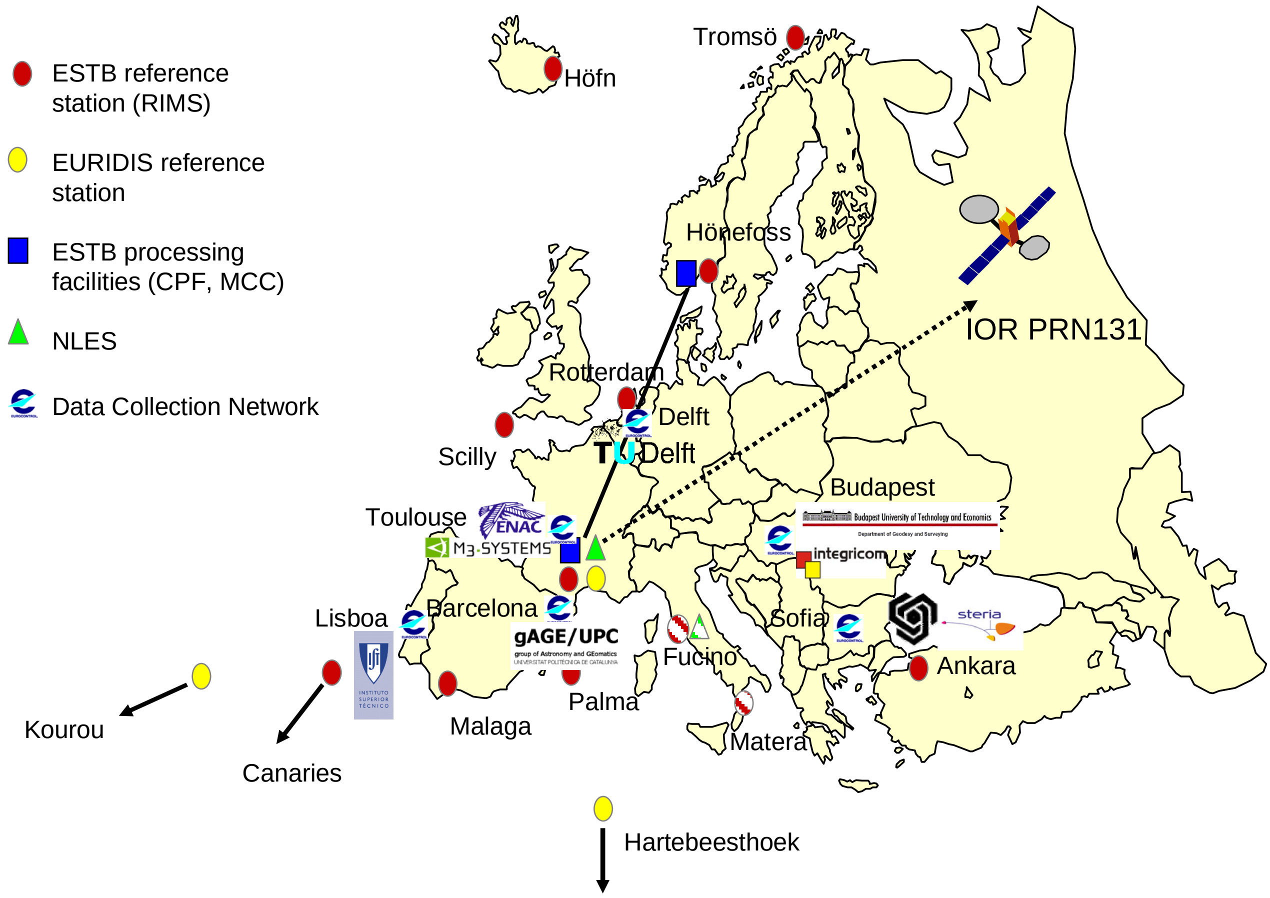


Figure 1 *The Data Collection Network*

The work presented in this paper is mainly related to the technical validation, and in particular to how the Data Collection Network is contributing to the definition of a methodology to assess and validate the performance that can be achieved using the EGNOS system.

This paper describes the latest results from the Data Collection Network, the latest features of the tools used for data analysis, data processing and automatic results generation process. A summary of the ESTB and first EGNOS performances obtained by the network is contained, as well as a summary of the lessons-learned from the data evaluation campaigns performed up to now. Those lessons-learned will present the techniques used for the analysis of anomalies identified due to either local effects such as multipath, antenna/receiver effects, malfunctions of the signal in space, or other unexpected effects like ionospheric storms, GPS satellite clock malfunctions...etc.

Finally the paper will describe how the network is being extended by the implementation of a so-called Global Monitoring System, able to automatically compute the system performances over Europe by re-using the existing GPS networks data, such as IGS, and applying the SBAS messages collected locally by the network users.

2. THE DATA COLLECTION NETWORK

Before the deployment of the EGNOS system, ESA implemented the EGNOS System Test-Bed (ESTB) which is a prototype of EGNOS with a limited number of monitor stations. The ESTB has been providing a signal-in-space since February 2000 to support the system development as well as giving potential users the opportunity to gain experience with EGNOS-like signals. This allowed the initiation of various GOV activities using this first SBAS signal-in-space in preparation for the time when the real EGNOS validation can begin.

With the ESTB on the sky, as no tools existed for evaluating EGNOS-like signals, Eurocontrol developed the PEGASUS [8] [9] tool in order to provide its Stakeholders with a means of evaluating the first ESTB performances through coordinated data collection campaigns. These first ESTB data collections help the ATSP to gather experience on how the data should be collected from an SBAS receiver, but also to understand how an SBAS system really works. In addition to that, the development of PEGASUS and its validation with real data has enabled the first SBAS performances to be generated and anomalies analysed.

These initial data collection campaigns quickly showed that some work would need to be done to standardise the way the data should be collected and processed. It also highlighted the importance of the way the results are displayed and presented in order to be checked against the RNP requirements which are vaguely defined in the SARPS document. Moreover, while generating results appears to be quite an easy task, more or less automated within PEGASUS, understanding the results and interpreting the cause of the anomalies identified in the measurements is not so straight forward. Some experience would need to be gained on analysis and understanding if a measured anomaly in the results was coming from malfunctions on the transmitted Signal-In-Space, on the tools used or for example the way the data is collected or processed.

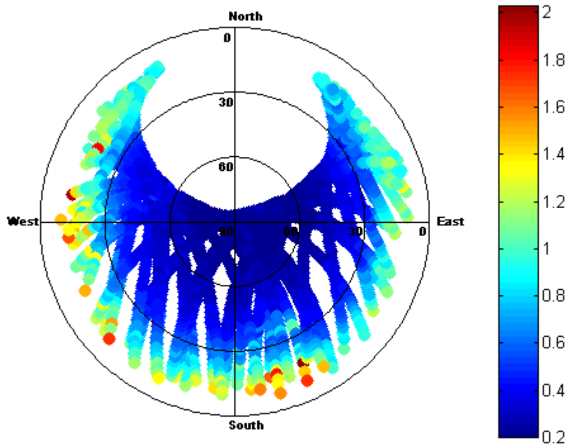
Eurocontrol realise the need to perform data collection on a more regular basis in order to establish a good understanding of the performance of an SBAS Signal-in-Space over a longer time interval and over an area with a good geographical distribution, and to start building up experience on the data processing and analysis techniques to be used in the operational validation process. With this objective in mind, Eurocontrol established a small network of four data collection sites (Barcelona, Toulouse, Lisbon and Delft) in addition to the existing sites controlled by the ATSPs, to perform weekly ESTB data collections and analysis of the obtained results. More recently, this initial network of four sites has been extended further to the Eastern European region with the addition of two more stations; in Budapest and in Sofia, complementing the existing Data Collection Network [*Figure 1*].

Initially, a data collection environment was set up on each site, composed by an SBAS receiver and antenna connected to a computer, installed with the software to log the data from a receiver, and PEGASUS to process and analyse the results. The antenna coordinates were precisely surveyed at centimetre level, and a multipath assessment was done to identify the best antenna location for each site, but also to characterise its possible error effect on the measurements [*Figure 2*].

3. A METHODOLODY TO ASSESS EGNOS PERFORMANCE

The sites of the Data Collection Network in addition to the States contributions will be the baseline for the validation monitoring activities that will be performed in the frame of the EGNOS Operational Validation to demonstrate that the user requirements defined in ICAO SARPS. A series of static measurements will be made over extended periods with the goal to establish the performance of the system that would be experienced by a potential user, and to verify the stability of the performance of a certain time period. Moreover, a series of flight experiments will be performed to verify that the performance experienced at static sites is also achieved in the dynamic conditions representative of a typical airborne user.

Currently the data collection network is contributing by means of the dedicated weekly campaigns, to the definition of a methodology to be applied for analysis and



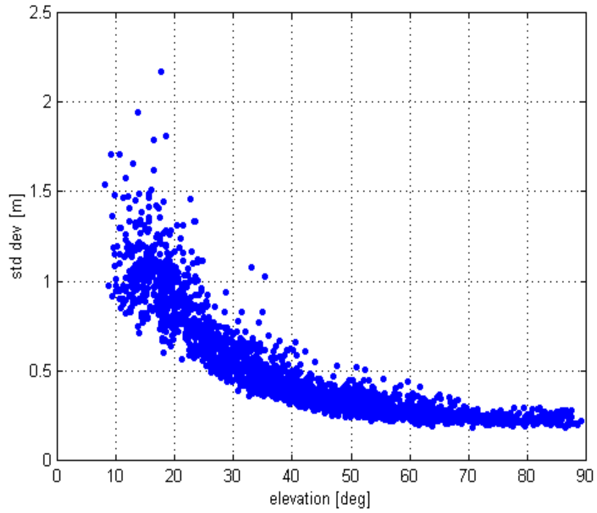


Figure 2 *The top figure presents the sky plot for the combined multipath and receiver noise error (Mc - linear combination of phase and code observations - standard deviation in meters). The figure below shows the same values against satellite elevation. Both figures relate to the data collection site at the MGP- TU Delft (The Netherlands)*

assessment of the EGNOS system performances for the static and dynamic tests.

When computing the achieved performance from measured data, it is necessary to define specific tests and clear pass fail criteria for each of the different RNP parameters. This involves making assumptions in the definitions of those parameters from the ICAO SARPS document, which does not define a precise method to evaluate these parameters from measured data.

Those methods for evaluating the different RNP parameters from measured data, constitute one of the three identified main axes [Up] in the methodology for analysing the data collected [*Figure 3*]:

[Up] The actual achieved performance can be generated for any data-set collected at a specific location over a specific period (i.e. 24 hours). These local performance results can be checked against the RNP requirements. It is not possible to use these results directly to validate the performance over the whole ECAC area or up to the very low probabilities required for Integrity and Continuity. The result will be either acceptable performance or a list of identified anomalies (i.e. unacceptable performance)

[Down Left] The anomalies that have been identified in the local performance [Up], should be analysed in detail to identify the cause, the probability of re-occurrence and possible mitigation techniques

[Down Right] A global assessment should be performed based on the local and daily data sets. This assessment will address the spatial and temporal stability of the Accuracy and Availability performance by combining the measured results from different locations with simulations and extrapolation. More in-depth investigation into the Integrity and Continuity performance is also part of this analysis axis.

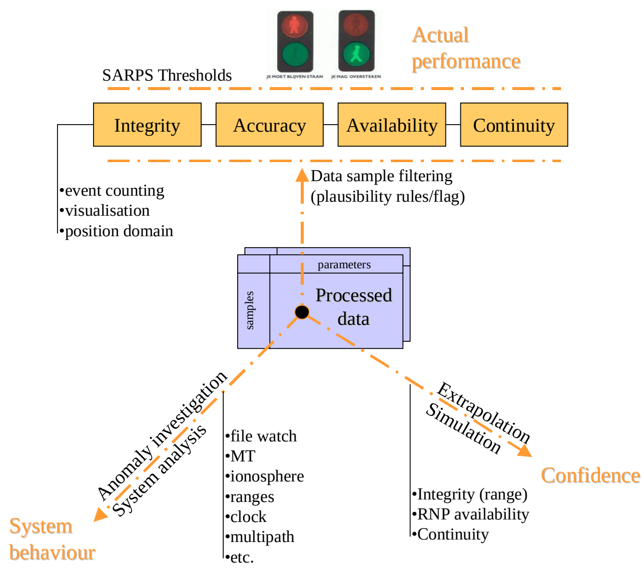


Figure 3 *GNSS data analysis methodology*

4. A FIRST GLANCE AT THE PERFORMANCE

The EGNOS performances requirements from the SARPS must be achieved with a MOPS compliant receiver. The RTCA MOPS DO229C [5] standards define the minimum requirements for a certifiable SBAS receiver to be used by the Civil Aviation community.

PEGASUS is a software prototype able to process receiver-native data, from a limited set of SBAS receivers, and compute the position and integrity solution in accordance with the RTCA MOPS DO229 standards.

The weekly data collections have served not only to intensively test the PEGASUS software functionality, but also to validate that it is compliant with the applicable standards through the cross-check of results obtained using similar tools developed independently by other parties, such as the BRUS [10] tool developed by the gAGE Politechnical University of Catalonia.

Recently, the automatic generation of a First Glance report on the measurements has been integrated into PEGASUS. This report summarises the results obtained after applying a set of proposed algorithms [2] on the measurements, to generate performance values that can be checked against derivates of the RNP requirements that hold for single site/day data sets. *Figure 4* presents the First Glance report observed at the Eurocontrol Experimental Centre in Brétigny-sur-Orge (Paris) with the EGNOS post-SIS-1 deployed system configuration.

Site	[EEC1] Eurocontrol Experimental Centre					Date	23/04/2004
Location	Lat:	48.6001	Lon:	2.3469		Alt	139.944
Receiver	Novatel OEM4		Software	Pegasus 3.2		PRN	124
Data set	Duration	Start	Stop	Rate	Total	Valid	Invalid
	04h59	00:00	04:59	1 Hz	18000	17638	362

Accuracy										
	all valid samples	APV-I			APV-II			CAT-I		
		Meas.	Scaled	Req.	Meas.	Scaled	Req.	Meas.	Scaled	Req.
HNSE(95%)	**1.14**	1.14	5.99	220	1.14	5.99	16	1.04	6.14	16
VNSE(95%)	**1.11**	1.11	5.72	20	1.11	2.29	8	1.13	1.46	4

Availability				
samples	17638	17638	17638	13652
Minimum Required		99%	99%	99%
Availability		**100.000%**	**100.000%**	**77.401%**

Continuity			
Events	**1**	**1**	**279**

Integrity				
	MI	HMI APV-I	HMI APV-II	HMI CAT-I
Total	**0**	0	0	0
Horizontal	**0**	0	0	0
Vertical	**0**	0	0	0

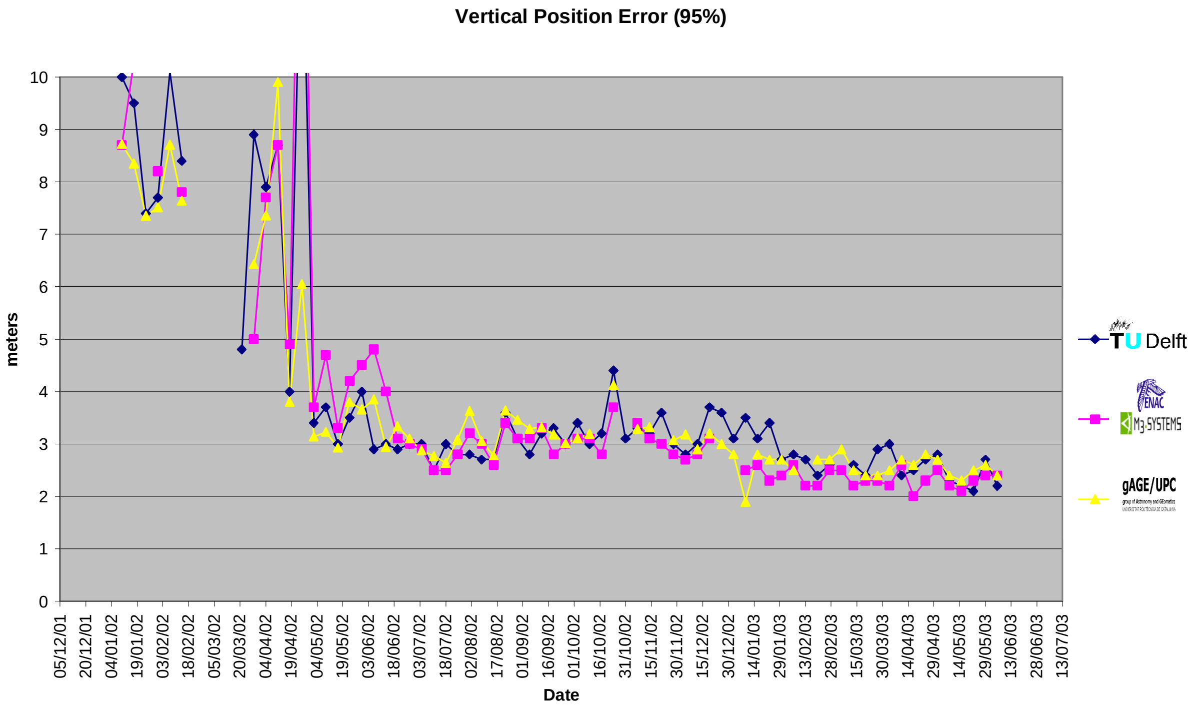
Protection level statistics					
	99%	95%	50%	mean	std deviation
HPL	**14.48**	11.60	7.49	8.16	2.07
VPL	**16.37**	15.10	10.28	10.74	2.06

Position error statistics					
	99%	**95%**	50%	mean	std deviation
HPE	1.41	**1.14**	0.69	0.71	0.24
VPE	1.34	**1.11**	0.48	0.51	0.32

Figure 4 *First Glance report of EGNOS post–SIS-1 (28 RIMS stations) performance measured at Eurocontrol Experimental Centre (Bretigny-sur-Orge, Paris) on Friday 23rd of April from 00:00h to 05:00h UTC*

Caution: EGNOS is still under test and development. Results may not be representative of the final EGNOS system performance. Pegasus software is still a prototype under validation. Results are not guaranteed and should be treated with care

Next *Figure 5* presents a summary of the performance obtained with PEGASUS during the ESTB campaigns. It is important to highlight how the system has been improving from the start of the ESTB broadcast up to now, passing from around 7 meters of accuracy to the current better than 3 meters, performance that is comparable to those obtained with Local Differential GPS systems.



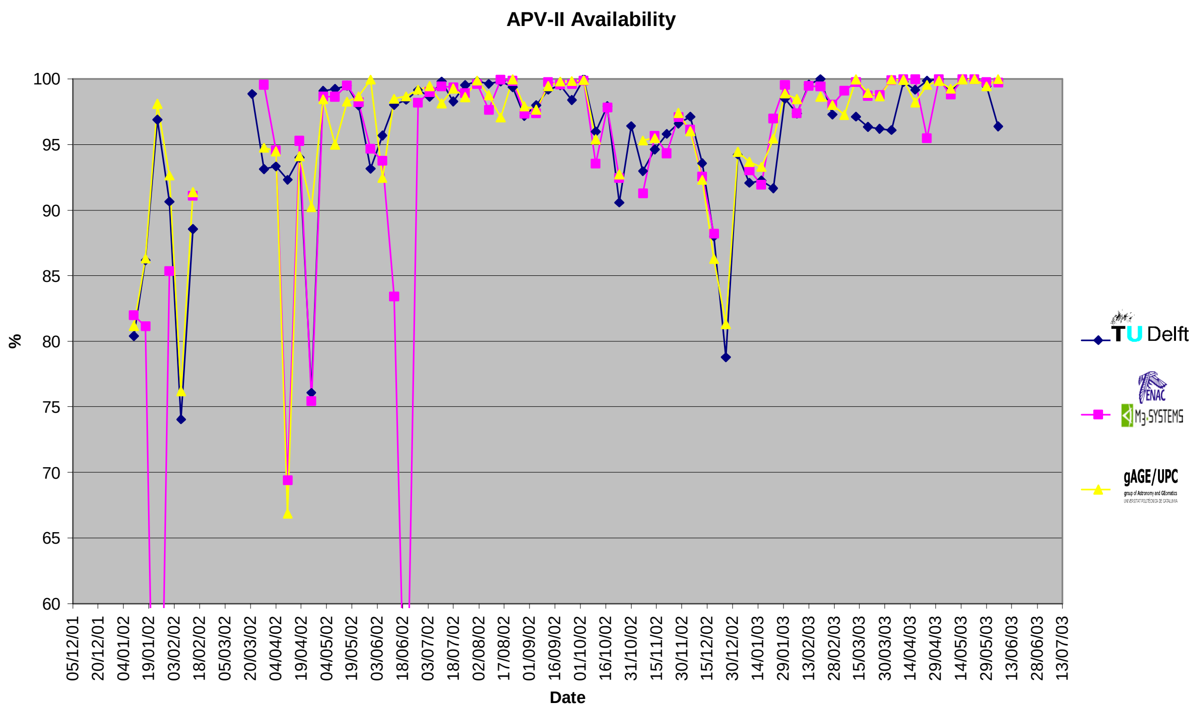


Figure 5 *Summary of the weekly performance measured at Delft, Toulouse and Barcelona with the ESTB, from January 2001 up to July 2003. The first figure presents the Vertical Position Error 95% values, while the second one shows the Availability of the system for APV-II operations (Approach Procedure with Vertical guidance and a defined Vertical Alarm Limit of 20 meters)*

5. ANOMALY INVESTIGATION

The first glance performances obtained with the EGNOS final system will be assessed on every data-set from the planned series of static and dynamic tests, and the test will be declared passed or failed. Obviously it would be easier if the system performance is so stable that for all the data sets collected during the complete stability campaign, the green light appears meaning that the results are fulfilling the requirements. But what to do if some anomalies appear that makes some of the tests fail?

Just a first check on the obtained performances is not enough to declare the system not compliant with the requirements if any anomalies are encountered. A detailed analysis will need to be done on possible measured integrity failures, discontinuity of service or other anomalies, to assess whether those are really related to system malfunctions or are caused by the data collection and evaluation environment.

Different methods and techniques have been used by the Network members to analyse the measured anomalies with the ESTB, and identify whether they were related to local effects such as multipath, antenna/receiver effects, malfunctions of the signal-in-space, or other unexpected effects like ionospheric storms, GPS satellite clock malfunctions...etc.

A representative set of measured anomalies and the way they have been investigated is presented in the following section.

Example 1: Jump in the Vertical Position due to Multipath

A jump on the position error, mainly for the vertical component, was periodically experienced on the results computed by Delft University. The phenomenon, indicated by the red box in *Figure 6*, consisted of error oscillations between -20 and +10 meters lasting for almost

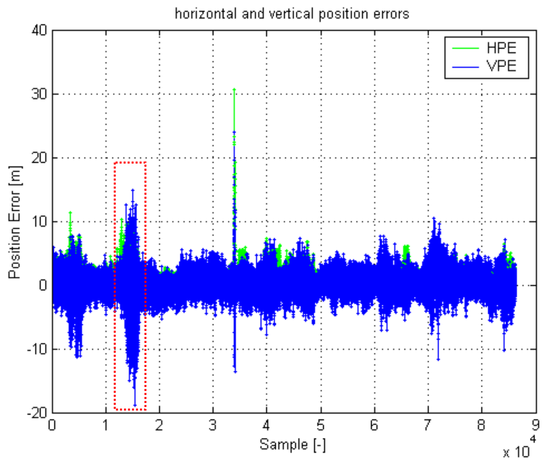


Figure 6 *Horizontal (HPE) in green and vertical position error (VPE) in blue – Delft, The Netherlands - December 26th, 2002.*

one hour, and repeated week after week slightly shifted in time.

The GPS satellite-configuration observed at a fixed location on the Earth, repeats itself every day, but approximately 4 minutes earlier. The jump in the VPE seems to be related to the satellite-configuration indeed, as the time bias is around 7*4 minutes (1680 seconds) from week to week.

Multipath occurs when not only the direct signal is received by an antenna but also one or more copies of the signal due to reflections. The reflected signal is a delayed and weaker signal. Phase, code and signal-to-noise ratio (SNR) of the composite signal are different from the direct signal. The final effect is a distortion of the correlation function on the GPS receiver, tracking the composite signal, which results in errors on the measurements. As multipath is related to the receiver-satellite geometry, it will repeat, for a permanent station, every day approximately 4 minutes earlier if the same satellites are monitored (same VDOP - Vertical Dilution of Precision).

Multipath errors can be analysed by taking special linear combinations (per satellite, per epoch) of the observations (phase and code on L1 and L2 frequencies). In particular for L1 code signal (CA-code pseudorange), the so called Mc combination can be defined:

$$Mc = C1 + \tfrac{1+\alpha}{1-\alpha} L1 - \tfrac{2}{1-\alpha} L2$$

with $\alpha = f_1^2 / f_2^2$, the ratio of the two GPS frequencies squared (thus Mc = C1 - 4.092*L1 + 3.092*L2)

C1 = C/A code observation (pseudo range) on L1 in [m]
L1 = L1 phase observation converted to [m]
L2 = L2 phase observation converted to [m]

This is an excellent combination to detect the presence of multipath because the geometric range to the satellite, the atmospheric delays and the clock errors are absent. Present are the carrier phase ambiguities (of both L1 and L2), but they are constants, as long as no cycle slips occur. The noise on L1 and L2 is at the cm level (including carrier phase multipath) and hence very small compared to the code noise. Therefore the noise of the pseudorange code observation will dominate the behaviour of this combination over time for unmodelled effects in the code measured data such as multipath.

With this Mc-combination of phase and code observations (Mc-combination) the multipath effect on the ESTB-monitored satellites during the error peak phenomena can be estimated [*Figure 7*]. The Mc combination is less than 1 meter for all satellites, except for PRN15 (in black, between –3 and +4 meter). These multipath errors combined with a relatively poor VDOP value (about 6) is the cause of the large error values on the vertical domain [13].

To complete the assessment, the receiver carrier to noise ratio C/N0 for the satellite PRN15 is checked [*Figure 7*].

When significant multipath is present, the received C/N0 will show a wave-like pattern because of interference of the direct with the reflected signal, and the change in path length due to a change in the satellite geometry. As expected, the PRN15 C/N0 values change with a period of about 25 seconds over 3-4 dB-Hz per cycle between 14:37:00 and 14:40:00 UT, following a wave-like pattern strongly correlated with the one for the VPE.

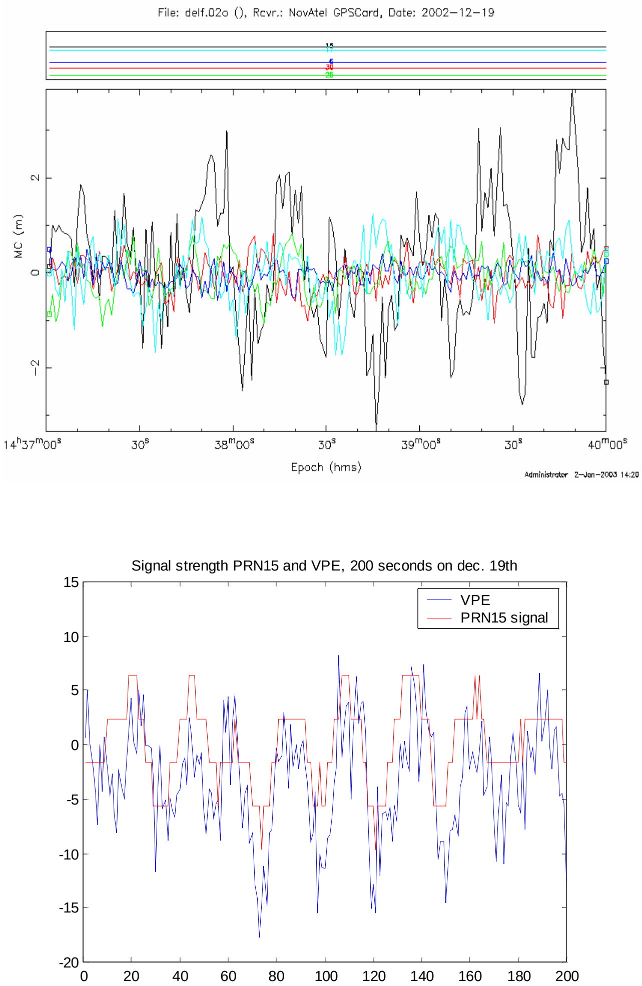


Figure 7 *The first figure presents the computed Mc-combination for PRN 6, 15, 17, 25 and 30 (with PRN15 in black). The second figure shows the VPE (in blue) and C/N0 values (in red, scaled and shifted vertically to match the VPE) for PRN15 satellites. On December 19th, 2002 (between 14:37:00 and 14:40:00 UT) Delft, The Netherlands*

It is concluded that environmental effects, such as multipath, could cause such errors on the measurements and be a potential source of anomalies, since those jumps on the position error could cause errors exceeding the computed protection level and be translated into integrity failures (HMI or MI – Hazardous-Misleading Information). Therefore it is advisable to have the capability to repeat similar assessments on any measured anomaly before to declare a test failed.

Finally, it is expected that with the final EGNOS operational system these kind of anomalies rarely happen, since with the increased number of GPS satellites monitored and improved geometry, compared to the ESTB, the influence of possible single signals with increased multipath error will be much reduced.

Example 2: Integrity failures caused by SIS anomalies on the MT02 and MT03 broadcast values

On February 6th – 2003, a set of Misleading Information failures (MI – Position Error > Protection Level) appeared after processing the data collected at the UPC Barcelona station. These integrity failures were related to a set of peaks appearing on the position error, mainly on the horizontal domain [*Figure 8*].

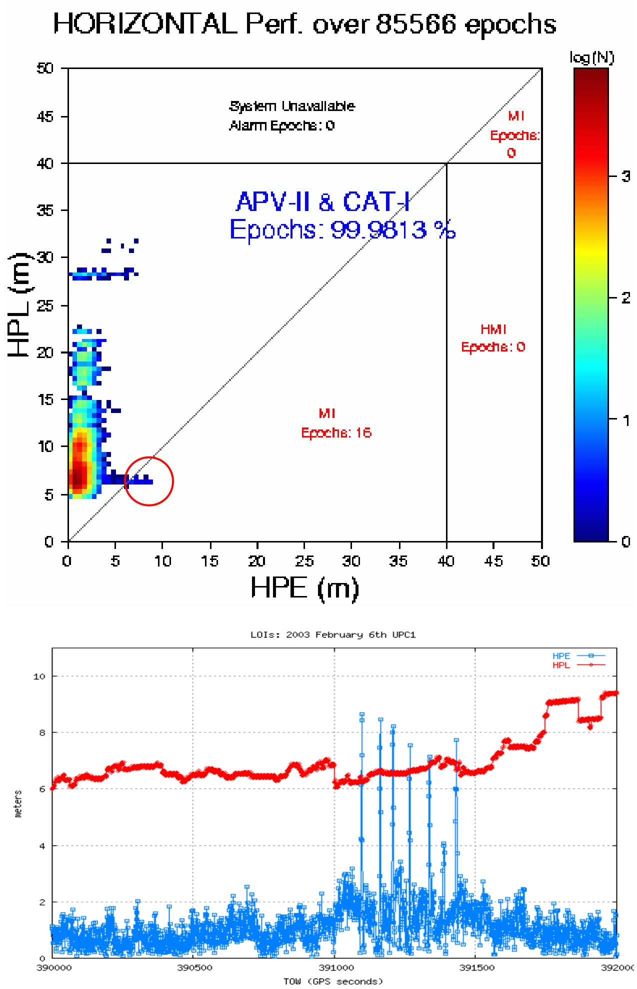


Figure 8 *The top figure presents the Stanford Plot in the Horizontal domain (HPE against HPL), with the measured MI highlighted in red. Second figure shows in detail the HPE peaks (in blue) over passing the HPL values (in red) – Barcelona, Spain – February 6th, 2003*

To assess the possible cause of the generation of such peaks on the horizontal position error, the broadcast pseudorange corrections for the satellites with UDREI<12 (defined in the MOPS DO229B [4] standard as the indicator value for a monitored GPS satellite to be included in the position computation) are analyzed. In addition it is also assured that the values for the IODF<3, indicating non-alarm conditions. As presented in *Figure 9*, the pseudorange corrections contained in the GEO signal in Message Type MT02 and MT03 present large oscillations between the Time Of Week = [391100:391500] when the integrity failures appear.

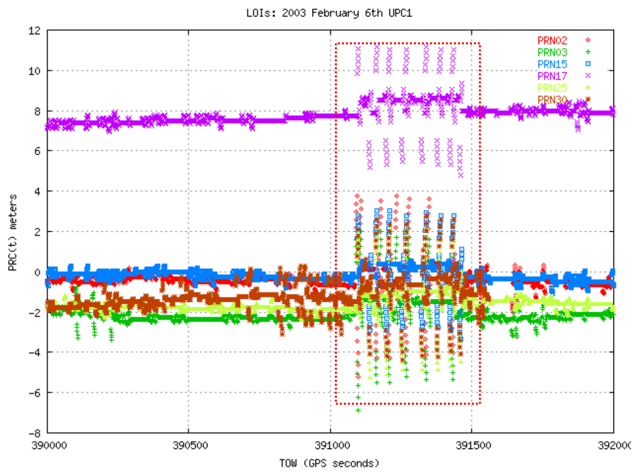


Figure 9 *Pseudorange correction oscillations broadcast in the MT02 and MT03 for all the GPS monitored satellites with UDREI<12* and IODF<3 – Barcelona, Spain – February 6th, 2003

Therefore, that time the integrity failures appearing were directly related to the contents of the GEO signal messages. Nevertheless, the anomalies were not measured by all the stations from the network, probably due to the different observed geometry of the satellites at each station during the period when the fast corrections oscillate. Removing some of the satellites, affected by the fast corrections oscillations, from the position solution computation makes the integrity failures disappear, even though the peaks on the position error still remain but with lower values.

Example 3: Integrity failures caused by SIS anomalies on MT26

On September 12th – 2002, some integrity failures (HPE>HPL) are measured, mainly in the horizontal domain [*Figure 10*]. A total of 60 MI are experienced in about 500 epochs. As for the previous example, the fast corrections broadcast for all the satellites in view during that period are assessed first, but that time everything appears to be nominal. To evaluate other possible cause of error, the ionospheric corrections collected are checked.

A jump on the ionospheric corrections applicable to satellite number PRN17 measurements is identified as the cause of the integrity failures [*Figure 10*]. Effectively when this satellite is removed for the computation the MIs disappear. The affected PRN17 satellite has a very low elevation during the period when the jump on the ionospheric corrections occurred. This explains why the loss of integrity of service was mainly experienced in the horizontal domain rather than in the vertical.

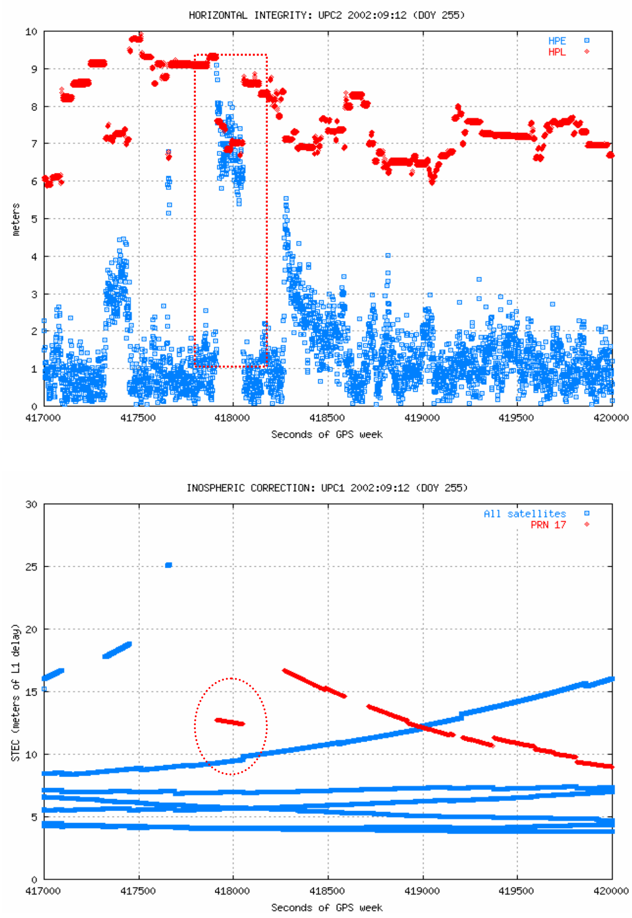


Figure 10 *The top figure presents the HPE (in blue) and HPL related values (in red). Below, the ionospheric corrections for all the visible monitored satellites are shown with the PRN17 in red* **-** *Barcelona, Spain – 12th September 2002*

For unknown reason, the inospheric delays broadcast in MT26 for the grid points around the PRN17 pierce point appear as correctly monitored, while the satellite should be excluded before and after the MI occurrence. The problem was related to a malfunction on the signal in space, and was reported to the ESA/CNES ESTB Team.

Example 4: Integrity failures caused by satellite clock jumps

On May 22nd – 2003, a set of eight consecutive epochs with Integrity events are measured. When assessing the prefit-residuals (error left on the measured pseudorange after applying all the modelled corrections) for all the satellites used in the solution computation, a big jump appears for the PRN29 satellite at the time the integrity failures occurred. Nevertheless, no jumps are found in the fast, ionospheric corrections or long term corrections, and also no change on the broadcast orbits set used for

PRN29 satellite are experienced when the jump happens [*Figure 11*].

It is concluded that the sudden jump identified on the C1 code pseudorange for PRN29 is related to an error on the GPS satellite clock. After 9 seconds the ESTB reacts declaring the satellite as not monitored (UDREI=14), but not with enough time to avoid the integrity failures and exceeding the required time to alarm of 6 seconds. Moreover, neither the consistency check nor the step-detector reacted to the code jump because the pseudorange measurement innovations for PRN29 at such epochs were between 0,5 to 13,7 meters, less than the screen threshold of 73,8 meters. A complete SBAS system, properly working to the requirements, would protect the user from such anomalies on the GPS signal. It would also be interesting to assess how the RAIM Fault Detection and Exclusion function would react to this anomaly.

Finally, it should be noted that the ESTB was not

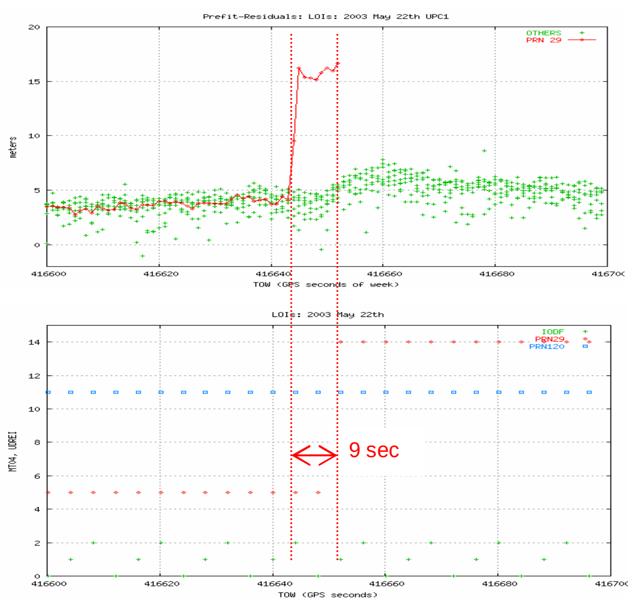
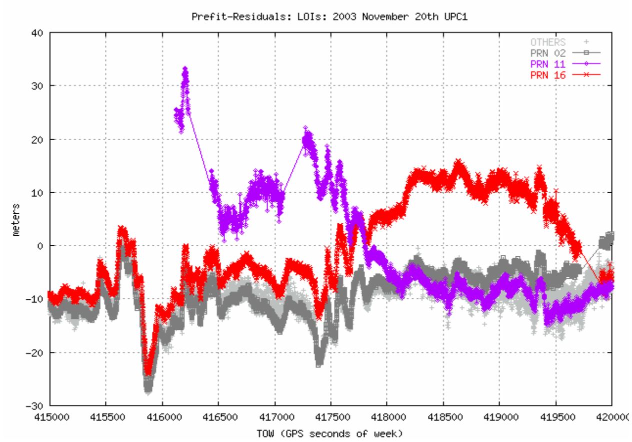


Figure 11 *Prefit-residuals for all the satellites used for position solution computation. A sudden jump on PRN29 satellite (in red) is experienced around TOW=416644s causing integrity failures for eight consecutive epochs. The figure below shows how the ESTB declares the satellite as not monitored 9 seconds afterwards, increasing the associated UDREI value from 5 to 14 (in red). IODF<3 indicating no alarm conditions for all the period of time – Barcelona, Spain – May 22nd, 2003*

designged to meet the time-to-alert requirement at the time it was defined as a system prototype. It is expected that with the final EGNOS system such anomalies would we warned to the user within the 6 seconds required.

Example 5: Integrity failures caused by Ionospheric storms

On November 20th – 2003, a large number of integrity failures (around 1000 epochs), were measured for the southern network stations, in both vertical and horizontal



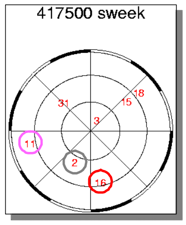


Figure 12 *Prefit-residuals for PRN11, 16 and 2 oscillating between +30 and -30 metres range. The small picture on the left presents the sky plot for one epoch for all the satellites in view, highlighted PRN11, 16 and 2 in south latitudes - Barcelona, Spain – November 20th, 2003*

domains. As in previous Example-4, the prefit-residuals are computed for all the satellites in view during that period of time. In particular the PRN 11, 16 and 2 satellite ranges are totally out of range, compared to those of all the other satellites. Curiously PRN11, 16 and 2, are all located at southern latitudes for the period with the range oscillations [*Figure 12]*.

The high Kp values (Ionospheric activity indicator) published on the web on a daily basis [*Figure 14*], confirmed that an ionospheric storm was experienced on that date on Europe. The comparison of the applied ionosphere correction on the measurements from the ESTB signal, with the ionospheric refraction computed from P2-P1 code and L1-L2 phase measurements, demonstrates that the ESTB was not reacting with large enough ionospheric corrections to compensate the ionospheric storm effect on the measurements [*Figure 14*].

A similar effect occurred on October 29th and 31st for the European northern latitudes. Thanks to the geographical distribution of the stations from the network, both storms could be captured and properly explained.

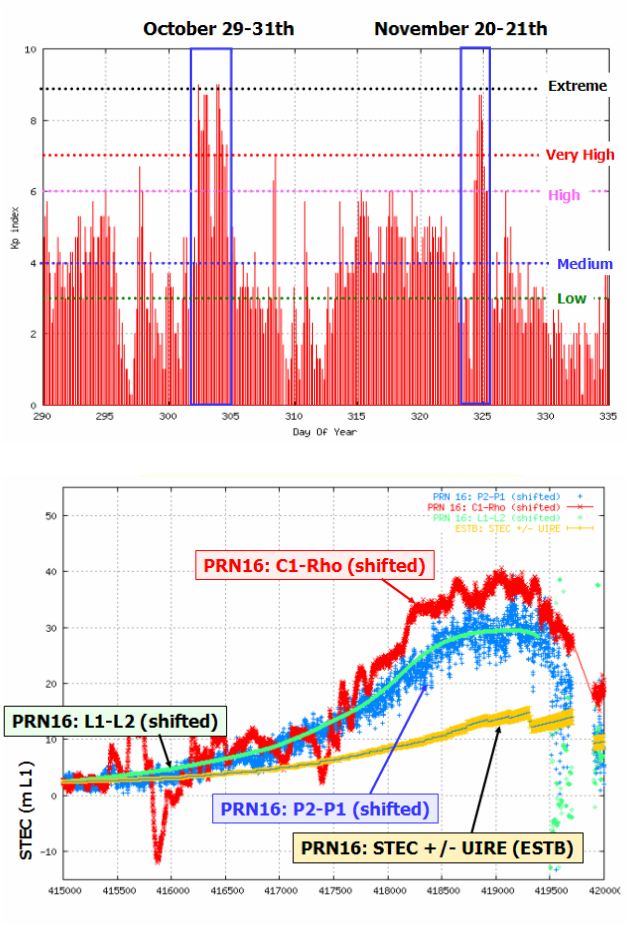


***Figure 14** The top figure presents the high Kp values (ionospheric activity indicator) published on the web for both ionospheric storm dates - the October 29^{th}-31^{st} and November 20^{th}-21^{st}, 2003. Below is presented a comparison between the ESTB STEC, with the confidence bounds (UIRE), and the ionospheric refraction computed from code P2-P1 and phase L1-L2 measurements for satellite PRN16 -- Barcelona, Spain – 20^{th} November 2003*

6. TOWARDS THE FINAL RESULTS

From previous studies [7], it is well known that the validation of the integrity requirement (10-7/h) would require collecting data continuously for a period longer than a hundred years. Therefore, to validate the requirements in a reasonable period of time just the data collected from the network would not be enough, and it would need to be supported by simulations or other methods to get up to the required level of confidence on the requirements from the measurements [15] [16]. It is also clear that for practical reasons it is not possible to do an exhaustive validation of all the RNP parameters in all locations under all conditions. Different techniques need to be developed for extrapolation of the local results from the network sites, with the final goal to perform a global assessment on the performances. A system like the Global Monitoring System (GMS) described in the following section could contribute to that, providing the capability to monitor widely the performances and also supporting the validation of the results from simulations or data extrapolation.

The Global Monitoring System

The Global Monitoring System (GMS) is able to monitor globally SBAS performances (WAAS, EGNOS, MSAS) by using the available public GPS networks. Those networks have been developed primarily for geodetic research, orbit determination or other scientific applications, and upload continuously GPS dual frequency measured data at 30 or 1 second data rate. The SBAS GEO broadcast messages are common for all the service area therefore an SBAS receiver can be emulated (without GEO ranging) for each site where only the raw GPS data are collected. Using tools like BRUS or PEGASUS, it is possible to apply the broadcast SBAS messages to the GPS measurements and compute the SBAS position and integrity solution. These messages can be gathered either from any data collection site or, in particular for the ESTB, from the ESTB Post Data Provided System (EPPS) internet ESA server [*Figure 13*]

On a daily basis, the GMS automatically collects all the GPS data set files from the public network stations though an ftp connection, combines them with the GEO SBAS data collected using a local SBAS receiver, and launches the process with BRUS or PEGASUS to generate Europe-wide SBAS performance. Results are sent by e-mail to a list of users as well as uploaded onto the website [
Figure 15].

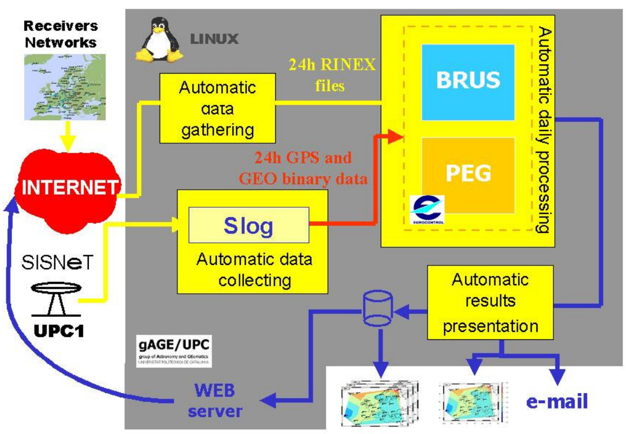


***Figure 13** Layout of SBAS Global Monitoring System*

7. CONCLUSIONS AND FUTURE WORK

This paper has presented a summary of the activities from the Data Collection Network that Eurocontrol set up around two years ago to perform weekly data collections and analysis with the ESTB signal. Those weekly data collections have contributed to gain knowledge on how the data need to be collected, processed and analysed in the frame of the Operational Validation activities once the final EGNOS SIS available. A proposal for a First Glance report on the results has been presented together with a summary of the measured ESTB performances. In addition, some of the anomalies encountered have been described as well as the way they were investigated.

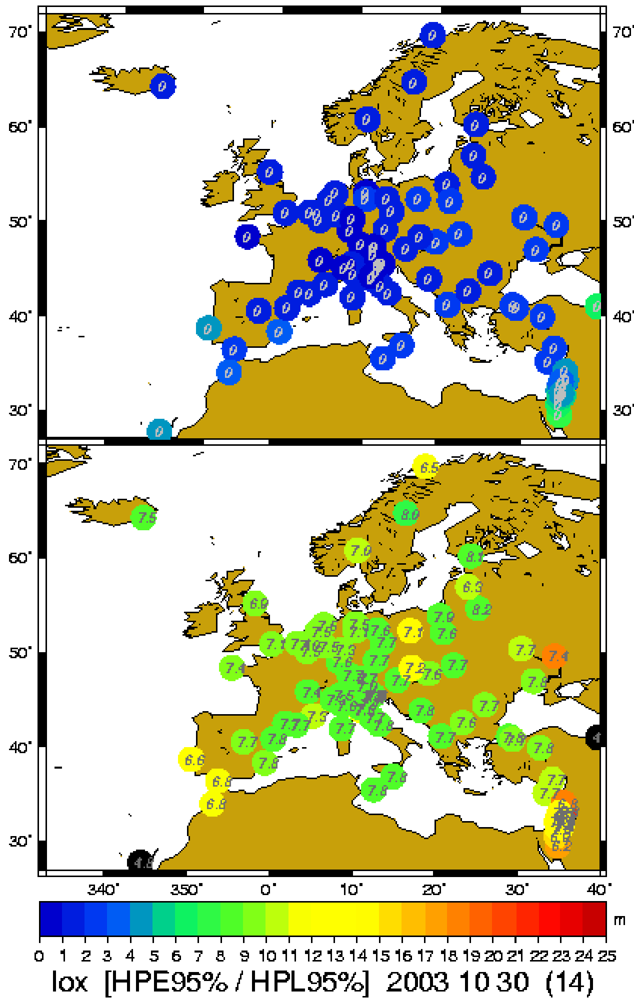


Figure 15 *The top Figure above presents the HPE (95%) values and the number of integrity events measured for each GPS station. At the bottom the HPL (95%) values are shown together with number of satellites used for position computation for the bubble number*

All these lessons learned will contribute in the future to the analysis of possible anomalies detected with EGNOS. It should be noted that all the anomalies presented have been measured with the ESTB, which was defined as a reduced prototype of the final EGNOS system in terms of scale as well as for the algorithms [11], which are not the same as those finally implemented for EGNOS. Therefore it is expected that with the final EGNOS operational system these kind of anomalies will rarely happen. The first campaigns made with the EGNOS SIS-1 definitely confirm that, since up to the time of writing no anomaly or integrity failure related to signal malfunction has been measured.

In the frame of the EGNOS performance validation activities, a series of flight experiments will also be carried out to verify that the performance experienced at the static sites is also achieved in the dynamic conditions representative of a typical airborne user. The paper has summarised the results from the static measurements, but in the frame of the network activities also some early dynamic trials have been performed. In particular the Portuguese Airforce collaborates with the Instituto Superior Tecnico of Lisbon collecting data regularly with an SBAS receiver installed on-board its Falcon-20 aircraft, and the University of Delft conducted some trials on a boat on the Schie-canal between Rotterdam and Delft in the Netherlands [14]. The results from these trials show that in general the performances obtained in a dynamic environment are enhanced from those measured statically, probably due to the reduction in multipath error.

Further work will focus on improving the network layout and the automation of procedures, evolving to perform continuous data logging, processing and results sharing automatically through ftp servers. Further work also needs to be done on the potential data exploitation and validation of the results generated by the presented GMS, and how all the results could be finally harmonised with those from the local network sites.

Further data collection campaigns, already beginning with the first EGNOS SIS, should continue contributing to the great deal of experience that has been gained up to now on measuring and evaluating SBAS performance, and that will provide invaluable knowledge to be used during the future EGNOS validation.

Follow the developments on the GOV and the Data Collection Network website:

http://www.eurocontrol.fr/projects/sbas

For information on EGNOS and the ESTB check the ESA web-site:

http://www.esa.int/navigation

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