THE EUROPEAN SPACE AGENCY FREE SBAS SOFTWARE DEVELOPMENTS: LEARNING, PRACTISING AND ACCESSING THE EGNOS PERFORMANCES IN REAL-TIME

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BIOGRAPHY

Ankit Raj Mathur obtained his MSc in Aerospace Communication Systems from ENST Telecom Paris / ISAE Supaero (France). Since 2004, he is working as a System Engineer in the ESA GNSS Regional Augmentation Systems Division in Toulouse, France. He has been involved in many projects related to EGNOS performance, SISNeT and EMS.

Dr. Félix Torán holds a Ph.D. in Electrical Engineering by the University of Valencia (Spain), with "Doctor Europeus" mention. Since 2000, he works at the European Space Agency (ESA) as System Engineer. He is currently working at the ESA GNSS Regional Augmentation Systems Division in Toulouse (France). His work focuses in EGNOS performance, software, standardization, mission and system evolution aspects. Since 2001 he is leading the activities related to the ESA SISNeT service. He has been the recipient of several international awards, has co-authored over 110 technical publications and holds one patent.

Katarzyna Urbanska holds a M.Sc. in Geodesy and Geographic Information with the specialization in Satellite Navigation by the University of Warmia and Mazury in Olsztyn (Poland). She is currently working in the French Space Agency (CNES) in the localization and navigation department as engineer for simulation tools. In 2009/2010 she worked in ESA EGNOS Project Office in the performance and tools section.

Miroslav Houdek works on many software development projects since 2001, currently working at Iguassu Software Systems (Prague, Czech Republic). He has worked in the frame of the ESA SISNeT-PECS project, developing new capabilities to existing ESA tools such as SISNeT, SISNeTlab, SBAS TeACHER, SBAS MeNTOR and SBAS Simulator.

Petr Bares, B.Sc. honours math and M.Sc. computer science, University of London. Since 1975 in space industry, 12 years staff member of ESOC/ESA, then Anite Systems Madrid, and since 1997 Managing Director of Iguassu in Prague. He has led Iguassu to win four ESA projects since Czech entry into ESA PECS in 2005 and to become the first Czech company to win in an ESA tender. Member of the Czech Board for Space Activities and leader of the Czech Space Alliance.

ABSTRACT

Since 2002, the European Space Agency (ESA) has introduced two important data access elements. First, the SISNeT (Signal-In-Space over the interNET) data server, and later, in 2003, the EMS (EGNOS Message Server) data server, offering real-time and online access to the messages transmitted by the European Space Agency (ESA) EGNOS System, respectively. In addition to the wide mosaic of

applications that SISNeT has opened and the potential of EMS in the context of EGNOS performance qualification and monitoring, ESA has found a remarkable potential oriented to SBAS Education behind those two services. Therefore, ESA is working, since 2002, on the development of five tools which support SBAS Education. All of them are available for free download, with no additional constraints or conditions. These tools are mainly based on the exploitation of SISNeT and EMS opportunities:

- **SISNeT User Application Software (UAS)**. This software is able to connect to the ESA SISNeT Data Server, obtain the EGNOS Messages in real-time, and present their contents through graphical panels dedicated to each message. This software tool is very helpful for students wanting to understand the information transmitted by SBAS systems, and moreover, it is has also been helpful in the domain of the ESA EGNOS Performance activities, and even in the test of receivers. The ESA SISNeT UAS software is available for download at: http://www.egnos-pro.esa.int/sisnet/uas

- **SISNeTlab** is a non-real-time complement to the SISNeT UAS. This tool is able to download the EGNOS messages corresponding to a period of time selected by the user, from the EMS server, and perform 15 different analysis types, providing graphical results. The ESA SISNeTlab software is available for download at : http://www.egnos-pro.esa.int/sisnetlab

- **SBAS TeACHER** constitutes a visual encoder / decoder of the SBAS messages. Indeed, SBAS messages encoding and decoding is a rather complex task. Thanks to SBAS TeACHER, this task is performed through a user-friendly interface. The ESA SBAS TeACHER software is available for download at : http://www.egnos-pro.esa.int/sbasteacher

- **SBAS MeNTOR** is a SBAS message generator, considered to be an evolution of the SBAS TeACHER. It allows creating or decoding a sequence of SBAS messages over a selected time period, as well as working with EMS like files. Moreover, it allows saving SBAS data (i.e. PRN mask, GIVE, UDRE) in an easy readable format. The ESA SBAS MeNTOR software is available for download at: http://www.egnos-pro.esa.int/sbasmentor

- **SBAS Simulator** is an online simulation software based on satellite navigation systems. It provides analyses and monitoring of EGNOS performance, as well as assessment of its future development, all performed in a simple manner. Consequently, SBAS Simulator allows accomplishing variety of tasks dedicated to understanding and learning SBAS systems. In addition, the tool does not require installation of any additional software. It is available to use at: http://www.egnos-pro.esa.int/sbassimulator

In addition to the above-mentioned tools, ESA has created a website providing EGNOS performance information in real-time, continuously measured by a European network of twelve monitoring stations. The service aims at supporting EGNOS application development, as well as providing EGNOS education and awareness. This website can be found at: http://www.esa.int/navigation/egnos-perfo

Moreover, ESA has published a book compiling all the technical knowledge resulting from EGNOS experience in more than previous 10 years by ESA and its Industry. The book is considered as an invaluable resource for a large variety of people: from SBAS students, teachers and the GNSS engineering specialist to the final system users and application developers.

This paper will describe all the above mentioned educational resources, which have been developed by the European Space Agency (ESA) in the last 7 years. These have been already tested with high success by recognised professors in several undergraduate and graduate GNSS programs and also used by variety of people, who express their general interest in SBAS.

INTRODUCTION

GNSS generally, and SBAS in particular, are large, complex and highly technical systems with a long history of research and development.

Aiming at providing the fundamentals of SBAS systems (EGNOS in particular), ESA has concentrated in the development of a number of public and free of charge tools designed to ease the exploitation of the EGNOS information for the training and education of future GNSS professionals

The ESa SISNeT service has become since 2002 then an important complement to EGNOS providing its wide-area differential correction and integrity information, as well as other added value services, to users over the Internet.

SISNeT and related resources such as the EGNOS Message Server (EMS) constitutes the main pillars for the development of a wide variety of tools with the only objective of teaching SBAS and making EGNOS more accessible to new users.

In the following sections it will be presented a brief description of the developed SBAS educational resources from the premier SISNeT User Application Software (SISNeT UAS) to the later SBAS Simulator.

SISNeT User Application Software (UAS)

The ESA SISNeT technology has become an important complement to EGNOS. It provides users with the messages in the EGNOS SIS via the internet in real time. The UAS tool interfaces with SISNeT and enables straightforward graphical analysis of the EGNOS messages. In the class room, user friendly access and graphical display of real-time EGNOS broadcast messages is a considerable aid in the understanding of EGNOS.

Figure 1 SISNeT UAS environment

The version 3.2 of the SISNeT UAS tool, supports real time analysis of all the message types currently broadcast by all three geos of EGNOS. SISNeT UAS 3.2 makes the EGNOS SIS real time broadcast messages and their analysis available to a wide range of users, including those not already experienced in SBAS. It is now available as a free download from the internet. More information can be fond at http://www.egnos-pro.esa.int/sisnet/uas.html

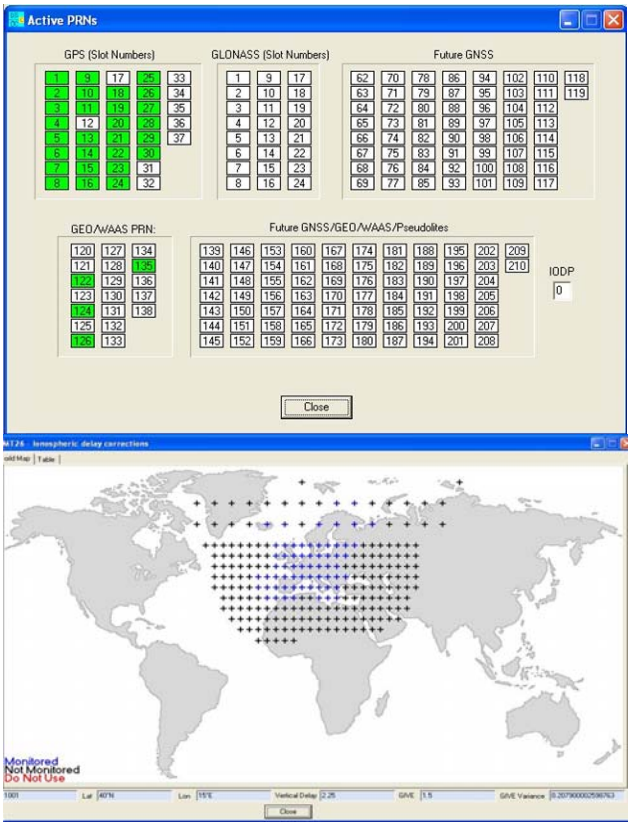

Figure 2 Some SISNeT UAS outputs

SISNeTlab

An important part of the rationale for SISNeT is to make the service it provides accessible to inexperienced users, especially those in schools and Universities. Aside from students, SISNeT can also benefit research scientists, Small and Medium Enterprises and other GNSS Engineering staff. The SISNeTlab tool provides these users with hands-on experience of the information broadcast by SBAS systems.

The SISNeTlab project was developed by ESA during the second half of the year 2004 and made available worldwide in April 2005.

The SISNeTlab tool allows selection and download of historical SBAS broadcast messages from the EMS server. This tool complements the download of real time EGNOS broadcast data by the SISNeT UAS tool discussed in the previous section.

SISNeTlab is designed to be very user-friendly, allowing quick and easy performance assessments of the various SBAS systems. The user inputs a desired time period, SISNeTlab then downloads the data from that interval. SISNeTlab presents that analysis in easily understood graphs and diagrams.

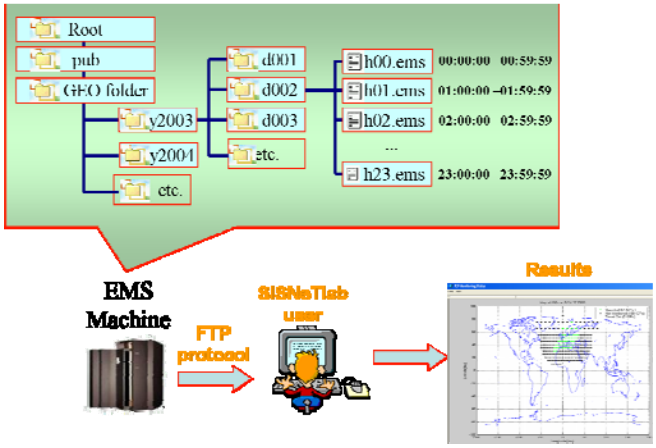

Figure 3 SISNeTlab environment

For any given SBAS satellite, SISNeTlab enables post-processing and analysis of:

- Occurrence distribution of message types.
- Message refresh rate.
- Message loss analysis.
- Ionospheric analysis.
- User Differential Range Error (UDRE) and Fast corrections analysis.
- Satellite monitoring status.
- Satellite long term corrections
- Fast correction degradation factors
- Fast corrections Timout Analysis
- Ionospheric error analysis
- Troposheric error analysis
- Residual error analysis
- Total corrections analysis
- XPL analysis
- Safety Index analysis

ESA conceived SISNeTlab as a modular tool, allowing to expand the capabilities by programming new applications in any programming language. If you are interested in contributing with a module, please contact us at SISNET@esa.int

To download SISNeTlab software, visit:
http://www.egnos-pro.esa.int/sisnetlab

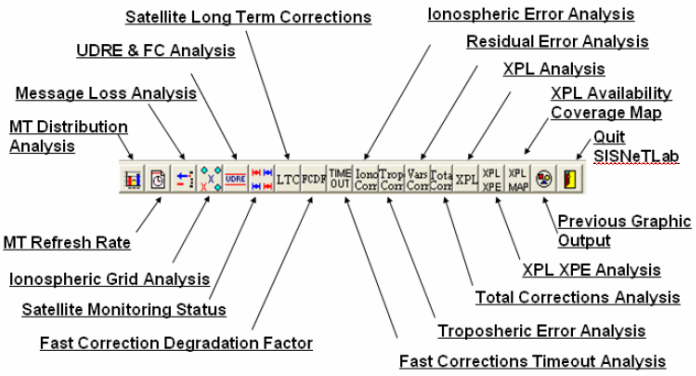

Figure 4 SISNeTlab main GUI Toolbar

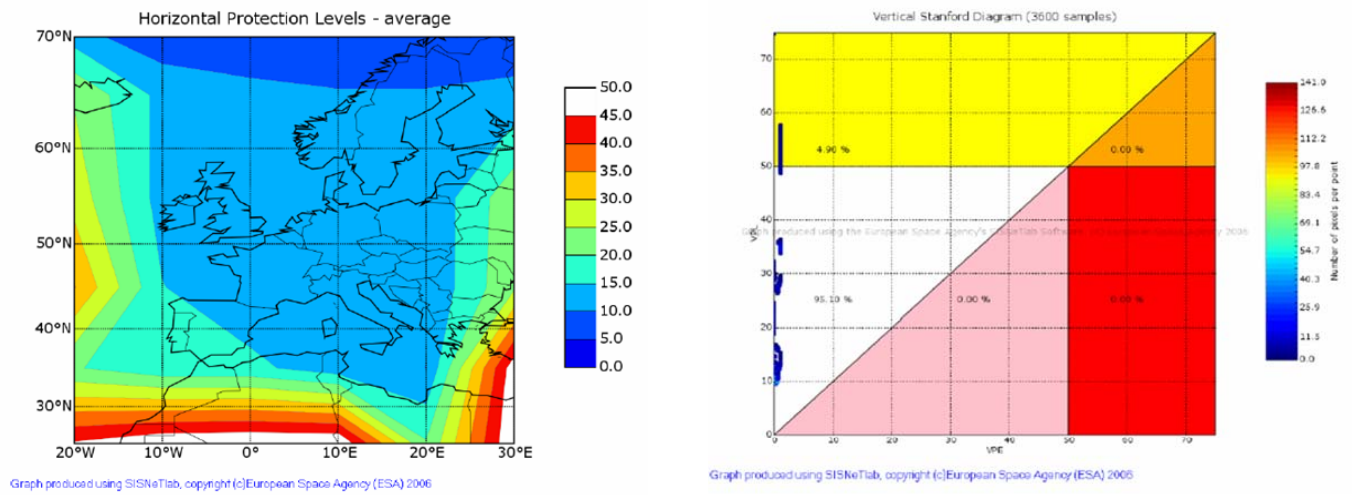

Figure 5 Some SISNeTlab outputs

SBAS TeACHER

The SBAS Tool for Education And Contributor to Harness EGNOS Research (SBAS TeACHER) was developed by Iguassu Software Systems for ESA with the objective to make the broadcast EGNOS messages more intuitive for the users.

SBAS message definitions are highly optimized in terms of low bandwidth requirements – they have to be because of the relatively low data bandwidth in the EGNOS SIS broadcast. But this means that for the EGNOS uninitiated, deciphering what a message actually means for the first time represents an uphill struggle.

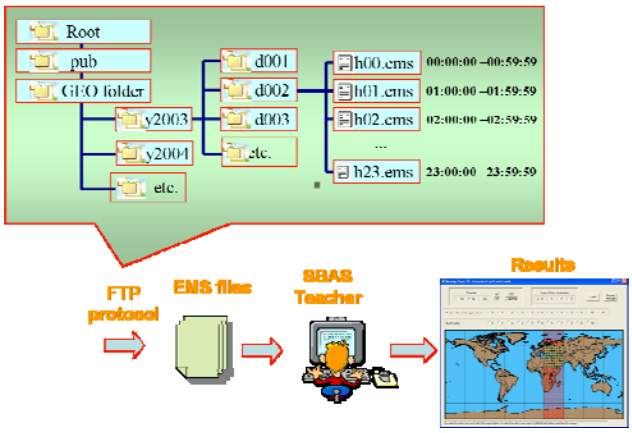

Figure 6 SBAS TeACHER environment

SBAS TeACHER allows decoding and encoding the SBAS messages in an easy way.

As with the case of SISNeTlab, SBAS TeACHER makes use of the of historical SBAS broadcast messages from the EMS server (coded in hexadecimal format) and decodes them producing easy and quick to understand snapshots for each message. Users can also define what they want to broadcast via a geographic "point and click" interface and then to generate the correct message content just pressing a button. Either of these features would be a huge boost for students struggling to understand the SBAS message definitions.

To download the SBAS TeACHER software, visit:
http://www.egnos-pro.esa.int/sbasteacher

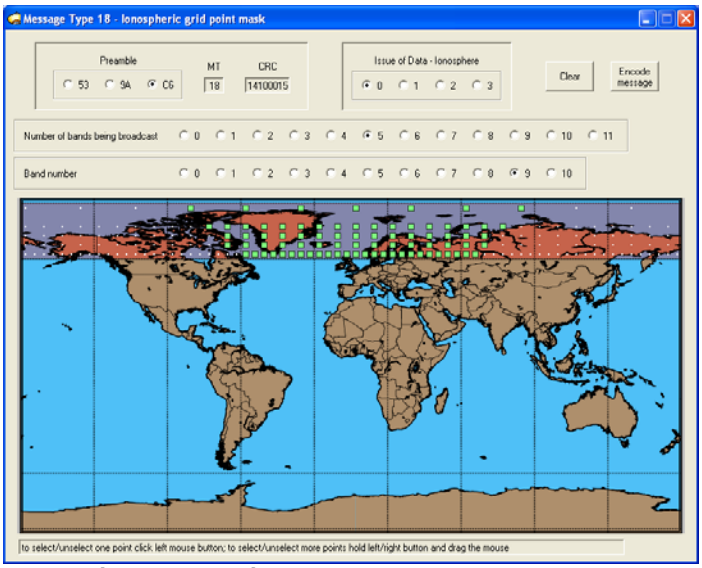

Figure 7 Sample SBAS TeACHER output

SBAS MeNTOR

ESA in association with Iguassu software systems has developed a simple tool, aptly named the SBAS MeNTOR (**SBAS ME**ssage GE**N**era**TOR**). This tool is an evolution of the SBAS TeACHER and allows creating or decoding a sequence of SBAS messages over a selected time period.

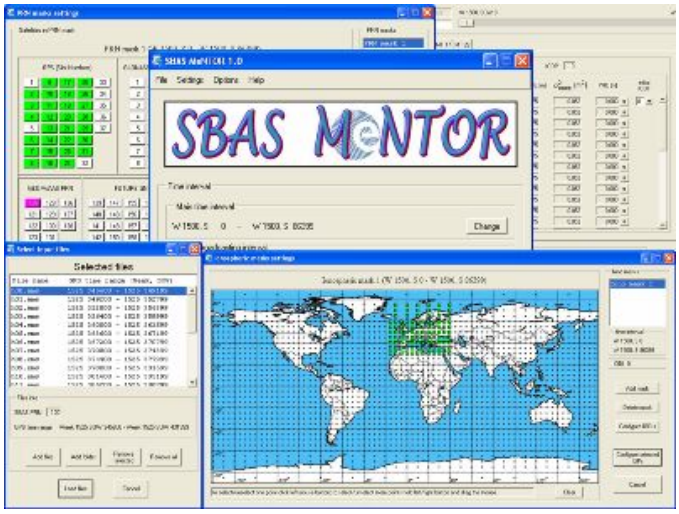

Figure 8 SBAS MeNTOR

While the SBAS TeACHER allows encoding or decoding one SBAS message at a time, the SBAS MeNTOR can work with EMS like files for data over a period of time.

To download the SBAS MeNTOR software:
http://www.egnos-pro.esa.int/sbasmentor

SBAS Simulator

There is a new opportunity for GNSS professionals, application developers, researchers and students to learn about the working of SBAS systems. The tool has been developed in collaboration between ESA and IGUASSU Software Systems, Czech Republic. This has resulted in a user friendly tool with sophisticated capabilities.

The SBAS simulator tool provides many of the simulation capabilities available within ESA to a wide range of those interested in EGNOS and SBAS. Looking into the tool it is clear that it will be a powerful aid in understanding and educating on SBAS systems, while offering EGNOS professionals simulation capabilities for a wide variety of scenarios without usage constraints.

Clicking through the functions reveals that the tool supports SBAS simulations for GPS, Galileo, GLONASS and GEO constellations, as well allowing the user to define their own constellations. Investigating the analysis tabs reveals a high level of flexibility and configurability. The wide range of analysis available includes:

- Protection Level simulations;
- Ionospheric simulations.
- Navigation system error;
- Coverage of satellites;
- Satellite ground tracks;
- Sky plot and 3D simulations;
- Inverse Depth of Coverage;
- Extended Depth of Coverage;
- Availability of the Depth of coverage;

The wide range of results can be produced quickly and provide an intuitive understanding of SBAS performance.

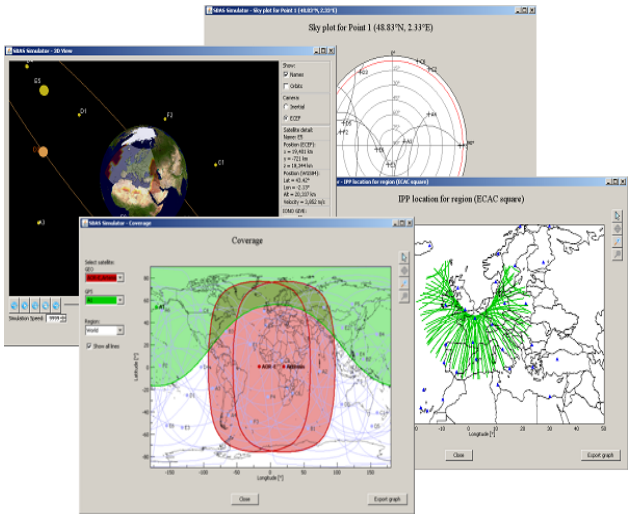

Figure 9 SBAS Simulator outputs

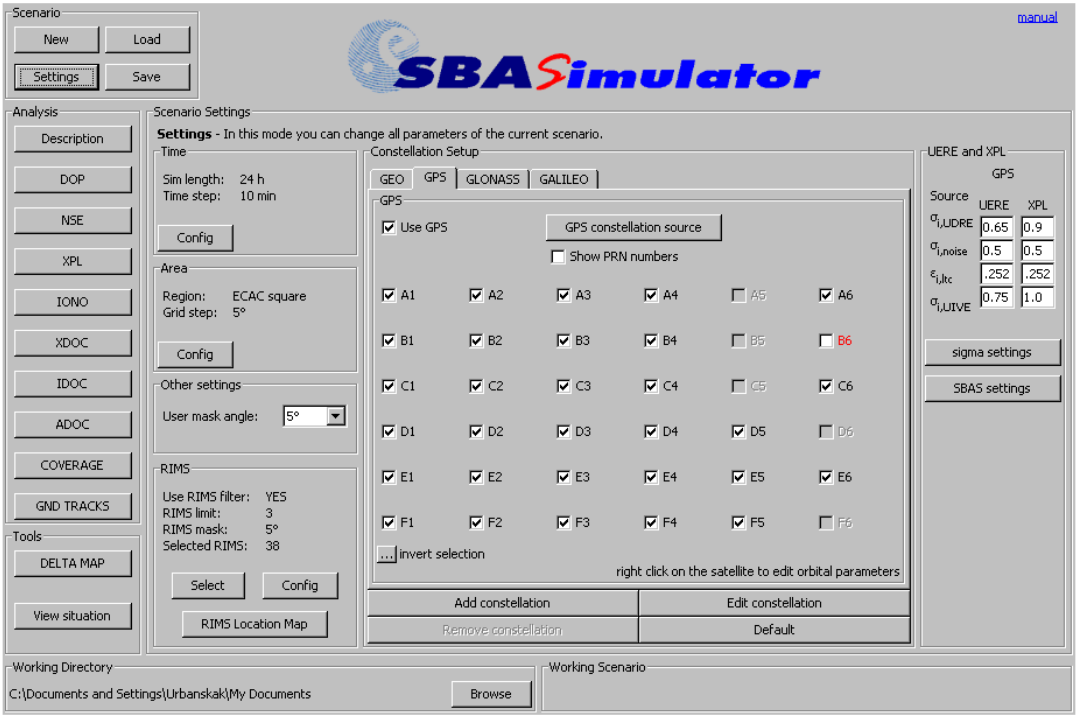

Figure 10 SBAS Simulator main GUI

The simulation results are based on emulating the System defined by ground RIMS stations and system errors. Interestingly, there is also the option to use real SBAS messages for NSE and XPL analysis.

The software operates as a system volume simulator and provides performance based on simplified macro models for the ECAC region. The performances over regions are only an approximation with no guarantee of the obtained results.

The SBAS simulator is just the latest tool available from ESA's website. This new addition to the portfolio of tools provides even more opportunities to learn and exploit SBAS systems. It can now be accessed on ESA's 'EGNOS for Professionals' website www.egnos-pro.esa.int/sbassimulator

EGNOS Real Time Monitoring Network

Since the beginning of the EGNOS program, ESA has been deeply involved in SBAS monitoring over Europe. Aiming at promoting the technical understanding of the EGNOS system, signals and service provided, the European Space Agency has created dedicated website providing EGNOS performance information in real-time, continuously measured by a European network of fourteen monitoring stations.

Figure 11 EGNOS Real time monitoring stations

The resulting graphical performances are updated in quasi-real time and so are excellent tools for performance monitoring. The collected data is provided by the EGNOS Real Time Partners, which include ESA, universities and industrial organizations, making this tool an excellent mechanism of performance monitoring and introducing new users to EGNOS

The information provided includes, for individual stations:

- Max, Min and mean of HNSE, HVSE, HPL, VPL, APV-1 & II Availability,
- Vertical and Horizontal MIs and HMIs,

For the system as a whole the information includes:

- Daily percentage of SIS & MT6 broadcast
- Monthly history plots of APV-I & II performance
- History of the percentage of SIS on the operational GEOs and each individual operational GEO

More information can be found here:
http://www.esa.int/navigation/egnos-perfo

EGNOS Book

GNSS generally and SBAS in particular are large, complex and highly technical systems with a long history of research and development. Key information describing the development and implementation of SBAS systems is widely scattered over numerous journals, conference proceedings, presentations etc.

In line with the ESA practice of "Shape and Share, the ESA is proud have shaped, together with the European Industry, the EGNOS technology and to share it now with the GNSS user community via this book. The EGNOS book serves as a record of the efforts of the many engineers at the ESA and the Industry who have worked so hard over the last 10 years to design and develop the EGNOS system.

The EGNOS Book is technical in nature and presents a complete overview of the EGNOS mission, system and architecture. It has been written for those GNSS engineering professionals, applications developers, satellite-navigation users and university students wishing to have a complete picture of the EGNOS and Satellite-Based Augmentation Systems (SBAS) technologies, principles and related applications. It provides a review of key GNSS fundamental concepts; introduces other existing/planned SBAS systems; presents and discusses EGNOS performance and applications. It also has dedicated chapters for the future GNSS systems, including GALILEO and the planned modernization programs of GPS, GLONASS and EGNOS.

The above mentioned topics are classified into 5 Chapters.

- **Chapter 1**: EGNOS fundamentals
- **Chapter 2**: EGNOS system architecture
- **Chapter 3**: EGNOS performance and applications
- **Chapter 4**: Other SBAS systems and
- **Chapter 5**: Future of GNSS

The book consists of 41 Sections, each one of them consisting of a dedicated article dealing with a specific aspect of the EGNOS system and is also complemented with 5 Appendixes.

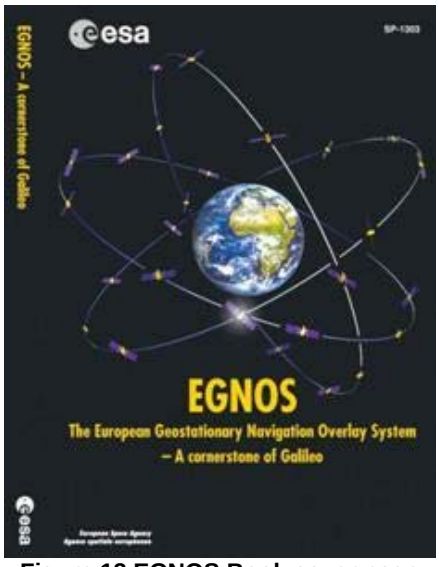

Figure 12 EGNOS Book cover page

The EGNOS Book will be an invaluable resource for SBAS students, teachers and other GNSS professionals.

What Do You Think?

In the following paragraphs, this section presents a brief description of the ESA SBAS educational resources, and provides some testimonials from those key players in making these resources develop their main mission: Teaching SBAS.

"A more "visual" way to show the student how the system works". ,The student can "visualize and analyze the SBAS messages in a very easy and direct way".

Dr. Jaume Sanz Subirana, Polytechnic University of Catalonia.

"The user interface is very simple and auto-explanatory" and "very easy to manage for a non expert user".

Pere Ramos, Polytechnic University of Catalonia.

"SISNeT User Application 3.1 is a powerful and user friendly tool that enables the users to monitor iin real time the data coming from the SISNeT service; hence it is useful for testing the effectiveness of other SISNeT software applications. This tool has been used in our Laboratory to check the validity of out binary decode of the MOPS standard in the framework of the SISNeT driver that we are developing for our activities. One positive aspect of the tool is that no prior knowledge is required to start using it. In fact, its use is very simple and intuitive, also for users with only a general knowledge about EGNOS corrections."

Fabrizio Dominici and Antonio Defina, NavSAS Group, Instituto Superiore Mario Boella.

"The SBAS tools provided by ESA are being used at the French Institute of Higher Education, SUPAERO, in the Satellite Navigation Course and the graphical explanation helps the students to better understand the different concepts and performance drivers. Some of the students are motivated to develop their final graduate thesis around these topics (e.g. contributing with SISNeTlab modules). The EGNOS P.O Staff have also been kind to provide tutorials to students on EGNOS, SISNeT and the various tools for education. On the whole I would strongly recommend the professors of Satellite Navigation to use these tools during their courses."

Prof. Michel Bousquet, Institut Supérieur de l'Aéronautique et de l'Espace, Supaero, Toulouse.

SUMMARY

This paper has presented a number of Educational tools developed by the European Space Agency (ESA) in the last 8 years, including:

• **Five software tools,** available free-of-charge, allowing the real-time and non-real-time visual analysis of the EGNOS broadcasted messages, as well as their visual encoding and decoding;

• **A real-time performance monitoring network**, providing access to the EGNOS performances through a Web interface;

• **An EGNOS book**, presenting a complete overview of the EGNOS mission, system architecture, interoperability and extension capabilities, performance, planned evolutions and applications.

The above-mentioned resources have been already tested with high success by recognized professors in several undergraduate and graduate GNSS programs. The way to access these resources (most of them free) has been explained in this article.

It is believed by the Authors that the presented resources will provide a useful contribution to the GNSS Education and professional community.

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