International Journal of Aviation, Aeronautics, and Aerospace

Volume 7 | Issue 3 Article 1

2020

Assessment of EGNOS performance for civil aviation flight phase in the edge coverage area

bilal beldjilali
Department of Space Geodesy, Center of Space Techniques, bbeldjilali@cts.asal.dz
Salem Kahlouche
Department of Space Geodesy, Center of Space Techniques, skahlouche@cts.asal.dz
lahouaria Tabti
Department of Space Geodesy, Center of Space Techniques, ltabti@cts.asal.dz

Navigation-based satellite is an essential technology widely used for civil aviation. Systems that provide this service are known as GNSS (Global Navigation Satellite System). This is the set of systems which use a constellation of satellites, located in orbits distributed in a way to provide full coverage of the Earth, to offer the possibility to an unlimited number of receivers to calculate the exact position of an aircraft in three dimensions: latitude, longitude and altitude, with a precision that can reach a few centimeters in real time (Beldjilali, 2017). The most known and widely used system currently in the world is the American system GPS, other systems were developed such as the Russian system GLONASS and the Chinese Beidou, others are being developed such as the European one Galileo (Lyon, 2006). Unfortunately, GNSS alone cannot meet certain application requirement; for example, for the civil aviation, the service continuity and integrity required in different flight phases cannot be guaranteed only by GNSS. For that, complement systems are developed to achieve those exigencies; named SBAS for (Space Based Augmentation Systems) are radio-navigation-satellite systems intended to improve GNSS systems providing together superior performance in terms of positioning accuracy, availability, service continuity and provided information integrity (Tabti, 2020). These systems transmit different corrections and integrity messages for each GNSS satellite which are calculated through a network of ground reference stations. Several nations have implemented their own SBAS systems like the American

WAAS (Wide Area Augmentation System) and the European EGNOS (European Geostationary Navigation Overlay System). In addition to aeronautics application, SBAS systems are now used in all areas requiring high precision and high integrity (Ciollaro, 2008; Oday, 2011; Roturier, 2006).

Problem

One of the International Civil Aviation Organization (ICAO) objectives is to define standards that navigation systems must meet for different flight phases of a civil aircraft. The performance requirements associated with these different flight phases, in particular those corresponding to the landing of an aircraft, as illustrated in Figure 1, are very high (ICAO, 2012).

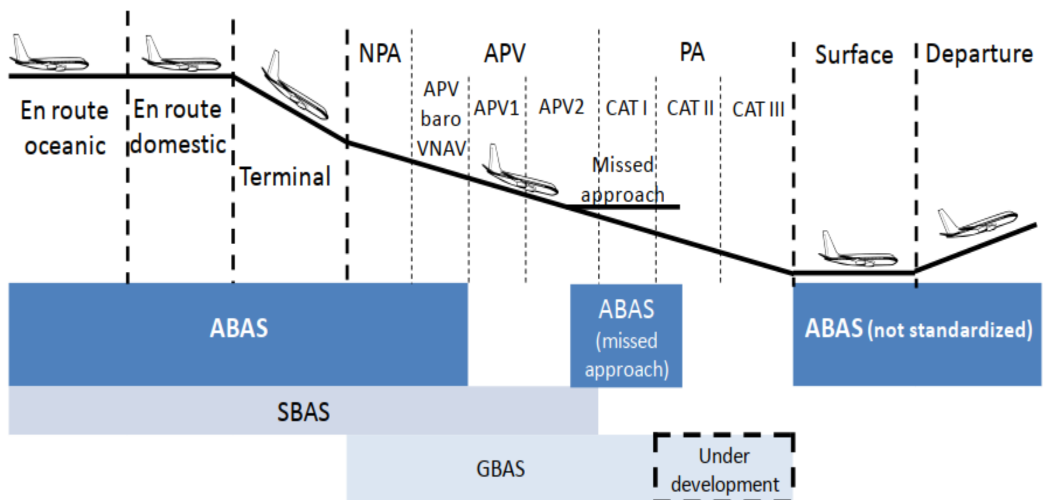

*Figure 1.*Flight phases of a civil aircraft as defined by ICAO (Giuseppe, 2016).

For any GNSS system, which is expected to improve both precision and reliability, the ICAO is working to characterize the values for the different flight phases of a civil aircraft that the systems must achieve in order to be certified

(ICAO, 2005). Figure 2 is an illustration of the navigation parameters delivered from the GNSS receivers in function of the ICAO requirements.

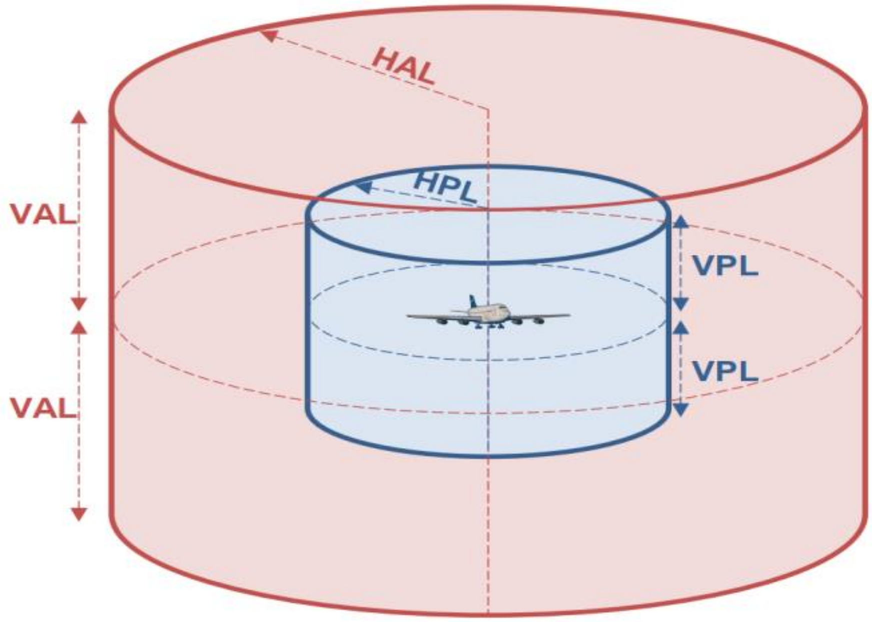

Figure 2.Parameters of the confidence degree.

The aircraft in Figure 2 present the estimated position as calculated by the GPS system; the HPL (Horizontal Protection Level) and VPL (Vertical Protection Level) are two parameters estimated by EGNOS, it can be explained as the maximum error allowed of the H (Horizontal) and V (Vertical) components. The last two parameters HAL and VAL (Horizontal and Vertical Alert Limit) are the maximum values that the HPL and VPL must not exceed, the values of these two parameters are defined by the ICAO for each flight phase as summarized in Table1.

Table 1

Flight Phases Accuracy, Availability, Continuity, and Integrity Values (ICAO, 2005)

Operation type	Accuracy		Integrity				Availability	Continuity
	H	V	Alert time	HAL	VAL	Integrity risk		
En-route	3,7 km	n/a	5mn	7,4km to 3,7km	n/a	10^{-7}/h	0,99 to 0,99999	1-1 10^{-4}/h to 1-1 10^{-8}/h
En-route, terminal	0,74km	n/a	15s	1,85km	n/a	10^{-7}/h	0,99 to 0,99999	1-1 10^{-4}/h to 1-1 10^{-8}/h
NPA	220 m	n/a	10s	556m	n/a	10^{-7}/h	0,99 to 0,99999	1-1 10^{-4}/h to 1-1 10^{-8}/h
APV I	16 m	20 m	10s	40m	50m	2.10^{-7}/ approach	0,99 to 0,99999	1-8 10^{-6}/15s
APV II	16 m	8 m	6s	40m	20m	2.10^{-7}/ approach	0,99 to 0,99999	1-8 10^{-6}/15s
CAT I	16 m	4 m to 6 m	6s	40m	10m to 15m	2.10^{-7}/ approach	0,99 To 0,99999	1-8 10^{-6}/15s

Currently, the European system EGNOS is one of the most used SBAS systems for civil aviation; Figure 3 shows the importance of this system by illustrating airports which are actually (March 2020) used it in some flight phases.

DOI: https://doi.org/10.15394/ijaaa.2020.1479

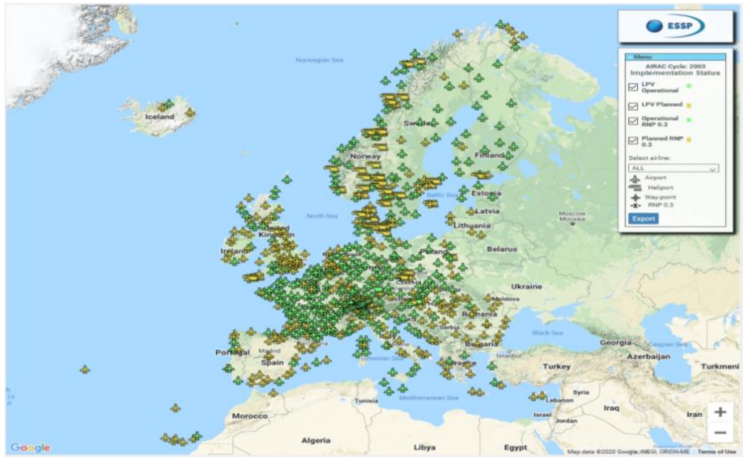

*Figure 3.*Airports using EGNOS in some flight phase (EGNOS, 2020).

The efficiency and performance inside EGNOS system coverage area are determined by the ESA based on a set of data collected from a network of ground stations. Unfortunately, for some regions as in North Africa, there are no ground stations; for that, information about these areas are based mainly on simulation and interpolation methods. The distance between ground stations influence the efficiency of the models used for the interpolation which can generate non precise information about the coverage area and the level of the precision guaranteed by EGNOS which can influence air traffic.

Purpose

The purpose of this research is to determine if the interpolation model used by the ESA to determine the coverage area of the EGNOS system is efficacious enough to predict the actual status of the system in far regions; then ground stations network, Ranging Integrity Monitoring Stations (RIMS), are used in this interpolation. This study will be realized by collecting real data from GPS station and comparing the obtained results by those giving from the ESA calculated center. The position of the receiver will be calculated in different sites, near Airports, located in North Africa with different distances from RIMS stations installed in this area. The influence of the distance between RIMS stations and airports will be investigated to evaluate the efficiency of EGNOS system for civil aviation application in terms of *accuracy*, *degree of confidence*, *availability* and *integrity*.

Research Questions

The research questions for this project were:

1. What is the actual level of the EGNOS system in coverage area edge; does it meet the requirements established by ICAO for civil aviation in the North African area?
2. Is the interpolation model use by ESA in the estimation of the EGNOS coverage area effective enough in regions without RIMS stations?
3. What is the influence of the distance between RIMS stations and airports on the efficiency of the EGNOS system?

DOI: https://doi.org/10.15394/ijaaa.2020.1479

Literature Review

EGNOS provides more precise positioning data which improves existing GPS services and develops a wide range of new services for different segments such as civil aviation. EGNOS consists of transponders on board three geostationary satellites and an interconnected terrestrial network comprising 40 stations RIMS (EGNOS, 2020). The EGNOS signal provides a constant level of positioning accuracy in its coverage area which extends mainly over Europe and North Africa. The corrections messages can be received directly from EGNOS satellites, with an EGNOS compatible GPS receiver, without any communication costs (Sauer, 2003). Figure 4 illustrate EGNOS RIMS stations network in addition to its actual coverage area.

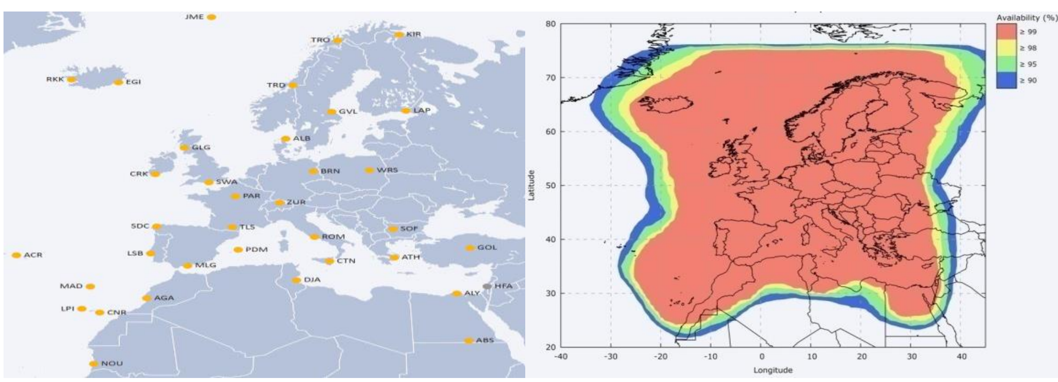

Figure 4.RIMS station and the coverage area for EGNOS system (EGA, 2019).

Each EGNOS satellite broadcasts its messages on the L band with a rate of 250 bits per second. It uses the same modulation as GPS signal L1 C/A, but with a rate 5 times higher. These symbols, with a baud rate of 500 sps (symbols per second), are modulated using a spreading code of 1023 bits with a rate of 1.023MHz. This signal is then modulated in BPSK with a carrier frequency of 1575.42MHz. A total of 63 messages types can be transmitted, but for the moment only 20 are defined and 18 are used by EGNOS as mentioned in Table 2 (Tabti, 2020).

Table 2

Description of EGNOS Messages (EMS, 2004)

Message Type	Description
1	PRN mask
2-5	Fast correction
6	Integrity Information (EDREI)
7	Degradation factor for quick correction
9	Position parameters of the GEO satellite (ephemeris), (X, Y, Z, time, ..)
10	Degradation settings
12	UTC SBAS time
17	Position parameters of GEO satellites (Almanac)
18	Mask of the Ionospheric grid
24	Fast correction / slow correction
25	Slow correction
26	Ionospheric delays

The EGNOS system makes it possible, via a network of stations, to transmit to users in the service area corrections to the pseudo-distances of the satellites. These corrections allow the receiver to correct errors such as the inaccuracy of ephemeris and satellite clocks or delays of the GPS signal caused by the Ionospheric and Tropospheric layers. The user collects all the differential correction messages and calculates the corrected pseudo-distance l_{corr} on the basis of the measured pseudo-distance l_{mes} for each satellite; this correction is given by (Simon, 2012; Tabti, 2019; Walter, 2010) as:

$$l_{corr}(t) = l_{mes}(t) + RC_{fast}(t) - RC_{iono}(t) + RC_{tropo}(t) + RC_{clock}(t) \tag{1}$$

$\boldsymbol{RC_{fast}}$**, Fast correction**, is used to correct rapidly varying errors such as clock and ephemeris errors. Equations (2) and (3) summarize the calculation of these corrections in meters (Eurocontrol, 2003).

$$PR_{corrected}(t) = PR_{\text{measured}}(t) + RC_f(t_{0f}) + RRC(t - t_{0f}) \tag{2}$$

$$RRC(t_{0f}) = \frac{RC_{f\text{ current}} - RC_{f\text{ previous}}}{t_{0f\text{ current}} - t_{0f\text{ previous}}} \tag{3}$$

Where t is the time of applicability, and t_{0f} is the time of applicability of the most recent message in (s), $PR_{corrected}$ is the corrected pseudo-distance, and PR_{measured} the pseudo-distance measured in (m), RC_f is the fast correction, and RRC is the variation of the correction in (m).

$\boldsymbol{RC_{iono}}$ **Ionospheric corrections**: EGNOS transmits ionospheric corrections for each of the points called IGP (Ionospheric Grid Points) of a virtual grid located at an altitude of 350 km. The calculation of the ionospheric correction is given by:

$$RC_{iono} = \left[1 - \left(\frac{R_e cosE}{R_e + h_I}\right)^2\right]^{-1/2} \times \tau_{IPP} \tag{4}$$

Where E is the elevation angle of the satellite relative to the user (radians); R_e is the approximate radius of the Earth (6378.13363 km); h_I is the height of the maximum electron density (350 km). $\tau_{IPP}$is the PPI delay (Eurocontrol,2003).

$\boldsymbol{RC_{tropo}}$ **Tropospheric correction**: The EGNOS system does not transmit any tropospheric corrections, but the user estimates it by spatial and temporal interpolation using a model defined by the Minimum Operational Performance Standards (MOPS):

$$RC_{tropo} = -(d_{hyd} + d_{wet})\frac{1.001}{\sqrt{0.002001 + sin^2(E)}} \tag{5}$$

$d_{hyd}$and d_{wet} is the dry and wet contributions to the zenith delay.

$\boldsymbol{RC_{clock}}$ **Satellite clock corrections:** The satellite clock correction factor that influences the pseudo-distance is given by (Eurocontrol, 2003):

$$\mathrm{RC_{clock}(t)} = \delta\Delta \mathrm{T_{sat}(t)} \times \mathrm{c} \tag{6}$$

The update of the clocks is given by the following equation:

$$\delta\Delta T_{sat}(t) = \delta a_{f0} + \delta a_{f1}(t - t_0) \tag{7}$$

$\delta\Delta T_{sat}$ is the clock correction (s); δa_{f0} is the clock error correction (s); δa_{f1} is the correction drift and it is equal to 0 when the Velocity Code is 0 (s).

Also, EGNOS broadcast parameters which allow the user to evaluate the degree of confidence in the differential corrections and to estimate a limit of his position error; these parameters called protection levels (PL) which define an area where the real position of the user is with very high certainty (EMS,2004). In real time, the protection levels are calculated at all times by the receiver using the following parameters (Giuseppe, 2016):

Message type 1; to get the PRN mask.

Message types 2-5, 6, and 24 for orbit and ephemeris errors.

Message types 18 and 26 for ionospheric error.

The horizontal and vertical protection level calculation is given by:

$$HPL = K_h \times \sigma \tag{8}$$

$$VPL = K_v \times d \tag{9}$$

For civil aviation Kh is fixed at 6 and Kv is fixed at 5.33 for the PA (precision approach) phases. This parameter can nevertheless be modified for other applications. d and σ are the Vertical and horizontal variance of the estimated position as a function of the matrix G and W

$$G_i = [-cosEli\ sin\ Azi \quad -cosEli\ cos\ Azi \quad -sinEli \quad 1] \tag{10}$$

$$W = \begin{bmatrix} {}^{1}/{\sigma_1^2} & 0 & \dots & 0 \\ 0 & {}^{1}/{\sigma_2^2} \dots & & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & {}^{1}/{\sigma_N^2} \end{bmatrix} \tag{11}$$

σ_i^2 is the sum of the variances for each satellite (m^2) it is calculated by:

$$\sigma_i^2 = \sigma_{(\mathrm{i,flt})}^2 + \sigma_{(\mathrm{i,UIRE})}^2 + \sigma_{(\mathrm{i,air})}^2 + \sigma_{(\mathrm{i,tropo})}^2 \quad (12)$$

$\sigma_{(\mathrm{i,flt})}^2$ is the variance of the residues of the slow and fast corrections (m^2);

$\sigma_{(\mathrm{i,UIRE})}^2$is the variance of the residues of the ionospheric corrections (m^2);

$\sigma_{(\mathrm{i,air})}^2$is the variance of the airborne receiver errors (m^2);

$\sigma_{(\mathrm{i,tropo})}^2$is the variance of the residues of the tropospheric corrections (m^2).

Methodology

In the aim to evaluate EGNOS corrections, especially for civil aviation; on different sites chosen for this study, in the first time the position will be calculated using GPS alone; while in the second time, the pseudo-distance will be corrected using EGNOS parameters. The corrections messages used in this work are obtained from ftp://serenad-public.cnes.fr based on the FTP service. It is a site containing the data of EGNOS ground stations, SBAS messages and raw data in different download formats.

The data collected between 2018 and 2020, were analyzed using gLAB software (Sanz, 2012)and our results are compared with the ESA model. Table 3 and Figure 5give the approximate position of the five sites used in this study; those sites are chosen near airports in the edge of the EGNOS coverage area as far as possible from RIMS stations.

Table 3

Localization of the GPS Stations Used in the Study

ICAO airports	City	Latitude	Longitude	Altitude (m)
DAOO	Oran	35°51'29".83 N	0°18'49".71 W	76.88
DABP	Skikda	36°52'57".73 N	6°56'10".87 E	48.98
DAAY	Naama	34°03'11".34 N	1°39'08".99 W	1235.70
DAAQ	Bousaada	35°12'39".74 N	4°11'02".99 E	637.74
DAFH	Hassi Rmel	32°56'59".45 N	2°55'58".94 E	760.50

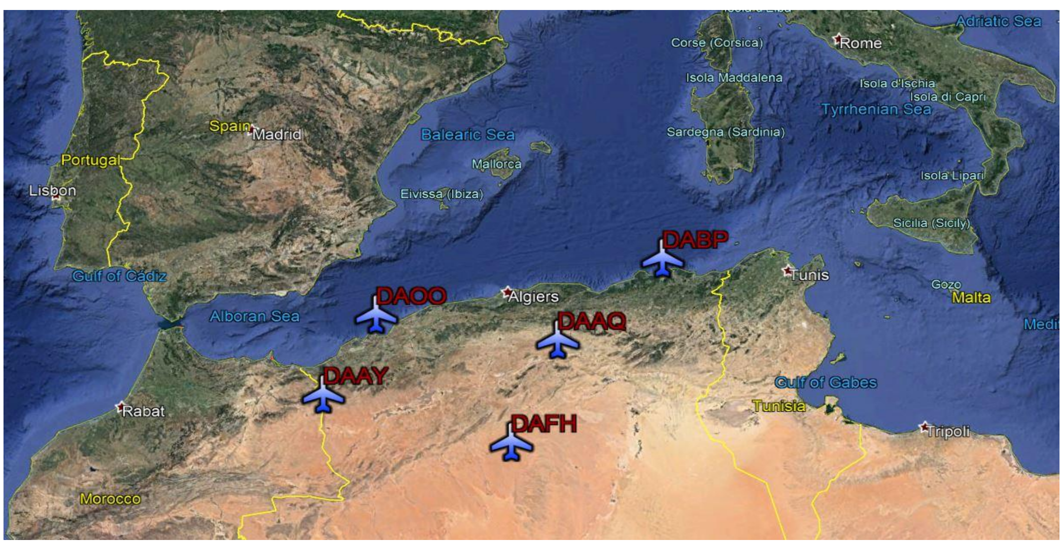

Figure 5.*Location of GPS stations used in the study.*

The first step in our work was to evaluate the ***accuracy*** of the EGNOS correction and compare the results obtained with the requirement requested by

ICAO as mentioned in Table 1. In the first time we calculated the position accuracy for each site with GPS signals only, in the second time the position was be calculated by applying EGNOS correction(equation 1) and the two solutions will be compared. Figure6 shows the variation of the Northing, Easting and Up error on the first site (DAOO airport, Oran); we can see clearly for this site that the position accuracy is significantly improved using EGNOS correction especially for the Up component, the error was reduced from 9m using GPS only to 4m using GPS+EGNOS.

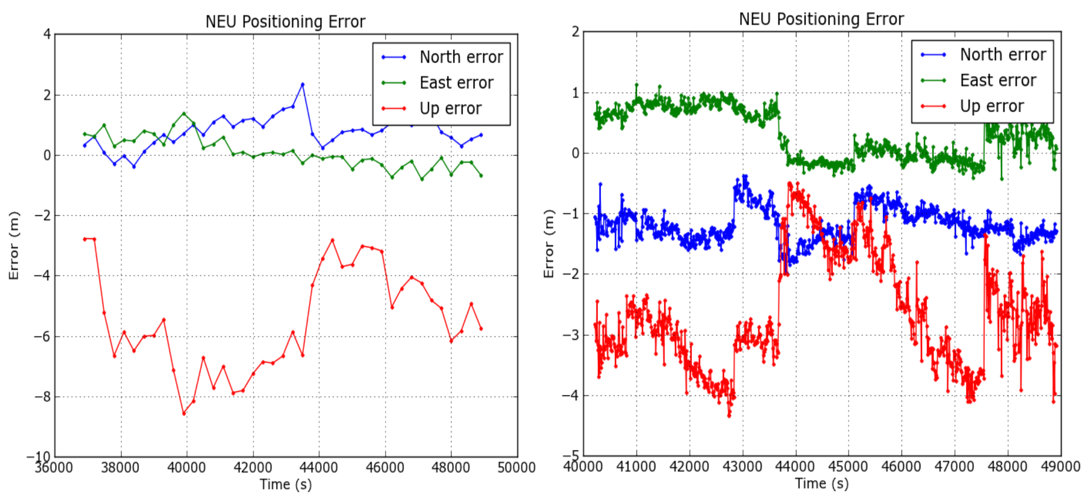

Figure 6.Comparison between Northing, Easting and Up position errors (left GPS only and right GPS+EGNOS) on the Oran site.

To clarify the importance of the EGNOS correction, Figure 7 shows only the planimetry error. The distribution of the solutions obtained from EGNOS is denser and closer, which is explained by the robustness of the EGNOS system against errors.

https://commons.erau.edu/ijaaa/vol7/iss3/1
DOI: https://doi.org/10.15394/ijaaa.2020.1479

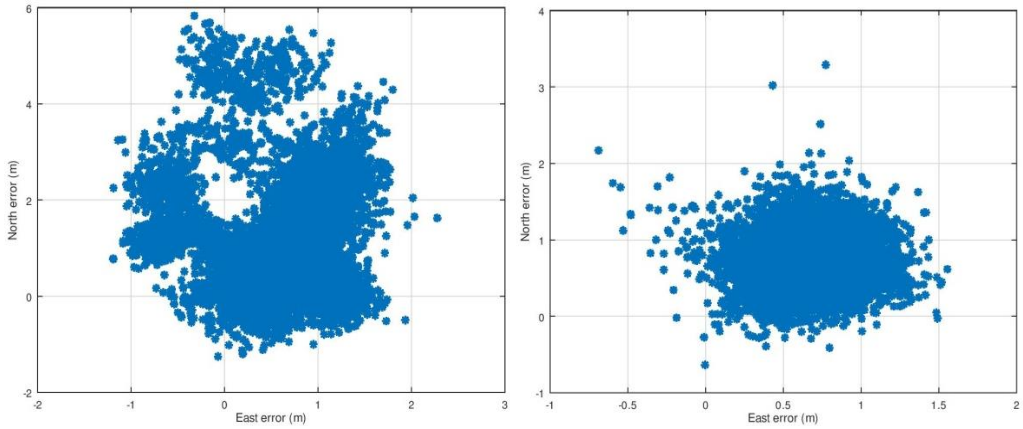

Figure 7.Distribution of the planimetry error (left GPS and right GPS+EGNOS).

Table 4

Accuracy Comparison Between GPS and GPS+EGNOS(m)

Airport (City)	GNSS	North error	East error	Up error
DAOO (Oran)	GPS	6.6584	3.0641	4.9187
	GPS+EGNOS	3.0806	1.2151	2.1936
DABP (Skikda)	GPS	6.6084	3.0848	4.6126
	GPS+EGNOS	2.9351	1.2884	1.9406
DAAY (Naama)	GPS	5.2009	2.9298	4.5513
	GPS+EGNOS	2.5295	1.1343	2.3961
DAAQ (Boussaada)	GPS	6.6899	2.8921	4.5401
	GPS+EGNOS	2.9424	1.2526	2.1216
DAFH (Hassi Rmel)	GPS	9.0102	2.9504	4.3924
	GPS+EGNOS	3.6885	1.8685	2.3750

The previous table (Table 4) summarizes the errors variation between the two solutions (GPS, GPS+EGNOS) for all sites used in this study. The EGNOS corrections influence are clearly observed, for our study area the positions are improved significantly and we can conclude that the accuracy obtained can conclude that EGNOS will be used for all flight phase until CAT I which need a precision of 16m in planimetry and 4m in altimetry. For the 5 airports this requirement (accuracy) is respected.

The second step in our study was to evaluate the ***degree of confidence*** of the EGNOS system. For this evaluation, the Horizontal and Vertical protection level for each site is examined (equations 8 and 9). The following figures (Figures 8 to 12) show the results obtained.

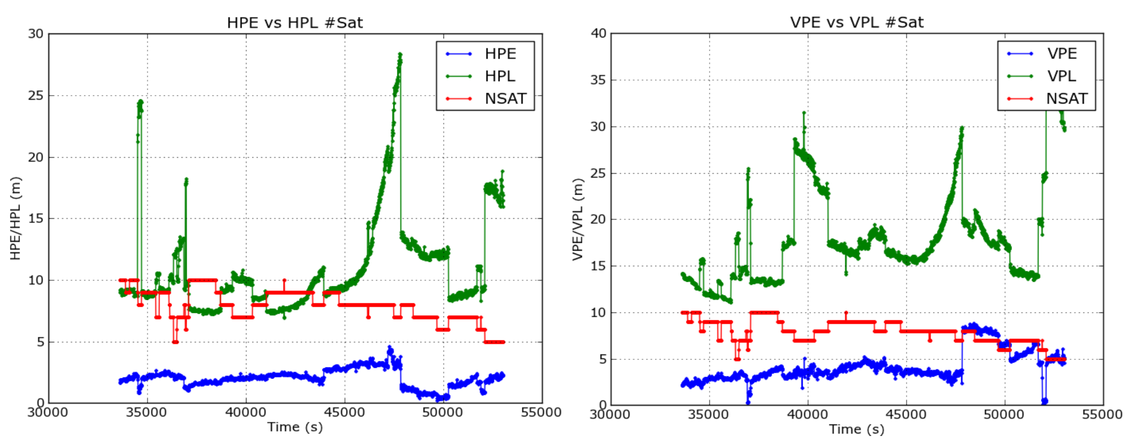

*Figure 8.*Protection level (left Horizontal and right Vertical) for DAOO airport.

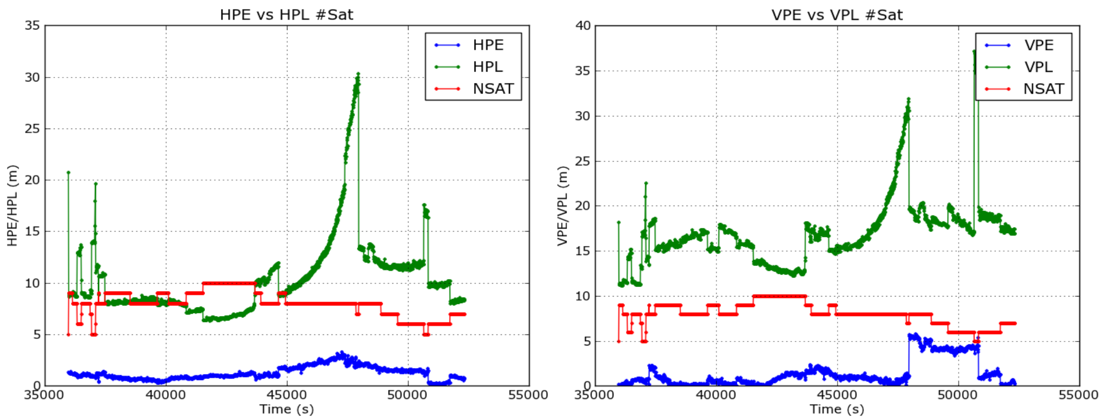

Figure 9.Protection level (left Horizontal and right Vertical) for DABP airport.

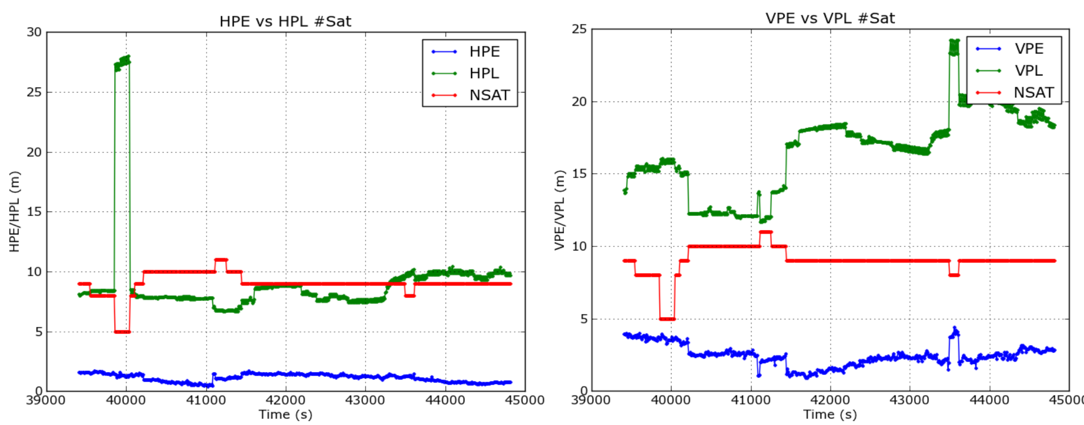

Figure 10.Protection level (left Horizontal and right Vertical) for DAAY airport.

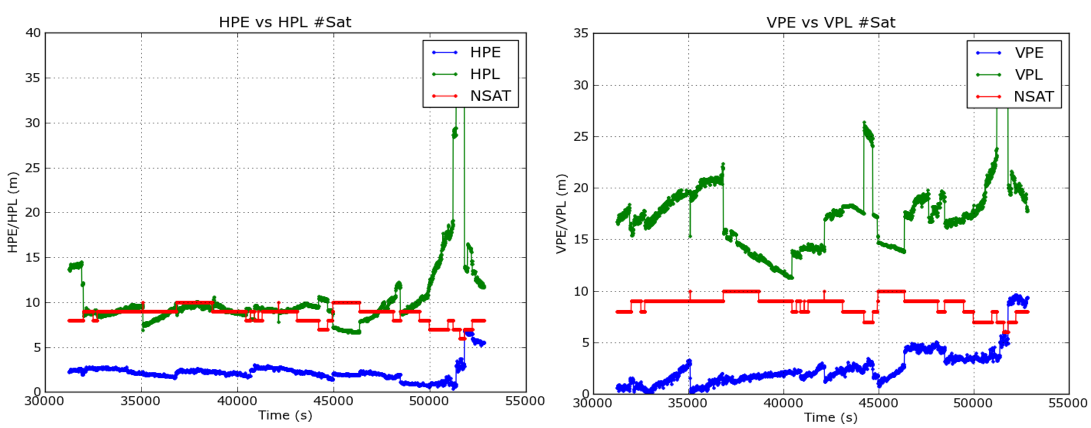

Figure 11.Protection level (left Horizontal and right Vertical) for DAAQ airport.

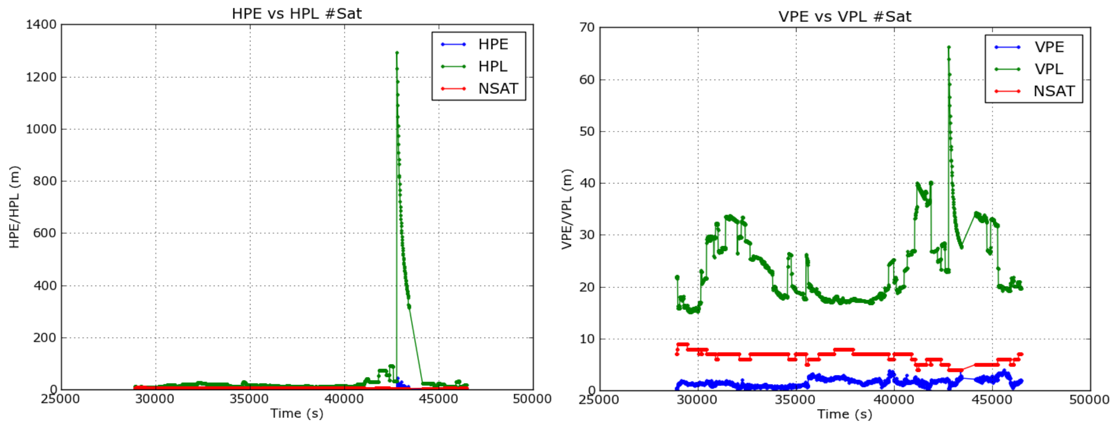

*Figure 12.*Protection level (left Horizontal and right Vertical) for DAFH airport.

From the previous figures, we can conclude that only 4airports meet the requirements of the ICAO phase APV I. For the DAFH Hassi Rmel airport, the HPL and VPL exceed respectively the 40m and 50m required for the phase APVI. The last step in our study was to evaluate the ***Availability and integrity*.** One of the ways used to represent both the availability and the integrity of EGNOS on the same graph is by using "**Stanford diagram**". This type of graph, initially used for the validation of SBAS systems, represents for a known position, the protection limit (VPL or HPL) according to the vertical or horizontal positioning error (VPE or HPE). The alarm limit values (VAL or HAL) are indicated on the two axes, as well as the line (y=x) used to identify non-integrity events. The evaluation of integrity is done by comparing protection level with positioning error, if XPL is greater than XPE we can conclude that the integrity is not guaranteed by EGNOS system in this area. In addition, availability is calculated from the number of XPL samples, if XPL>XAL then no integrity guarantee can be established for the calculated position) (Giuseppe, 2016). Figures 13 to Figure 17 are the vertical and horizontal Stanford diagrams of each airport.

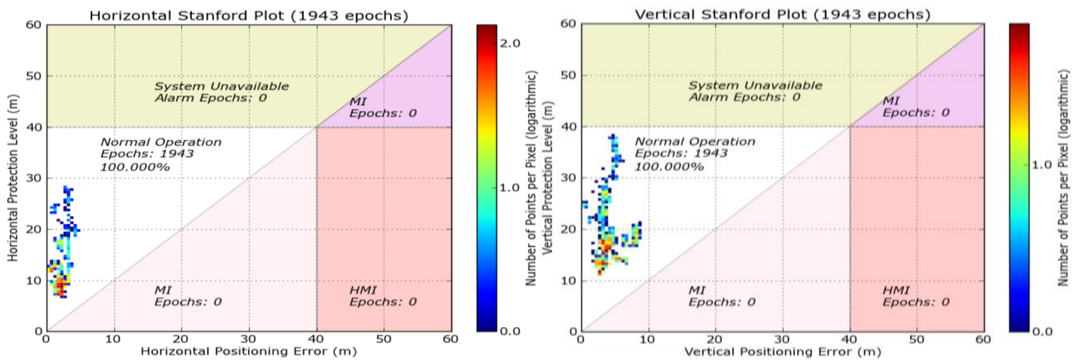

Figure 13.Horizontal and Vertical availability and the integrity for DAOO airport.

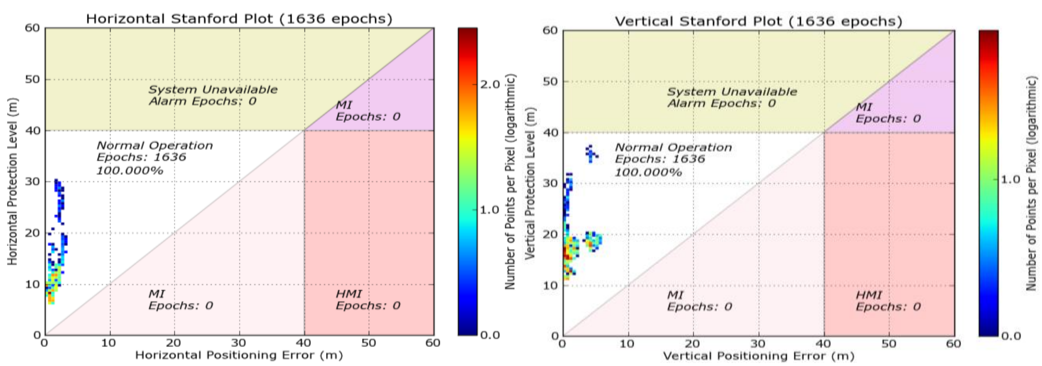

Figure 14.Horizontal and Vertical availability and the integrity for DABP airport.

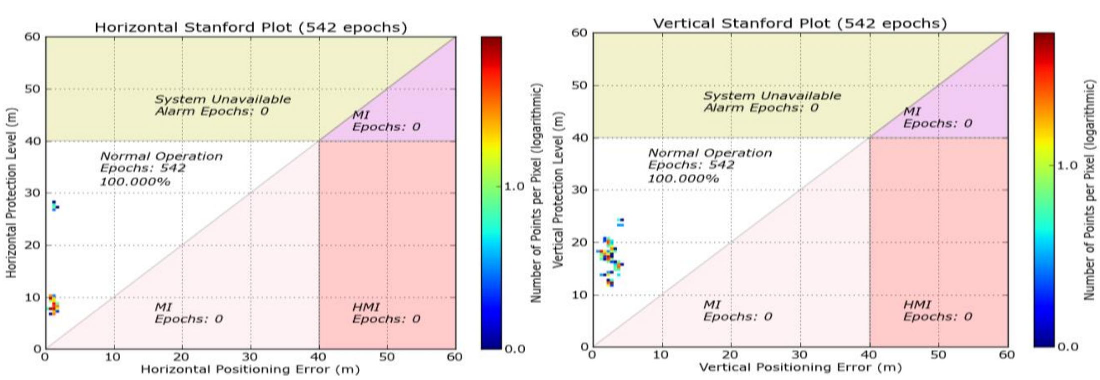

Figure 15.Horizontal and Vertical availability and the integrity for DAAY airport.

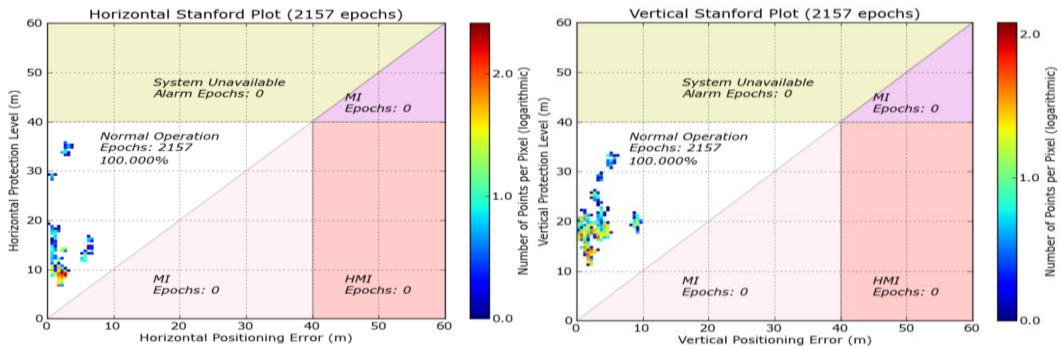

Figure 16.Horizontal and Vertical availability and the integrity for DAAQ airport.

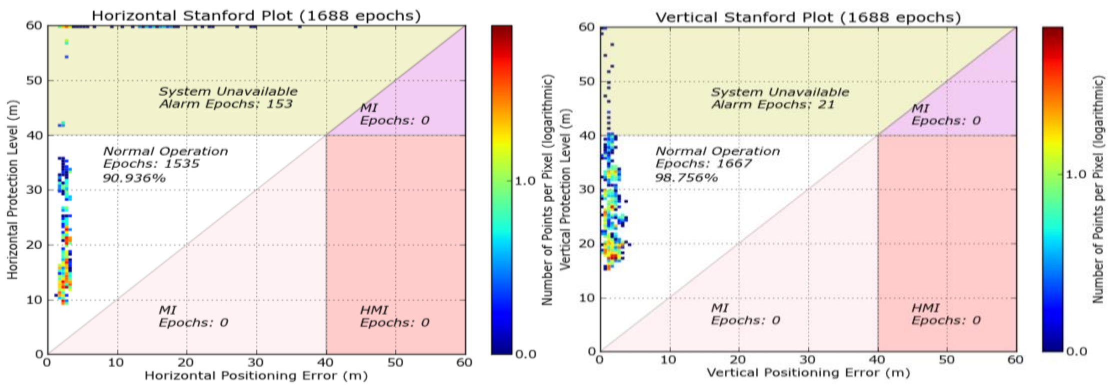

Figure 17.Horizontal and Vertical availability and the integrity for DAFH airport.

The Availability required by ICAO for all flight phase must be great than 99.99%. In our case, this value is respected for both vertical and horizontal component by the first 4airports which are situated north latitude 34°, and the only site which has less value is the DAFH Hassi Rmel airport (90.936 % for the Horizontal component and 98.756% for the Vertical component).

Conclusions

EGNOS satellite signals currently cover most of Europe, with different coverage areas depending on the service guaranteed. In this work, we analyzed

DOI: https://doi.org/10.15394/ijaaa.2020.1479

the expected EGNOS performance for 5 airports in the north of Africa (Algeria) without a RIMS station. During this study the accuracy, protection level, availability and integrity are also analyzed. For all airports in the study area, the accuracy is improved significantly by applying EGNOS correction. In the other side, for the degree of confidence, the EGNOS performance results on airports situated above latitude of 34° have confirmed the accuracy and integrity according to the APV I approach by ICAO, which is crucial for aeronautical applications. However, in airport situated below latitude of 34°, the horizontal and vertical protection level exceeds respectively 1200 m and 60 m, which is higher than the required horizontal and vertical alarm limit (40 m and 50 m) so it is lie outside the air navigation coverage. Also for the availability and integrity, the same airports above latitude of 34° respect the ICAO requirements (99.99 % for both horizontal and vertical component), however it is not the case for the airports below 34°.

The main conclusions drawn from analyze carried out and to answer our research questions are as following:

- ***“The EGNOS service for civil aviation is guaranteed in area above latitude of 34°, the level guaranteed by the EGNOS system in this area can be used by aircrafts in all flight phase approach until APV I***”.
- ***“By analyzing EGNOS performance in some points in the extreme edge of the coverage area, we can see that the model is not stable in this zone. As***

a suggestion, aircraft used totally EGNOS for navigation must respect a safety margin for not being in critical situation".

- ***"From the two precedent points, in addition to all results carried out in this work, we can conclude that, despite that all sites are in the coverage area of EGNOS and the precision are well improved, but for civil aviation the service is not guaranteed in some sites; this is explained by enlarge distance to the RIMS stations".***
-

Recommendation

As a recommendation, the addition of RIMS stations in North Africa (Exactly in South Algeria) will certainly improve the geographic distribution of RIMS stations and will improve the homogeneity of the network for the EGNOS system. These sites could significantly extend availability performance far beyond the regions of the original reference network.

DOI: https://doi.org/10.15394/ijaaa.2020.1479

References

Beldjilali, B.,& Benadda, B. (2017). Real time software based L1 C/A GPS receiver.*Seminar on Detection Systems Architectures and Technologies (DAT)* doi:10.1109/DAT.2017.7889184

Ciollaro, M. (2008).*GNSS multi system integrity for precision approaches in civil aviation*(Doctoral dissertation). Naples, Italy: University of Naples.

EGNOS. (2020). *User support*. Retrieved from https://egnos-user-support.essp-sas.eu/new-egnos-ops

EMS. (2004).*European space agency: EGNOS message server: User interface document*. GNSS-1 Project Office. Ref: E-RD-SYS-E31-011-ESA.

Eurocontrol. (2003). *Technical notes on SBAS*. Doc. No.: PEG-TN-SBAS, Issue: I, Project: Pegasus.

Giuseppe, M. (2016). *Processing and integrity of DC/DF GBAS for CAT II/III operations*(Doctoral dissertation).Toulouse, France: University of Toulouse.

International Civil Aviation Organization. (2005). *Global navigation satellite system(GNSS) manual*.Doc 9849AN/457.

International Civil Aviation Organization. (2012). *Global navigation satellite system (gnss) implementation strategy for the ICAO Africa-Indian ocean (afi) region*. APIRG/18 Meeting, Authority of the Secretary of APIRG.

Lahouaria, T., Kahlouche, S., Benadda, B., &Beldjilali, B. (2020). Improvement of single-frequency GPS positioning performance based on EGNOS corrections in Algeria. *Journal of Navigation*, 1-15. doi:10.1017/S037346331900095X

Lyon, A., Guida, U., Fernandez, J.,&Perrin, O. (2006). EGNOS: A step closer to operational qualification.*Proceedings of the 19th International Technical Meeting of the Satellite Division of the Institute of Navigation* (ION GNSS 2006), pp. 906-912.

Oday, H. (2011): *WAAS integrity investigation for Canadian latitudes*. Retrieved from http://www.geomatics.ucalgary.ca/graduatetheses

Roturier, B., Chatre, E.,&Ventura-Traveset, J. (2006). The SBAS integrity concept standardised by ICAO-application to EGNOS. *Navigation-Paris-* (1303).

Sanz, J., Rovira-Garcia, A., Hernandez, M., Juan, J., Ventura-Traveset, J., Lopez, C.,&Hein, G. (2012). *The ESA/UPC GNSS-Lab Tool (gLAB): An advanced educational and professional package for GNSS data processing and analysis*. 6th ESA Workshop on Satellite Navigation Technologies Multi-GNSS Navigation Technologies. Proceedings. doi:10.1109/NAVITEC.2012.6423100.

Sauer, K. (2003).*Integrated high precision kinematic positioning using GPS and EGNOS observation*(Doctoral dissertation).London, England: University of London Department of Civil and Environmental Engineering Imperial College London.

Shiun, S. (2003). *Aircraft landing using a modernized Global positioning system and the Wide area augmentation system* (Doctoral dissertation).Palo Alto, CA: Stanford University.

Simon, J. Ostolaza, J. Moran, J. Fernandez, M. Caro, J. &Madrazo A. (2012). Performance of dual-frequency multi-constellation SBAS: Real data results with operational state-of-the-art SBAS prototype. *Proceedings of the 25th International Technical Meeting of the Satellite Division of the Institute of Navigation ION GNSS*.

Walter, T., Blanch, J., &Enge, P. (2010). Coverage improvement for dual frequency SBAS. *Proceedings of the International Technical Meeting of The Institute of Navigation*, San Diego, CA, pp. 344-353.*The Institute of Navigation, San Diego*, CA, pp. 344-353.