The European Space Agency Free Resources for SBAS Education: Learning, Practicing, and Accessing the EGNOS Performances in Real-Time

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BIOGRAPHY

Dr. Félix Torán holds a Ph.D. in Electrical Engineering by the University of Valencia (Spain). Since 2000, he works at ESA as System Engineer, currently working in the Mission and System Evolution Section of the EGNOS Project Office in Toulouse (France). His work focuses in EGNOS performance tools, SBAS standardization, software tools for SBAS Education, EGNOS Mission and System Evolution, and he is responsible of the ESA SISNeT service. He has co-authored over 100 technical publications and holds one patent. Together with Dr. Ventura-Traveset (ESA), he has been the recipient of two International Awards for the ESA SISNeT technology.

Dr. Javier Ventura-Traveset is working since March 1989 at the European Space Agency (ESA) involved in mobile, fix, earth observation, science and satellite navigation programs; he is currently the EGNOS Mission and System Manager in the EGNOS Project Office at ESA. He has over 18 years of professional experience in the Space sector and Satellite navigation fields.

Carlos López de Echazarreta holds a M.Sc. in Telecommunication Engineering by the Polytechnic University of Madrid (Spain). He has been working in EGNOS as System Engineer since 2005. He currently works within the Mission and System Evolution Section of the ESA EGNOS Project Office in Toulouse (France).

Ankit Raj Mathur obtained his MSc in Aerospace Communication Systems from Telecom Paris / SUPAERO (France). Since 2004, he is working for ESA as a System Engineer in the EGNOS mission and system evolution section. He has been involved in many projects related to SISNeT and EMS.

Pedro Pintor received his M.Sc. on Radio Astronomy and Space Science from Chalmers University of Technology (Sweden). Since 2005, he works on the EGNOS P.O. as a System Engineer, working on simulation algorithms, analysis of EGNOS performances, and the coordination of the EGNOS Real-Time Monitoring network.

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

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

This paper presents a large number of Education tools developed by the European Space Agency (ESA) in the last 5 years. These have been already tested with high success by recognized professors in several undergraduate and graduate GNSS programs. The way to access these tools (most of them free) will also be explained in this article. It is believed by the Authors that these tools will

provide a useful contribution to the GNSS Education and professional community.

Since 2002, ESA has introduced two important data access elements. First, the SISNeT (Signal-In-Space over the InterNET, see [2] – [5]) data server, and later, in 2003, the EMS (EGNOS Message Server) [6] data server, offering real-time and offline access to the messages transmitted by the ESA EGNOS system [1], respectively.

In addition to the wide mosaic of applications that SISNeT has opened (especially in urban environment), 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.

Indeed, ESA is working, since 2002, on the development of tools to support SBAS Education, mainly based on the exploitation of SISNeT and EMS potential such as SISNeT User Application Software (SISNeT-UAS), SISNeTlab and SBAS TeACHER.

In addition, ESA has created an online EGNOS performance monitoring tool [7], which provides in quasi-real time the measured performances by a European network of fourteen monitoring stations.

ESA has also identified the need of a starting point for new students wanting to obtain a deep technical knowledge about EGNOS. Responding to that need, ESA has produced the "EGNOS Book", co-edited with the support of European Industry, which compile all the technical knowledge resulting from EGNOS experience in the previous 8 years. The Authors believe that the "EGNOS Book" will be an invaluable resource for SBAS students, teachers and other GNSS professionals.

This paper presents a brief description of the developed SBAS educational resources, and provides some testimonials from some of the key players in making these resources develop their main mission: teaching SBAS. Finally it includes several Internet links allowing the reader to obtain more information and even download and try the tools in their current version

INTRODUCTION

The large complexity and the long history of research and development of the GNSS generally and the SBAS in particular, as highly technical systems, makes its study and analysis being a hard and a non effortless task.

Aiming at providing the fundamentals of SBAS systems (EGNOS in particular), ESA has developed a number of public and free of charge tools designed to ease the exploitation of the EGNOS [1] information for the training and education of future GNSS professionals

In 2002, ESA introduced SISNeT (Signal-In-Space through the Internet, see [2] – [5]), providing access to the EGNOS Signal-In-Space over the Internet and in real-time. In 2003, ESA introduced the EGNOS Message Server (EMS) [6], providing offline access to the EGNOS messages, through an FTP (File Transfer Protocol) server.

SISNeT and EMS, in addition to their demonstrated potential for navigation in urban areas and performance monitoring activities, respectively, constitute the main pillars for the development of a wide variety of tools with the objective of teaching SBAS and making EGNOS more accessible to new users.

The following sections present the developed SBAS educational resources, including three software tools, the EGNOS real-time monitoring network, and The EGNOS Book.

SISNET USER APPLICATION SOFTWARE (UAS)

SISNeT is an important complement to EGNOS. It provides users with the messages transmitted in the EGNOS SIS, via the Internet and in real time.

Figure 1: SISNeT UAS environment

As illustrated in Figure 1, the SISNeT internal infrastructure includes a Base Station, which receives the EGNOS messages and transmits them in real-time to the SISNeT Data Server, which is accessible to SISNeT users over the Internet.

The UAS tool implements the SISNeT User Interface (described in [8]), obtaining the EGNOS messages in real-time and enabling real-time graphical analysis of the EGNOS messages. It is worth to mention that the access to SISNeT is free-of-charge (for more details, please, visit the SISNeT website at http://www.egnos-pro.esa.int/sisnet).

In the classroom, user friendly access and graphical display of real-time EGNOS broadcast messages is a considerable aid in the understanding of EGNOS.

The latest version 3.1 of the SISNeT UAS tool, recently released by ESA, supports real-time analysis of all the message types currently broadcast by EGNOS. In addition, users can receive messages from the current three EGNOS GEO satellites (PRNs 120, 124 and 126).

SISNeT UAS 3.1 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, at http://www.egnos-pro.esa.int/sisnet.

Figure 2 shows some of the UAS real-time analysis windows, presenting the PRN mask, and the Ionospheric Grid Point (IGP) monitoring status, as well as the corresponding vertical delays and GIVE values at the IGPs (as the mouse pointer is over each depicted IGP).

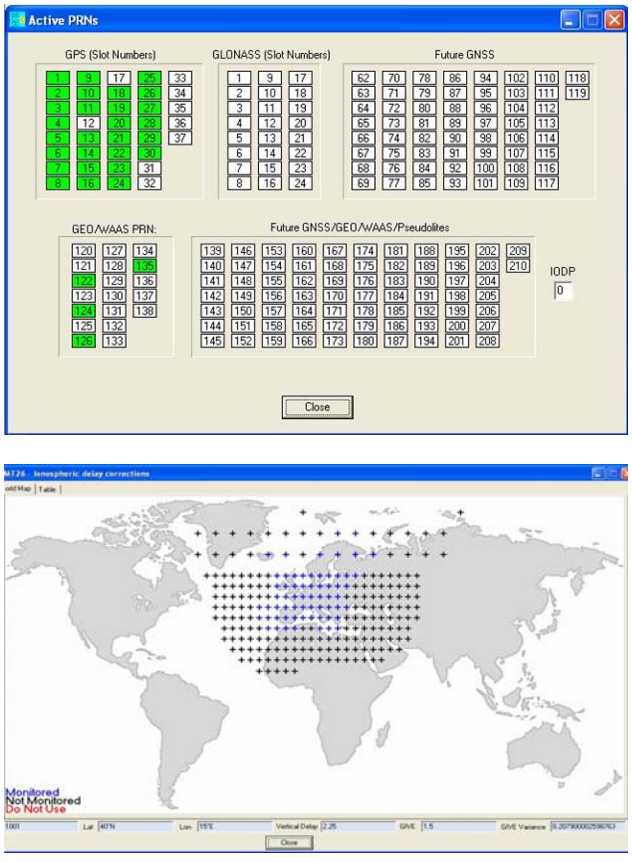

Figure 2: Some examples of SISNeT UAS outputs

SISNETLAB

The EGNOS Message Server (EMS) [6] constitutes a non-real-time complement to the ESA SISNeT data server. It opens the door to a wide mosaic of potential applications for research scientists, Small and Medium Enterprises and other GNSS Engineering staff.

The SISNeTlab tool is an EMS-based application, which provides these users with hands-on experience of the information broadcast by EGNOS. In the same way that the EMS server is a non-real-time complement to the SISNeT data server, SISNeTlab (a tool based on EMS) constitutes a non-real-time complement to SISNeT UAS (a tool based on SISNeT).

The SISNeTlab project was developed by ESA during the second half of the year 2004 and made available worldwide in April 2005, after a successful testing phase.

Figure 3 shows the SISNeTlab tool in context. SISNeTlab allows selection and download of archived SBAS broadcast messages from the EMS server.

SISNeTlab is designed to be user-friendly, allowing quick and easy performance assessments of the various GEO broadcasts available at the EMS server. The user inputs a desired time period, and uses the SISNeTlab toolbar (see Figure 4) to launch the desired analysis. Then SISNeTlab downloads the data from that interval and presents the analysis results in a graphical way. Figure 5 shows some examples of SISNeTlab graphical outputs.

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

- Distribution of message types.
- Messages refresh rate analysis.
- 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 Timeout Analysis
- Ionospheric error analysis
- Tropospheric error analysis
- Residual error analysis
- Total corrections analysis
- Protection Level analysis
- Safety Index analysis
- Protection Level availability maps.

ESA conceived SISNeTlab as a modular tool, allowing expanding the capabilities by programming additional modules in any programming language.

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

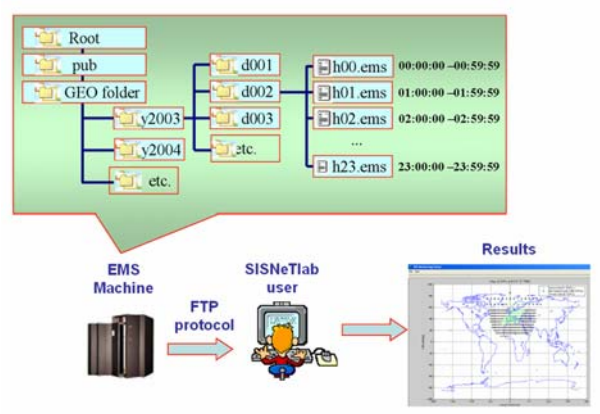

Figure 3: SISNeTlab environment

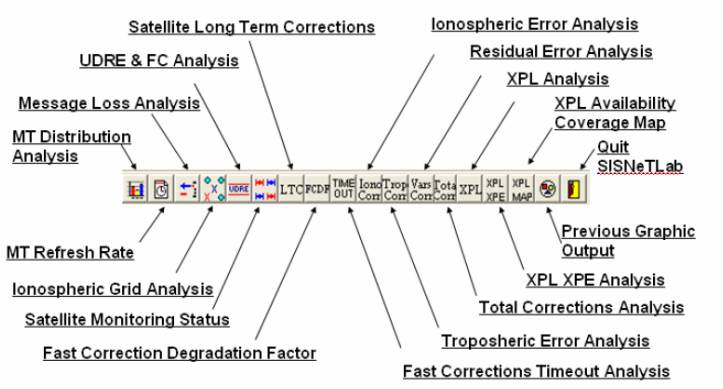

Figure 4: SISNeTlab main GUI Toolbar

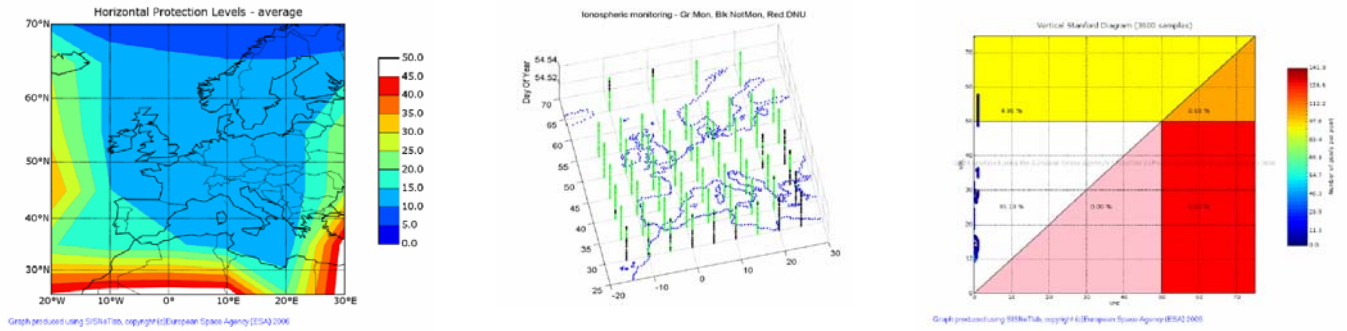

Figure 5: Some SISNeTlab outputs

SBAS TEACHER

The SBAS Tool for Education And Contributor to Harness EGNOS Research (SBAS TeACHER) [9] was developed by Iguassu Software Systems under ESA contract, with the objective to allow decoding and encoding SBAS messages in a graphical and intuitive way, so that the SBAS message contents can be more effectively learned by students and new Engineers working in the SBAS field. At the same time, this tool was conceived as an SBAS message encoder / decoder to be used by SBAS Professional Engineers in different activities.

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 SBAS SIS broadcast. But this means that for the EGNOS uninitiated, deciphering what a message actually means for the first time may easily represent an uphill struggle.

Figure 6 shows the SBAS TeACHER tool in context. The message to analyse is expected in hexadecimal format. It can be directly typed by the user, or obtained (copy-paste) from an EMS file previously downloaded by the user or already stored on the user computer. It is also possible in some cases to copy-paste the message to analyse from SBAS receiver files.

The SBAS message is typed or pasted into an edit box, as illustrated in Figure 7, and after clicking on the "Decode message" button, a window is opened, presenting the decoding of the message in a user-friendly way. Figure 8 shows an example of one of those windows, where Message Type 18 of MOPS DO-229D [10] is decoded.

The opposite operation can also be performed, i.e. the encoding of a new SBAS message, also following a user-friendly procedure. The user can click on one of the buttons of the SBAS TeACHER toolbar (see Figure 7), to select the message type to encode, and once the corresponding graphical window is opened, the user can define the message contents by means of user-friendly interface components, like slide bars, radio-buttons, etc., and in some cases even clicking on a map.

Either of these features would be a significant aid for students willing to understand the SBAS message definitions. The characteristics of SBAS TeACHER make it very useful also for GNSS Engineers needing to encode and decode SBAS messages in a quick and visual way.

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

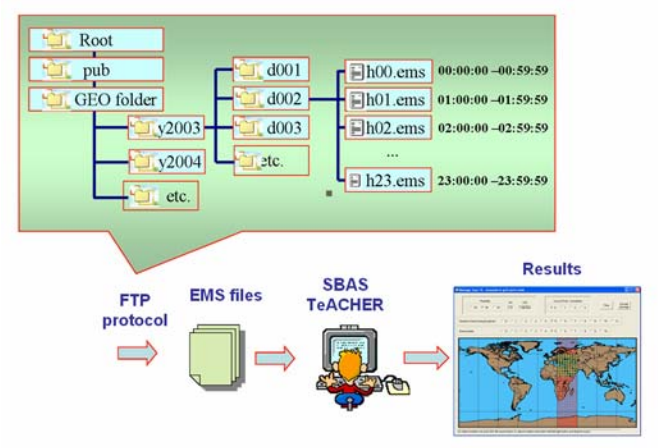

Figure 6: SBAS TeACHER environment

Figure 7: SBAS TeACHER main GUI

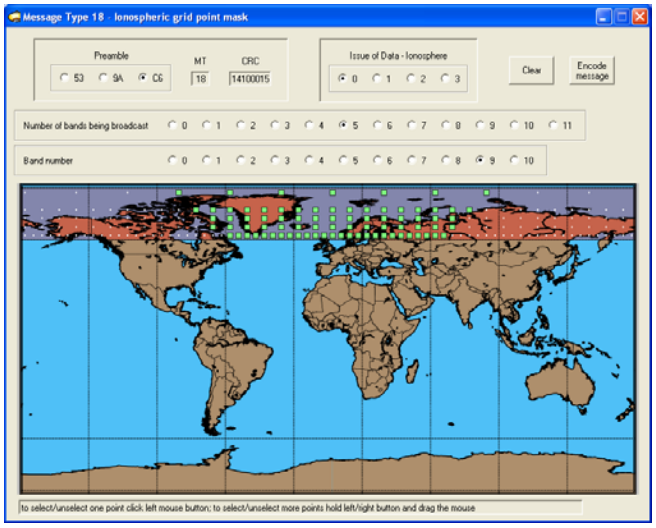

Figure 8: One SBAS TeACHER output (MT_18)

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 a dedicated website, providing EGNOS performance information in real-time, continuously measured by a European network of fourteen monitoring stations. Figure 9 depicts the geographical location of those stations.

Figure 9: 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 graphical information provided includes, for each individual station:

- Maximum, minimum and mean of HNSE, VNSE, and HPL / VPL;
- Navigation System Error and Protection Levels versus time;
- APV-1 Availability,;
- Vertical and Horizontal Stanford diagrams.

For the system as a whole the information includes:

- Satellite message broadcast status
- Satellite and IGP monitoring status
- Grid Ionospheric Vertical Error
- Mean Protection Levels over Europe for last hour

More information can be found through the following link: http://www.esa.int/navigation/egnos-perfo

THE "EXPERT" EGNOS REAL TIME MONITORING NETWORK

Following the success of the ESA EGNOS real-time monitoring network, ESA is going further by working on the ESA EXPERT Network, which will be formed by other extra twenty-five low-cost standard commercial receivers.

EXPERT aims to introduce European universities and space organizations into the EGNOS community and more in general to Satellite Navigation and to enhance, as well, links between ESA and Education.

The EXPERT network is based on win-win collaboration between ESA and partners (mainly European Universities). On the one hand, ESA provides partners with the EXPERT receiver, consisting on Protection Level sensors (based on low cost commercial receiver modules for the mass market) and plotting software. On the other hand, partners must make available a computer with an internet connection and a station manager who will act as the responsible for the receiver loan and contact point for delivery, installation and maintenance of the station. ESA manages the EXPERT network, granting the communication for future upgrades and extension of the network, as well as constituting a first interface with ESA for most of the partners.

In the current first phase, the EXPERT Network is going to deploy twenty-five EGNOS receivers all over Europe. From previous experiences, it was clear the station had to be as independent and automatic as possible and ESA has considered this an important design requirement. This is expected to pay back once the whole network is set up. Thanks to this, the EXPERT station and the EXPERT software have been developed to work with a zero daily maintenance time except, of course, for some sporadic and simple changes of configuration.

The second most important requirement was to have a simple design. That is why the receiver continuously provides the receiver messages through the serial port where the EXPERT software logs this data onto the correspondent receiver file, so the information can be available for future analyses. The EXPERT software also automatically and periodically plots and uploads to an ESA FTP the real-time graphs plotted in every station. Figures 10 and 11 show some examples of the generated plots.

All these graphs are stored and delivered to users accessing the EGNOS Real Time website. Additionally, data from previous days is also stored to an archive for performance analyses.

ESA encourages any interested organization or university to get involved in this win-win project. Hosting will set up a continuous link with ESA and promote the organization or university in the Satellite Navigation field.

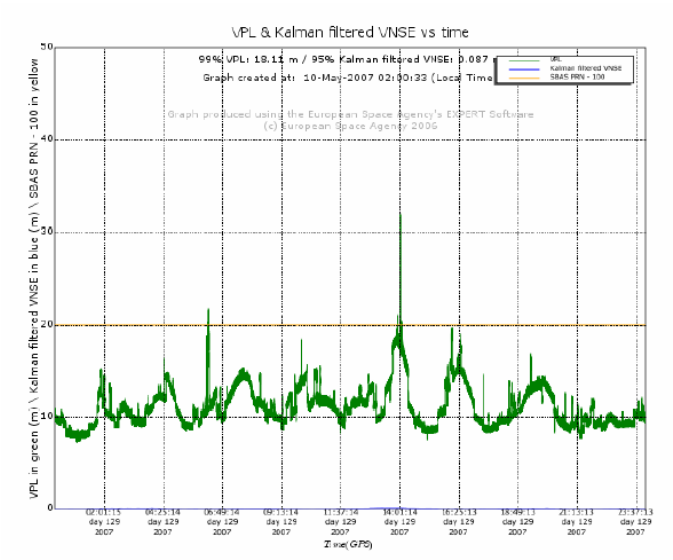

Figure 10: EXPERT VPL & Kalman VNSE vs. time plot

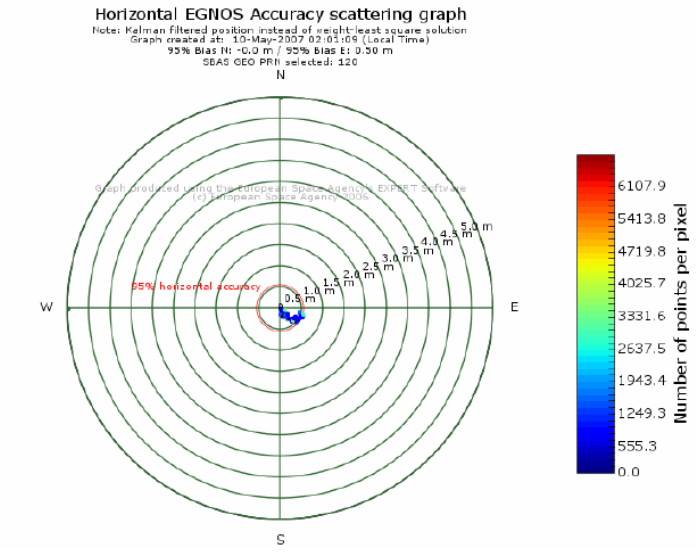

Figure 11: EXPERT Horizontal Accuracy plot

For joining EXPERT and any detail on EXPERT, please contact us through the following email address: egnos.expert@esa.int.

THE EGNOS BOOK

One of the main drawbacks when facing the study and analysis of the GNSS systems, and especially SBAS, is the lack of a reference handbook. Key information is usually widely scattered over numerous journals, conference proceedings and presentations.

The EGNOS book [1] (see cover page in Figure 12) 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. In line with the ESA practice of "Shape and Share", ESA is proud to 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 is technical in nature and presents a complete overview of the EGNOS mission, system architecture, interoperability and extension capabilities, performance, planned evolutions and applications.

It has been written for 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.

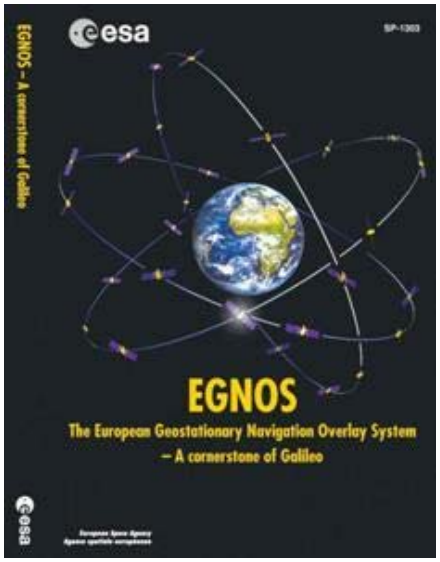

Figure 12: EGNOS Book cover page

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. Under the technical supervision of Dr. Javier Ventura-Traveset (European Space Agency) and Dr. Didier Flament (Alcatel Alenia Space), this book has been mostly co-authored by recognised GNSS Engineers in each specific domain, either from the EGNOS European Industry, the European Space Agency (ESA) or internationally recognised experts from USA, Japan, Russia, Canada and India. The book is also complemented with 5 Appendixes.

It is believed by the Authors that the "EGNOS Book" will be an invaluable resource for SBAS students, teachers and other GNSS professionals.

FUTURE WORK

ESA plans to continue working on developing resources for Education about SBAS systems. In particular, three lines of work have been identified and are under study at this moment:

- Developing a support tool to teach SBAS systems, with 3D characteristics, so that the different sources of errors can be understood by students, as well as the main performance concepts as Integrity, Accuracy, Availability and Continuity. At this stage, this project is just an idea, which will be shaped and likely (TBC) converted into a development during 2008.
- Developing a new version of the SBAS TeACHER tool, able to encode / decode messages over time. For instance, this will allow creating a sequence of messages simulating a particular system behavior, allowing to analyze the performance of the system using other tools, or test receiver behavior, etc.
- To include the performance graphs from all the EGNOS geostationary satellites and to have a comparison of error between GPS only mode and the GPS+EGNOS mode of operation of the receiver.

SUMMARY

This paper has presented a number of Educational tools developed by the European Space Agency (ESA) in the last 5 years, including:

- **Three 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.

REFERENCES

[1] J. Ventura-Traveset, D. Flament (editors). *EGNOS: The European Geostationary Navigation Overlay System –A cornerstone of Galileo*. ESA SP-1303, ESA Publications Division, ESTEC, Noordwijk (The Netherlands), December 2006. http://www.esa.int/SPECIALS/ESA_Publications/SEMNMPN0LYE_0.html

[2] F. Torán-Martí and J. Ventura-Traveset. Status and Evolution of the ESA SISNeT Technology. *Proc. of the European Navigation Conference (ENC) 2006*, Manchester (UK), May 2006.

[3] F. Torán-Martí, J. Ventura-Traveset, E. Gonzalez, A. Catalina, C. Barredo and A. Salonico. Positioning Via Internet: SISNeT Catches GPS in Urban Canyons. *GPS World*, April 2004. http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=92688

[4] F. Torán-Martí, J. Ventura-Traveset and R. Chen. The ESA SISNeT Technology: Access to the EGNOS Services through Wireless Networks and the Internet, *Proc. of ION GPS 2002*, Portland (Oregon, USA), September 2002.

[5] F. Torán-Martí, J. Ventura-Traveset and J.C. de Mateo. Satellite Navigation and the Internet: Introducing the SISNET Technology, *Dr. Dobb's Journal,* March 2002, 17-26.

[6] European Space Agency. *EGNOS Message Server Official Website*. Available at http://www.egnos-pro.esa.int/ems

[7] European Space Agency. *EGNOS Real Time Performance website.* Available through the EGNOS for Professionals Website at: http://www.egnos-pro.esa.int

[8] European Space Agency. *SISNeT User Interface Document*. Issue 3, Revision 1. Available at http://www.egnos-pro.esa.int/sisnet/uid.html

[9] European Space Agency. *SBAS TeACHER Official Website*. Available at http://www.egnos-pro.esa.int/sbasteacher

[10] RTCA. *DO-229D. Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*. Issued 12-13-06. Prepared by RTCA SC-159. Available through http://www.rtca.org