UPDATE ON AUGMENTED NAVIGATION FOR AFRICA(ANGA)

by

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ABSTRACT

SBAS-supported operations for navigation in aviation provide more safety, enhanced navigation effectiveness, and contribute to reducing operational costs for airlines, while improving the accessibility to airports and green environment in terms of reduced carbon footprints.nSBAS therefore stands out as an enabling technology, providing real opportunity for the development of aviation sector in Africa. Airlines should therefore stay abreast of its developments and be prepared to adjust their innovation strategies towards its use in Africa as it aligns with African Union's (AU) agenda for Single African Air Transport Market (SAATM), Nigerian Communications Satellite Ltd, Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) and Partners are poised for the provision of SBAS services in Western and Central Africa, with a potential for extension in other regions multilaterally and collaboratively for the entire continent and surrounding waters. Promoting acceptance and adoption of SBAS services in Africa's aviation sector as a means of navigation continent-wide is one of the recommendations and takeaways made during Continental Cost Benefit Analysis (CBA) of implementation of SBAS in Africa organized in May, 2022 by African Union Commission (AUC) and African Civil Aviation commission (AFCAC); specialized arm of African Union (AU) on aviation matters. We emphasized the need for specialized institutions and partners in Africa to undertake capacity building and awareness activities for the applications of SBAS in aviation and non-aviation sectors.

The paper highlights impacts and benefits of SBAS Services in Africa based on pilot projects conducted in Togo, Cameroun, Congo and Nigeria meant to accelerate and encourage stakeholders to accelerate deployment of the technology in both aviation and non-aviation sectors. The last part of the paper describes real time DFMC SBAS testbed that has been set up in view of the demonstration that started this Spring in 2023. The testbed use ANGA signal broadcast by ASECNA's demonstration infrastructure to produce both valuable demonstration L1 and L5 augmentation messages. The Signal in Space (SiS) is broadcasted by NigComSat1-R GEO satellite. To our knowledge, this will be the first DFMC SBAS demonstration SIS to be broadcasted through NIGCOMSAT-1R SBAS GEO in Africa, and one of the first in the world.

NIGCOMSAT LTD

- The Nigerian Communications Satellite LTD (NIGCOMSAT) is a Government owned Enterprise established 4th April, 2006.
- Under the supervision of **Federal Ministry of Communications, Innovation and Digital Economy.**
- We provide **innovative** and **cutting-edge** satellite communications solutions operating and managing a geostationary communication satellite-NigComSat–1R.
- A **cooperative agreement** with National System of Satellite Communication and Broadcast of Republic of Belarus; owners of Belintersat-1. We provide Carrier Spectrum Management (CSM) for the Eastern European Country satellite.
- We have secured Federal Executive Council Approval to commence design, manufacture, integration, test and launch of NIGCOMSAT-2; a High Throughtput Satellite (HTS) on 6th July, 2022.

ASSETS OF NIGCOMSAT LTD

- **NIGCOMSAT-1** was launched 13th May, 2007.
- **NIGCOMSAT-1** was de-orbited on 10th November, 2008
- **NIGCOMSAT-1R** was launched on 19th December, 2011
- **NIGCOMSAT-1R**, is the insurance replacement for **NIGCOMSAT-1**
- Quad-band (Ku, Ka, C and L Bands) for Telecommunications, Broadcast and Navigation Services
- At Geostationary Orbit (42.5°E)
- Launch mass of 5,100 kg
- Service Life > 15 years

NIGCOMSAT LTD

Our vision:

To be the **leading satellite communications solutions provider** in Nigeria and Africa.

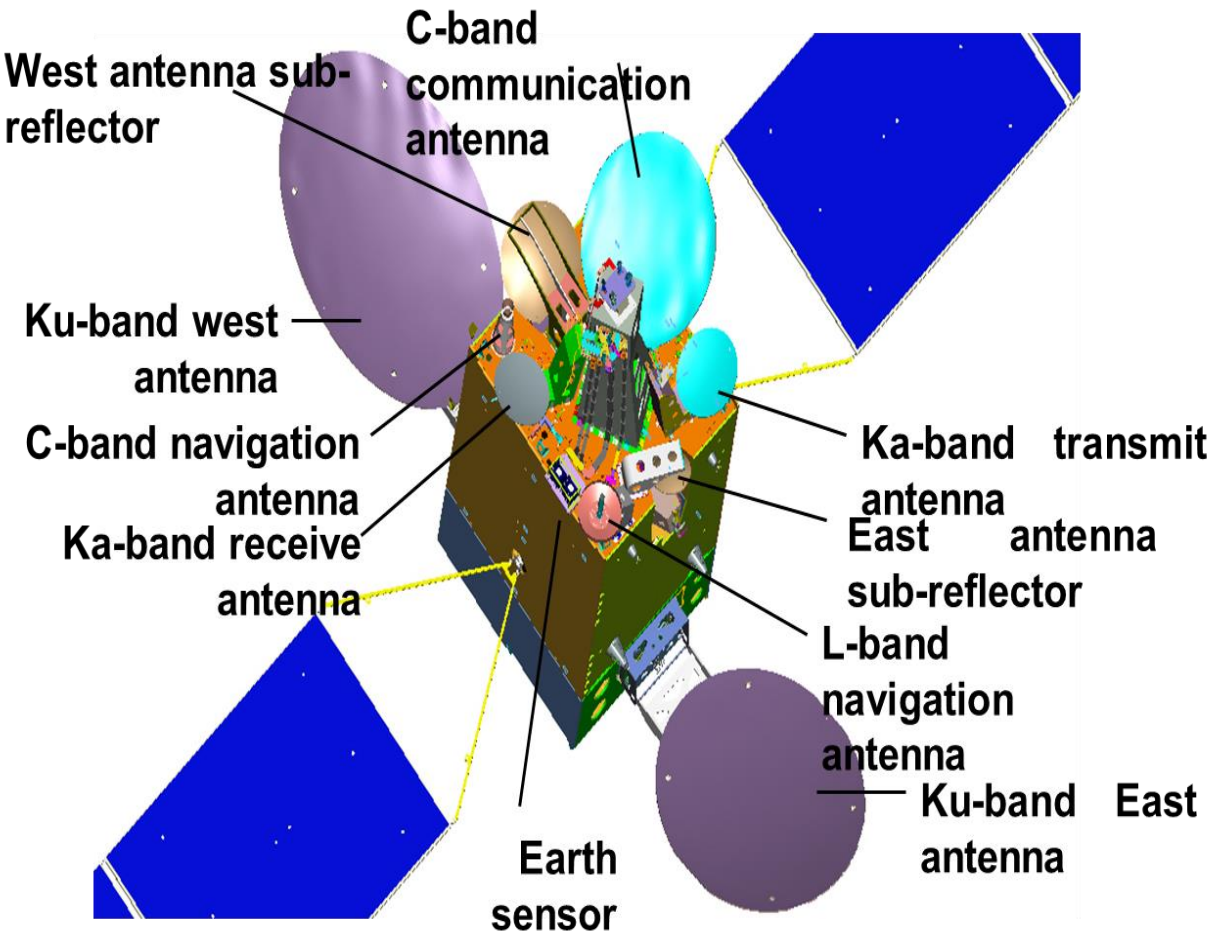
Our mission:

To provide **seamless connectivity and satellite communication** through **innovation**.

Our core values:

- Leadership
- Innovation
- Integrity
- Professionalism
- Customer-Centric

NigComSat-1R



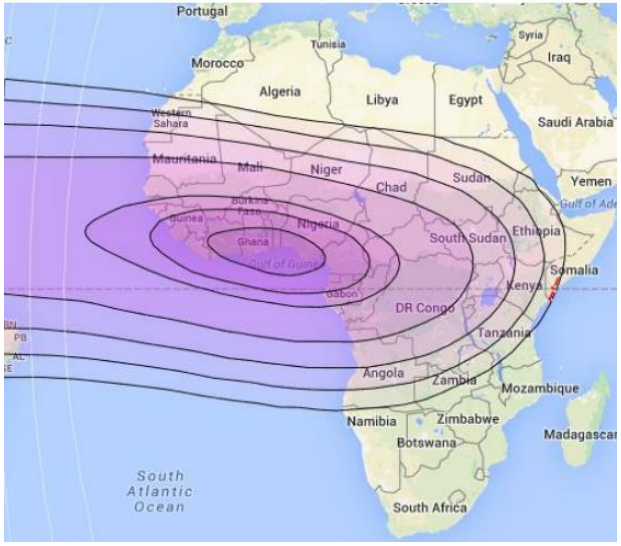
Location: 42.5 Degrees East.

The communication Payload comprises of **28 transponders:**

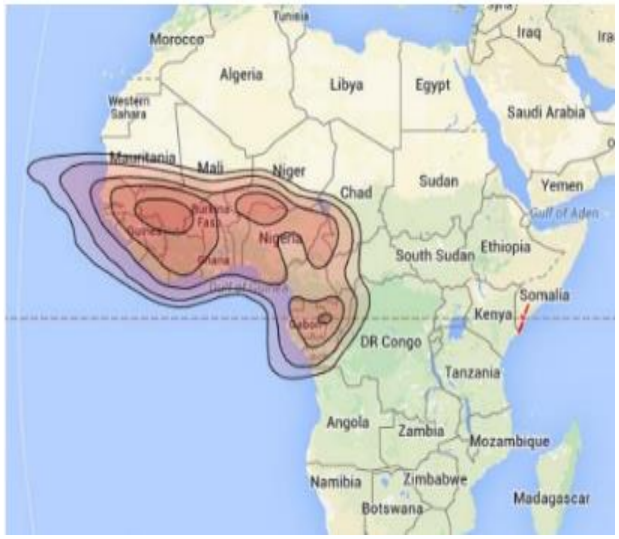
- **C – band** 4 transponders
- **Ku – band** 14 transponders
- **Ka – band** 8 transponders
- **L – band** 2 transponders

NigComSat-1R Satellite Foot Print

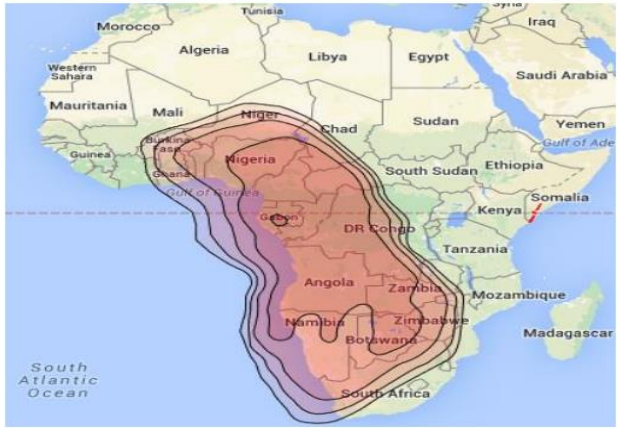
C-Band Ecowas 1 beam



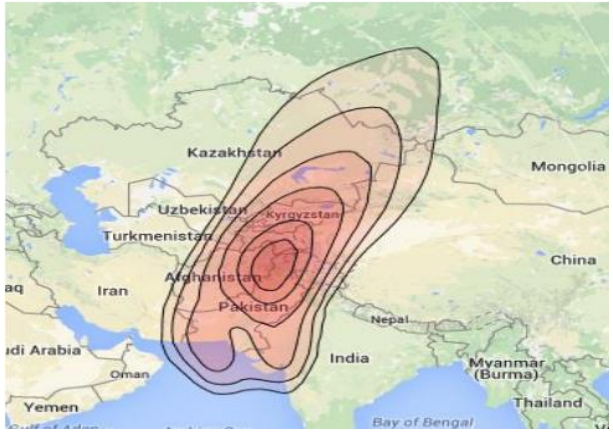
Ku-Band Ecowas 1 beam



Ku-Band Ecowas 2 beam



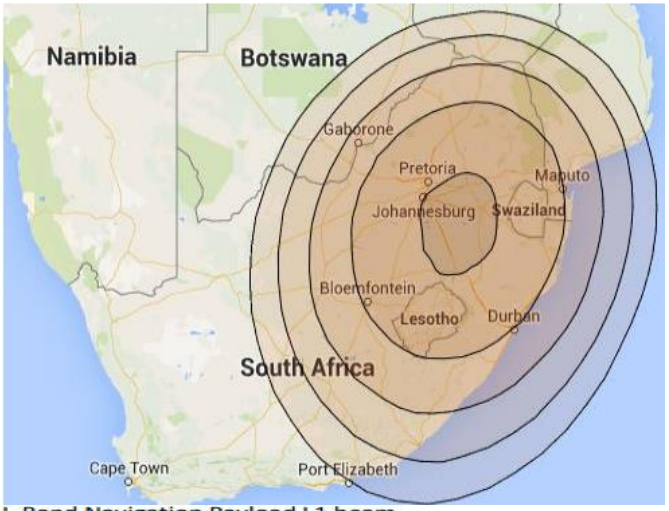
Ku-Band Asian (Kashi) beam



NigComSat-1R Satellite Foot Print

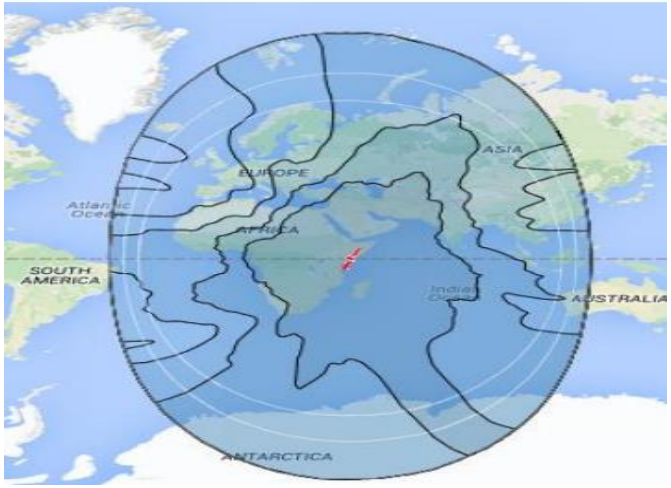
Ka-Band Nigeria Spot beam

Ka-Band South Africa Spot beam



Ka-Band Europe Spot beam

L-Band Navigation Payload L1 beam



NIGCOMSAT-1R as a Hybrid Satellite

- NIGCOMSAT-1R is a hybrid satellite with a Navigation (L-Band) payload for a Space Based Augmentation System meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS).

Africa's SBAS: Africa's Satellite Based Augmentation System.

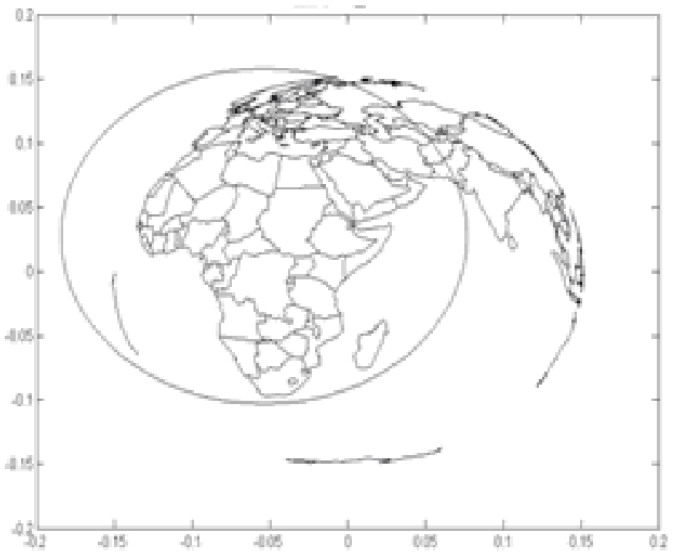
- **SBAS compensates for errors of GNSS in terms of Integrity and Accuracy**
- Provide **Continuity and Availability**
- Makes differential corrections and then broadcasts the integrity messages as an augmented signal of the original GNSS Signal in Space (SiS) through Geostationary satellite ***(Our NigComSat-1R)*** for a wide coverage
- Conforms to **global standard to enhance Interoperability, Compatibility and Zero Interference.**

NIGCOMSAT-1R NAVIGATION PAYLOAD

- *10MHz ultra stable crystal oscillator was used for the L-band payload to meet the performance requirements of frequency conversion stability and accuracy.*

10MHz Master Oscillator

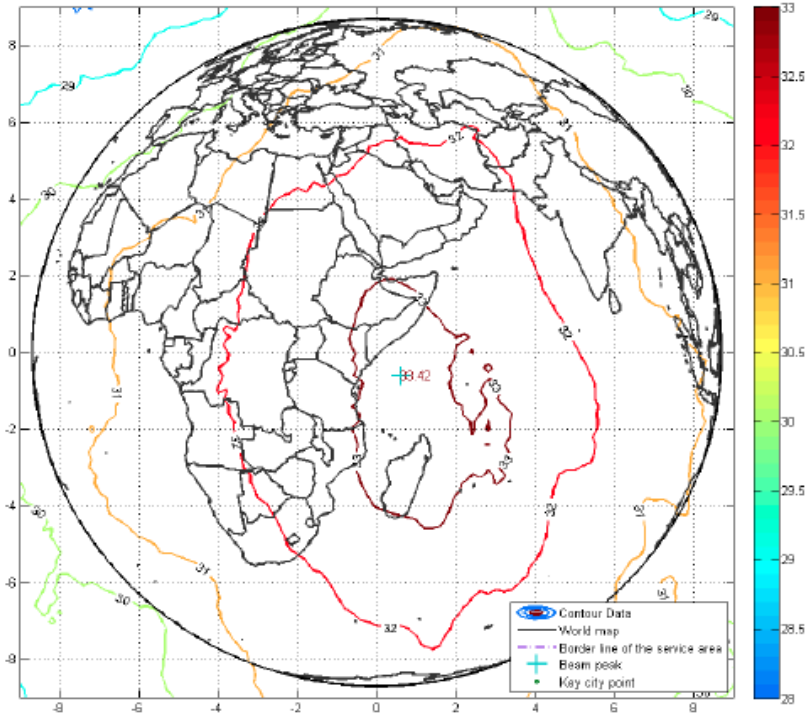
NIGCOMSAT-1R NAVIGATION PAYLOAD



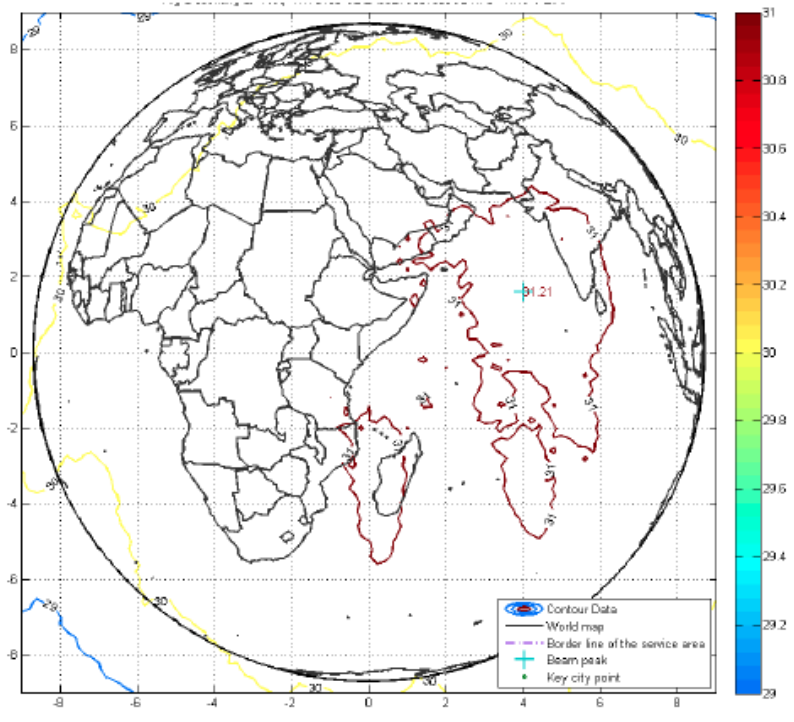
The Uplink coverage beam of NIGCOMSAT-1R Geo-Navigation Satellite using C –Band Horn Antenna.

NIGCOMSAT Master Control Station with C-L Band Antenna Systems

NIGCOMSAT-1R NAVIGATION PAYLOAD



The downlink coverage beam of NIGCOMSAT-1R Geo-Navigation Satellite on L1 Frequency



The downlink coverage beam of NIGCOMSAT-1R Geo-Navigation Satellite on L5 Frequency

Channel	Frequency (MHz)	Polarization	Bandwidth (MHz)
L1-Downlink	1575.42	RHCP	4
L5-Downlink	1176.45	RHCP	20

MULTILATERAL COOPERATION TO DRIVE ACCEPTANCE AND ADOPTION OF SBAS IN AVIATION AND NON-AVIATION SECTOR IN AFRICAN CONTINENT.

There is socio-economic benefit of SBAS technology in Africa as validated by business viability assessment of NIGCOMSAT project, validated by stakeholders as it concerns reviews conducted recently on huge GNSS/SBAS infrastructural gap in Africa and as validated by the Continental Workshop on Cost Benefit Analysis (CBA) for SBAS Implementation in Africa held on 30-31 May, 2022 at Kigali and thus need for national, multilateral, regional and continental body cooperation with aviation stakeholders in the forefront to galvanize efforts in the implementation of continent-wide SBAS system.

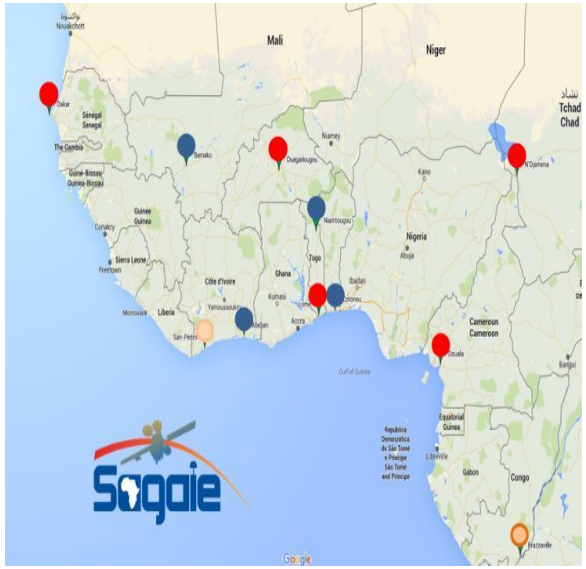
Outcomes, comments and recommendations during the CBA workshop were submitted to African Union policy organs for considerations.

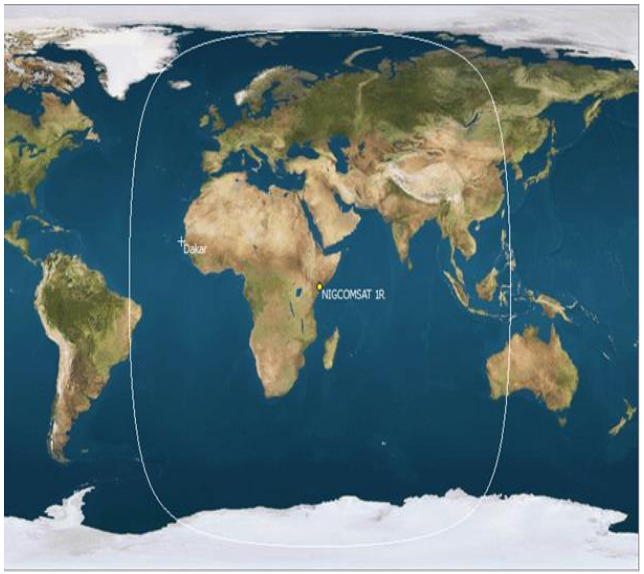
NIGCOMSAT Ltd on it's part with stakeholders' support (ASECNA, Thales Alenia Space (TAS), SatNav JPO etc continued with awareness /sensitization with real SBAS demonstration in Aviation and non-aviation sectors.

FIELD DEMONSTRATION TO DRIVE ACCEPTANCE AND ADOPTION IN AFRICA.

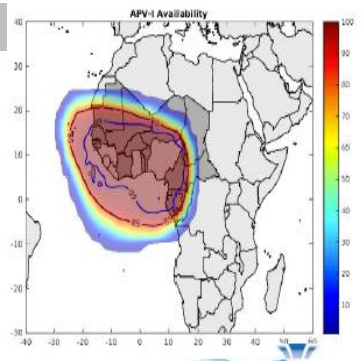
INFRASTRUCTURE DEPLOYED FOR THE DEMO

- ✓ Extended SAGAIE GNSS stations.
- ✓ Representative system prototype deployed in Dakar.
- ✓ Uplink station in Abuja and NigComSat-1R Navigation Payload





FIELD DEMONSTRATION TO DRIVE ACCEPTANCE AND ADOPTION IN AFRICA.



with ThalesAlenia Space

NIGCOMSAT

ATR 42-300

Platero

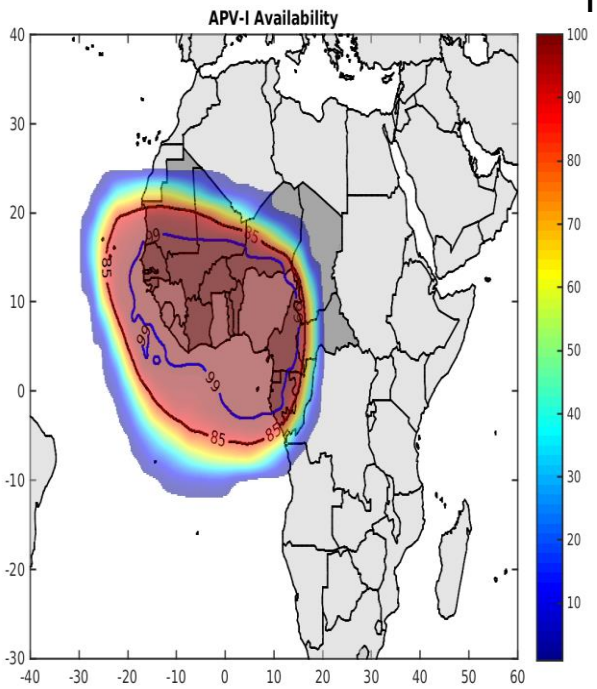
Flight Validation Platform for PBN Airplane and Helicopter procedures

with PildoLabs move smart

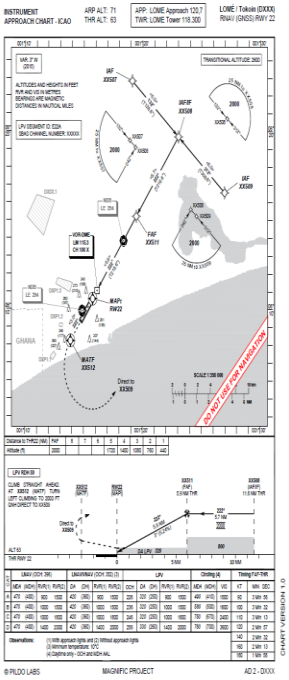
FIELD DEMONSTRATION TO DRIVE ACCEPTANCE AND ADOPTION IN AFRICA.

We began broadcast of a SBAS (Satellite-Based Augmentation System) signal over Africa & Indian Ocean (AFI) region since September 2020, providing the first SBAS open service in this part of the world via NIGCOMSAT-1R Satellite

RWY 22 at Lome International Airport, TOGO



APV-1 availability (05/10/2020)



OPERATIONAL BENEFITS OF SBAS

- Approach with vertical geometric guidance on non-instrumented runways
- Lower minima compared to Non-Precision Approach (NPA)
- Better stability than Instrument Landing System (ILS)
- SBAS performance is not sensitive to temperature fluctuations and has no barometric or temperature limitations.
- Performance not impacted by barometric pressure, temperature fluctuations or barometric mis-setting.
- SBAS provides benefits beyond aviation to all modes of transportation. i.e maritime, railroads, inland waterways etc.
- SBAS provides not just approach capability but en-route capability.
- SBAS does not require the installation or maintenance of ground-based navigation aids or landing systems.

OTHER BENEFITS OF SBAS AS IT CONCERNS IMPROVEMENT OF SAFETY AND REDUCTION IN OPERATIONAL COSTS AND ENVIRONMENT.

- Reduced Controlled Flight into Terrain (CFIT) risk/accident
- Reduced delays, diversions and cancellations due to weather conditions
- Reduced flight times
- Reduced fuel consumption
- Reduced CO2 and Noise emissions
- Reduced Flight crew workload by eliminating RAIM prediction requirements. RAIM=Receiver Autonomous Integrity Monitoring.
- Increases airspace capacity.

FEEDBACK FROM PILOTS ON SBAS FLIGHT DEMONSTRATION CARRIED OUT ON 27TH JANUARY, 2021 AT LOME INTERNATIONAL AIRPORT.

Air Côte d'Ivoire

'SBAS means flight safety through approaches with minima equivalent to ILS CAT-1 everywhere at all times'
Capt. Zouel Bayli

ASKY
The Pan African Airline

'SBAS can revolutionise navigation for the approach phase'
Capt. Patrice Moevi

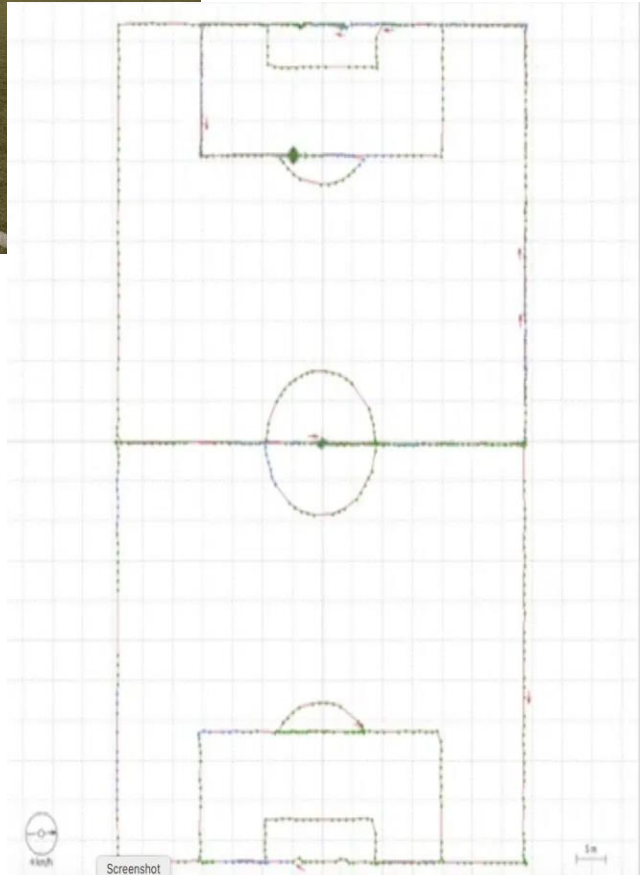
HELICOPTER DEMONSTRATION FLIGHT BETWEEN DOUALA AND KRIBI IN CAMEROON ON 2ND JUNE, 2021

The helicopter demonstration flight was conducted along a low-level, two-way route linking two Points in Space (PinS) approaches to the Douala airport and a point near the oil platforms located on the Kribi coast, both in Cameroon. The flight was performed using a helicopter provided by Heli Union and an SBAS validation receiver from Pildo Labs. The aim of the experiment was to demonstrate the ability of the SBAS system to improve the safety of satellite navigation for helicopters through increased GNSS performance as regards flight safety, efficiency & environmental protection for enroute navigation as well as the landing/approach phase.

SBAS APPLICATION IN NON-AVIATION SECTOR

The SBAS demonstration at Brazzaville, Republic of Congo between July 6 to 9, 2021 was in Non-Aviation sector delivering precise point positioning (PPP) to the centimeter level.

The national stadium Alphonse Massamba-Debat employing a dual-frequency GNSS chipset receiving GPS and Galileo signals. The SBAS demo corrections improved positioning from 3-10metres to centimetric level: 5 cm (East), 6.1 cm (North) and 14.4 cm (Up) with 68% confidence level. To show the improved accuracy, the demonstration device followed the marking of the football stadium.



SBAS APPLICATION IN NON-AVIATION SECTOR

The demonstration with our partners showed the system's ability to achieve positioning accuracy to within centimeters across the entire African continent. A world first, this satellite service paves the way for applications in a broad range of sectors, including precision agriculture, land and maritime transport, rail safety, drone navigation, mapping and surveying, mass-market applications etc.

We also demonstrate a special urgent warning alert service via satellite showing the system's ability to broadcast a warning message via SBAS signal to mobile phones, without requiring a terrestrial network. This service sends a message to the populations concerned, providing information on the type of danger and instructions to be followed. A typical example is warning alert for forest fires, landslide, terror raids etc.

ABUJA SBAS FLIGHT DEMONSTRATION USING BEECHCRAFT KINGAIR 350i WITH 2-DAYS OUTREACH WORKSHOP

SatNav Africa Joint Programme Office · NAMA · NigComSat · NCAA · ANGA Augmented Navigation for Africa

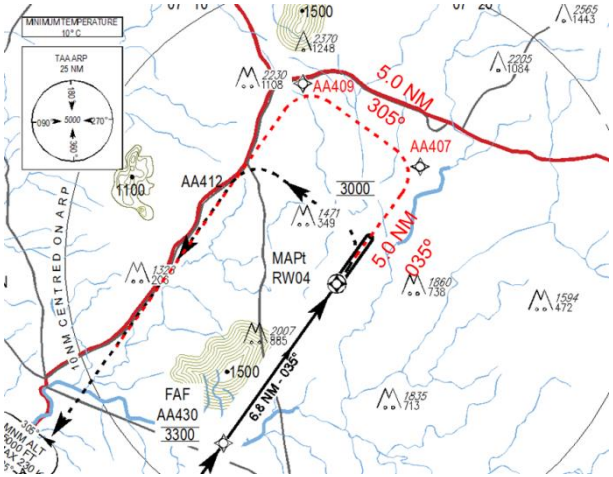
1st February, 2023

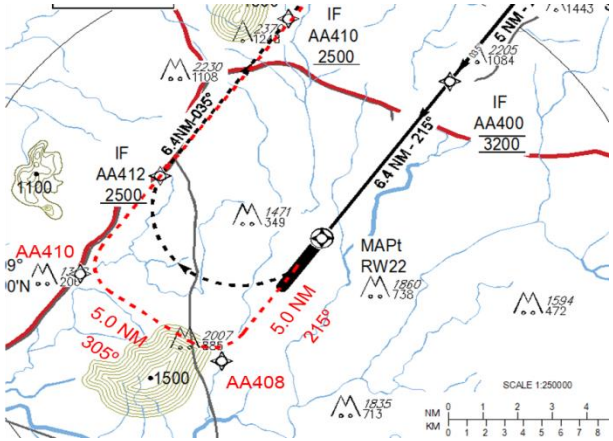
SBAS FLIGHT DEMONSTRATION USING NAMA'S 5- CAA WITH ANGA SIGNAL IN-SPACE(SIS) PROVIDED VIA NIGCOMSAT-1R COMMUNICATIONS SATELLITE

www.satnav-africa.com
www.anga-africa.org
www.nama.gov.ng

search

General aviation terminal of Nnamdi Azikwe international airport, Abuja (Nigeria)



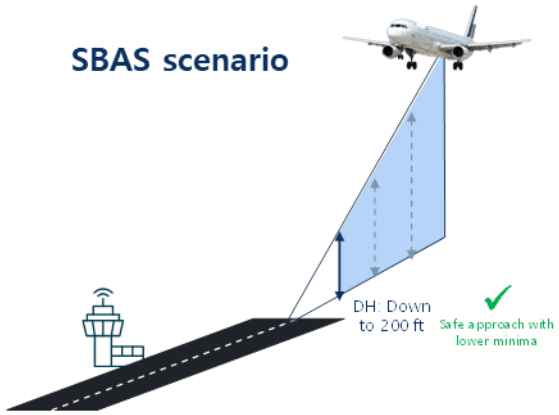


ABUJA SBAS FLIGHT DEMONSTRATION USING BEECHCRAFT KINGAIR 350i WITH 2-DAYS OUTREACH WORKSHOP

SBAS/GNSS APPLICATIONS

AVIATION

- ✓ Exponential development of SBAS services in the world with growing acknowledgement by aeropace users.
- ✓ We are working with relevant stakeholders in the aviation sector on SBAS initiative and program to help define the way SBAS system, should be deployed at best for the needs of the continent progressively.
- ✓ Most aircraft are expected to be SBAS capable from 2030. However, retrofit solutions are currently available at low cost.
- ✓ Reduced and simplified equipment on board aircraft: SBAS airborne equipment acquisition, integration and installation costs are very minimal.
- ✓ Flight crew training costs (≈ **0**).
- ✓ To encourage awareness and adoption of SBAS Technology for Navigation in the Aviation sector, we will continue to showcase its importance with partners to stakeholders by conducting SBAS Flight demonstration across African countries .



KEY RECOMMENDATIONS AND CONCLUSIONS OF THE CBA WORKSHOP SBAS IMPLEMENTATION IN AFRICA.

- In addition to the key non-aviation applications that were considered in the study such as maritime, agriculture, geo-information for survey and civil engineering; stakeholders noted the importance and benefits of SBAS applications in other areas such as urban planning, precise geo-location information, cargo tracking systems, rail & road transport, drone applications etc.
- It is recommended to explore options of involving other stakeholders in related industries and obtain governmental support in providing the basis of SBAS social infrastructure with wide economic benefits.
- Specialized institutions and partners in Africa are encouraged to undertake capacity building and awareness activities for the applications of SBAS in aviation and non-aviation sectors.
- Outcomes, comments and recommendations made during the workshop are to be submitted to African Union policy organs for considerations.

Evaluation of seven market segments resulted in the selection of the Maritime and Agricultural markets as the two sectors to focus immediate CBA analysis

Market segment selection and applications identification in non-Aviation Sector

Criteria: ✓ 2 pts ~ 1 pt ✗ 0 pts

Markets \ Evaluation Criteria	Market size	Market impact	Market conditions	Total	
Maritime	~	✓	✓	5	Priority sectors
Agriculture	✓	✓	~	5	Priority sectors
Drones	✓	✓	✗	4	
Geoinformation	✗	✓	~	3	
LBS	✓	✗	~	3	
Rail transportation	~	~	~	3	
Road and automotive	✓	✗	✗	2	

+ Attractiveness −

In both sectors, SBAS is expected to become a disruptive technology, with a highly positive market impact which can drive their development

Priority sector selection: Maritime and Agriculture

Maritime

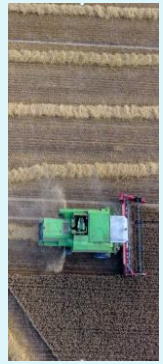
Key market features

- The maritime market is expected to have around **2.9 million SBAS-enabled operations by 2045**
- SBAS is expected to be a **more cost-effective solution than other legacy** GNSS-augmentation **technologies** in the sector (DGNSS beacons)
- The **improved accuracy and integrity** for vessel navigation, positioning, collision avoidance and traffic management will **positively impact both vessel operators and maritime authorities**
- The **market readiness** in the maritime industry is already **high**

Agriculture

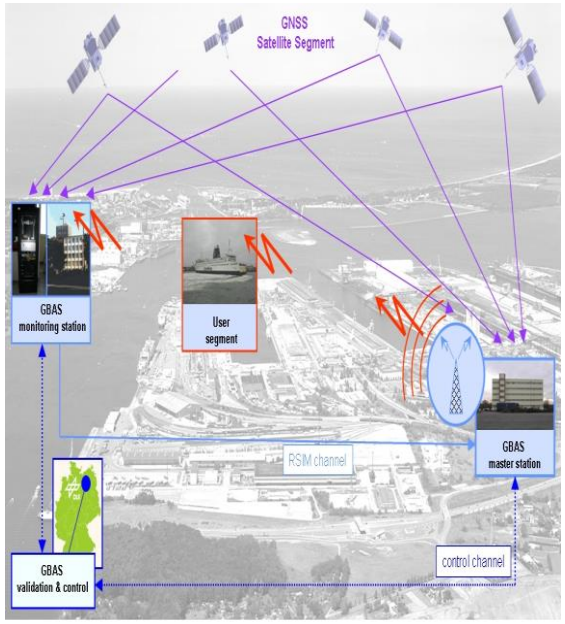
Key market features

- Agriculture represents around **15% of the continent's GDP** and employs two thirds of its population, so it is a critical market in African economy
- The SBAS market is expected to be very large, with **6.1 million operations** with **SBAS-equipped** machinery predicted **by 2045**
- There are various applications, such as tractor guidance and variable rate application technologies for lower-value crops, in which **SBAS can act as an enabling technology and greatly boost the productivity of the sector**



MARITIME

- Ocean navigation
- Port approaches
- Restricted waters guidance
- Auto



APPLICATIONS IN PRECISION AGRICULTURE

Automatic harvesting

Farmland planning

Automatic water spray

High efficiency

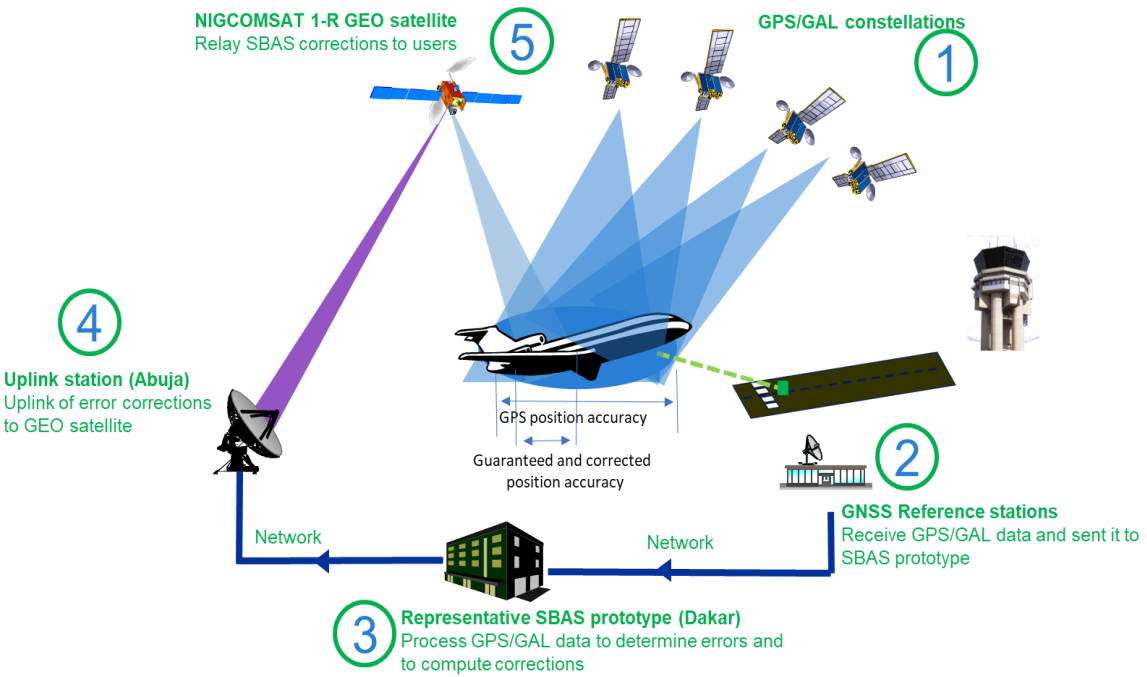
Enhances estimate on output of grains

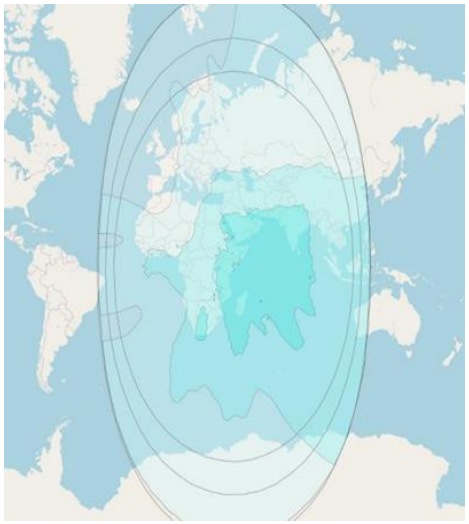
UAV spraying

Agricultural machinery automatic navigation system

DFMC SBAS PROTOTYPE ARCHITECTURE

- **ANGA** programme as initiated by ASECNA, recognised by ICAO is supported by NIGCOMSAT in a bid for continent-wide SBAS system with SBAS testbed providing L1 legacy service since **2021** through **Nigcomsat-1R GEO** satellite.
- This test-bed has been upgraded in **2023** to provide **DFMC test signal.**

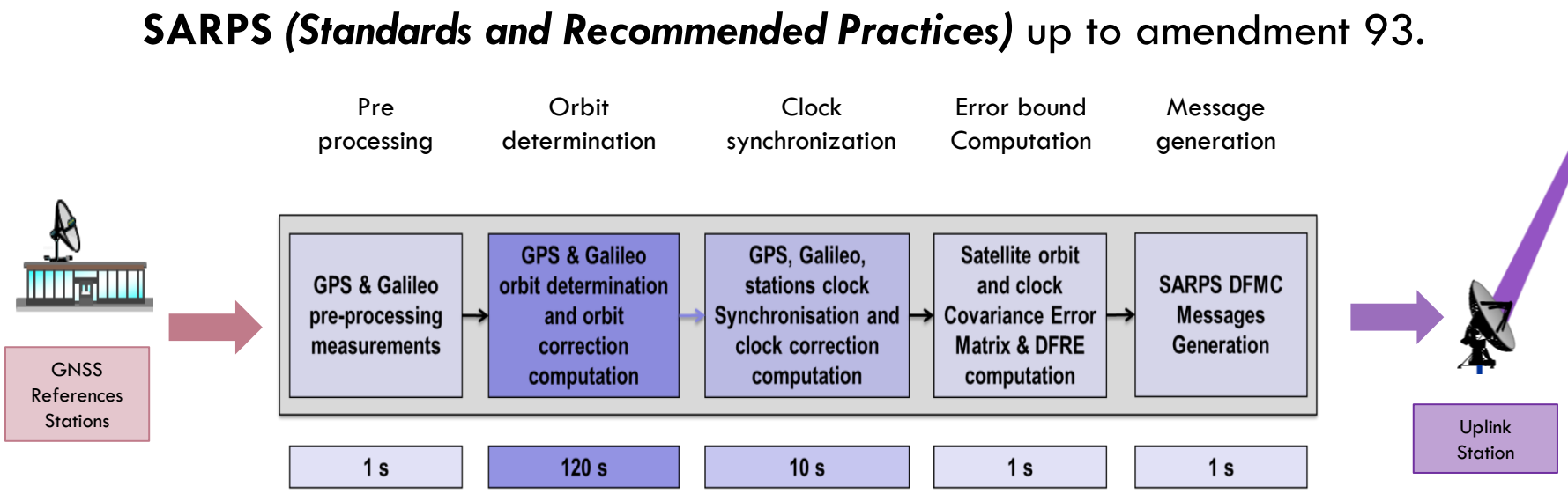




L band navigation payload L5 beam broadcast by NigComSat-1R

DFMC SBAS PROTOTYPE ARCHITECTURE

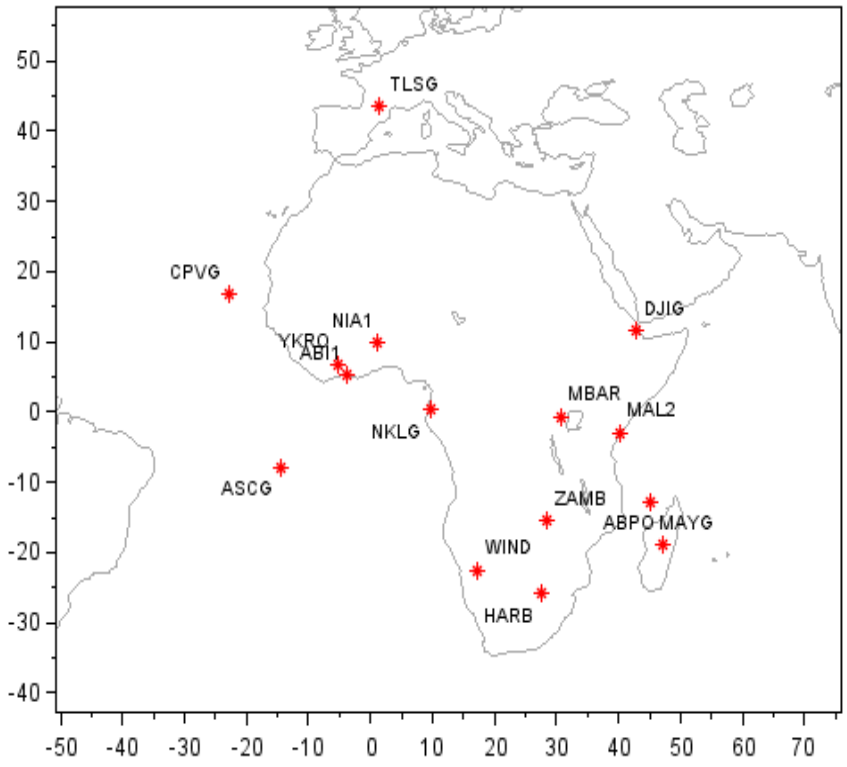
- The **DFMC** navigation kernel is inherited from the legacy algorithms used in the previous SBAS demo project.
- They are composed of 5 main algorithms module, that are pipelined to produce a **DFMC** SBAS navigation message every second:
- The SBAS messages broadcast by the prototype are **compliant to ICAO SARPS *(Standards and Recommended Practices)*** up to amendment 93.



DEFERRED TIME PERFORMANCE EVALUATION

- Prior to its integration in the demonstrator, the DFMC navigation kernel performances have been tested on several **real data, deferred time** scenarios.
- The stations network is composed of 15 stations, similar to the prototype's network.
- Measurements have been collected from different servers
  - **SAGAIE** (Stations ASECNA pour l'Etude de l'Ionosphère Equatoriale)
  - **REGINA** (REseau GNSS pour l'IGS et la Navigation)
  - Complemented by IGS

Both **GPS and Galileo** constellations were augmented



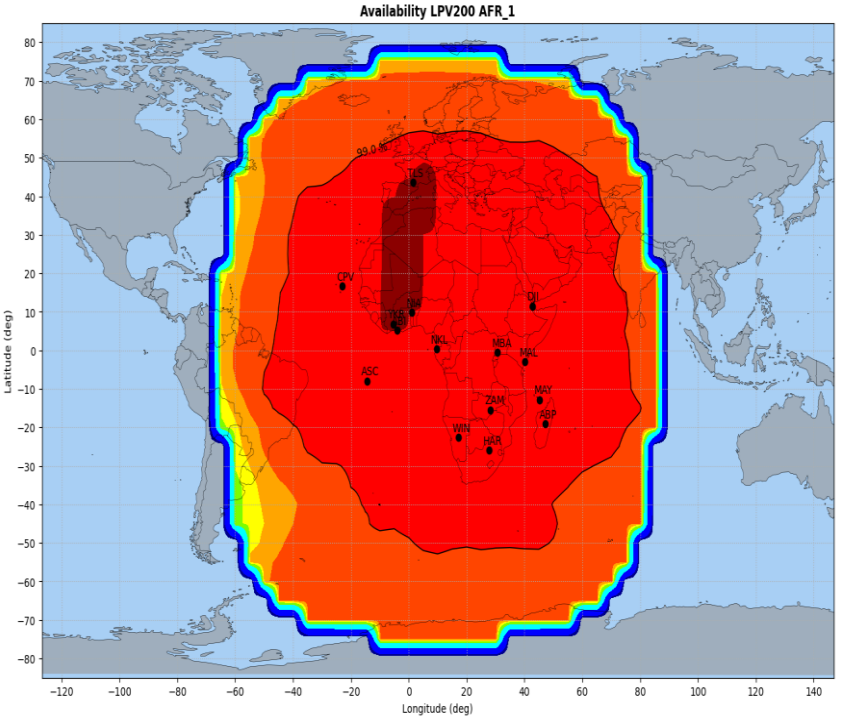
DEFERRED TIME PERFORMANCE EVALUATION ON REAL DATA

- **Availability** and other key performance indicator have been evaluated in the **last 10 days** of 12 day scenarios.
- Both scenarios are identical:
  - Same **15 stations,**
  - Same **15 GPS** + **22 Galileo** satellites
  - Same algorithms and same duration
- Only the initial date differs
  - **AFR_1** scenario, from 2021-12-14T00:00:00 to 2021-12-26T00:00:00, **with low ionospheric activity,**
  - **AFR_2** scenario, from 2022-03-06T00:00:00 to 2022-03-18T00:00:00, **with high ionospheric activity**

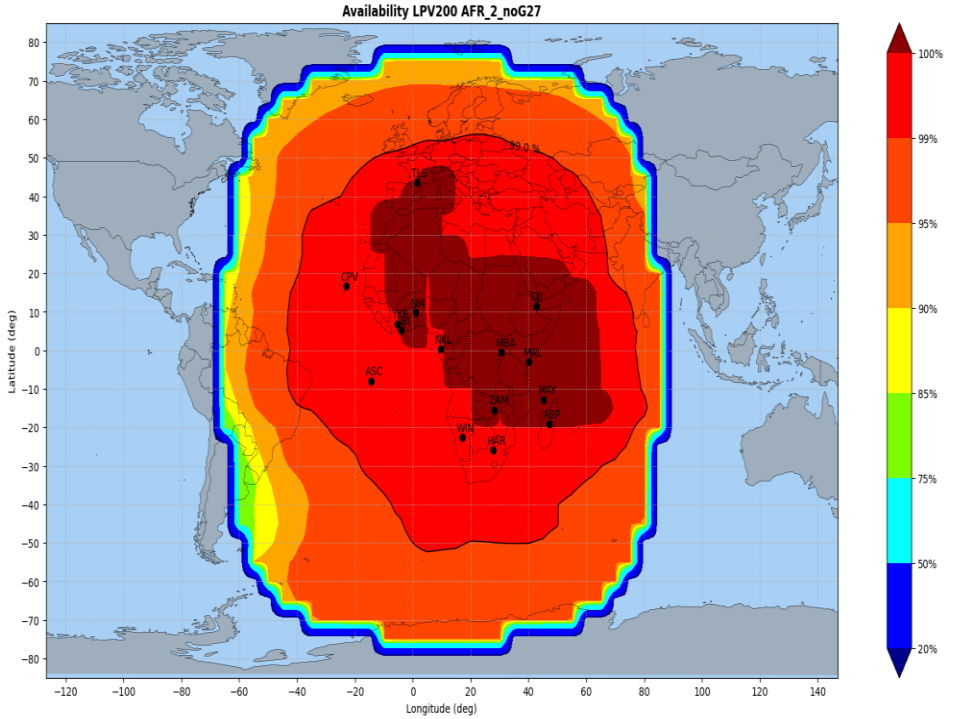
DEFERRED TIME PERFORMANCE REAL DATA EVALUATION

- **Availability Performances on AFR_1 & AFR_2**
- LPV200 (VPL < 35m) service covers the **entire African continent in both low and high ionospheric activity:**

AFR_1, December 2021 low ionospheric activity



AFR_2, March 2022 high ionospheric activity



DEFERRED TIME PERFORMANCE EVALUATION

- The performance assessment on non-real time, real data scenarios shows a **good maturity level** of its algorithms, and a **good performance level**/

- **Pseudorange Accuracy performances**

- GPS and Galileo satellite orbit and clock SREW << 1m:
  - GPS satellites: SREW = 0.8m @ 95%
  - Galileo satellites: SREW = 0.4m @ 95%

"SREW": Satellite Residual Error Worst.

The "Orbit and Clock SREW" represent the non-modeled orbit and clock residual, after SBAS corrections, projected at worst user location.

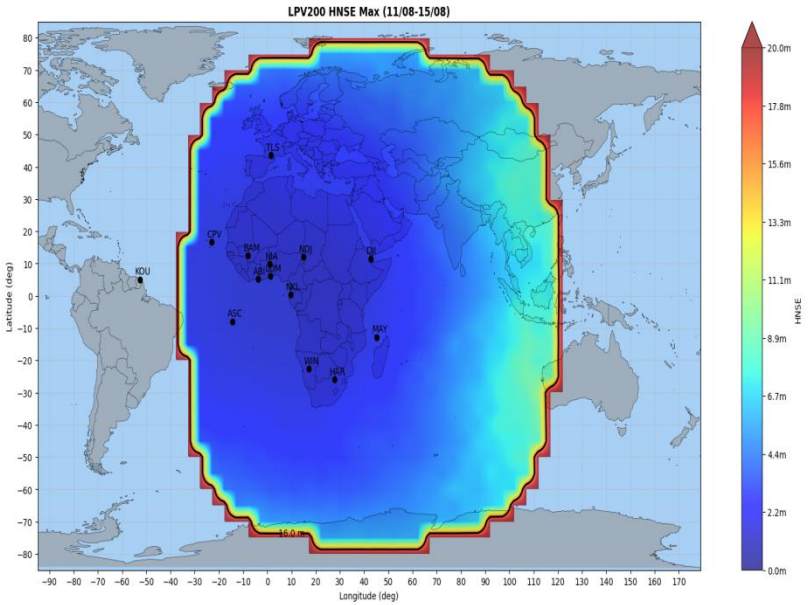
- **Integrity performances**

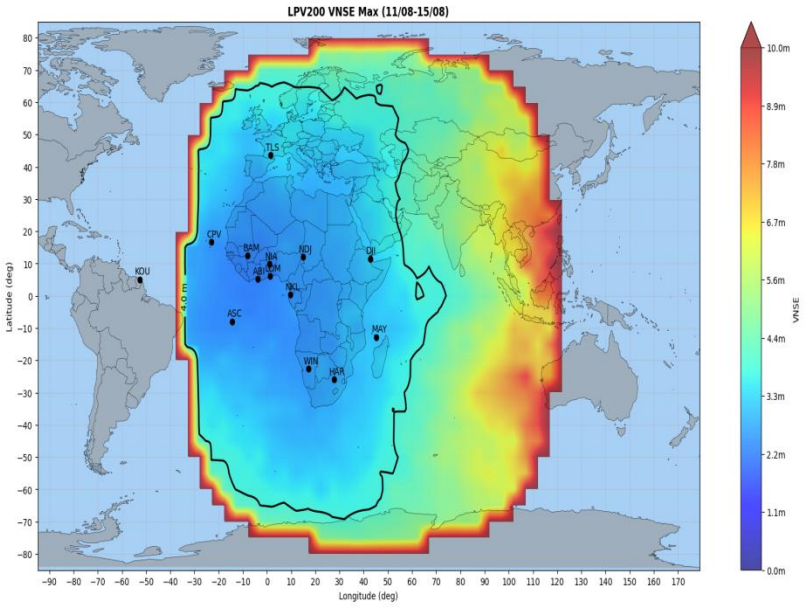
- For both scenario, **integrity** in the pseudorange domain **is respected** with **safety index below 3.7** for both GPS and Galileo satellite constellations.

$$SFI = \frac{SREW}{\sigma_{DFRE} \cdot \delta DFRE}$$

DFMC SBAS PROTOTYPE PERFORMANCE ANALYSIS

- The DFMC SBAS prototype data has been collected and analysed from **August 11th to August 15th.**
- **Position Accuracy Performance**
- The Navigation System Error (NSE) are compatible with LPV200 service
  - The horizontal NSE is **largely below 20m** in all the GEO broadcast area
  - The Vertical NSE is **below 4m** on the entire Africa.

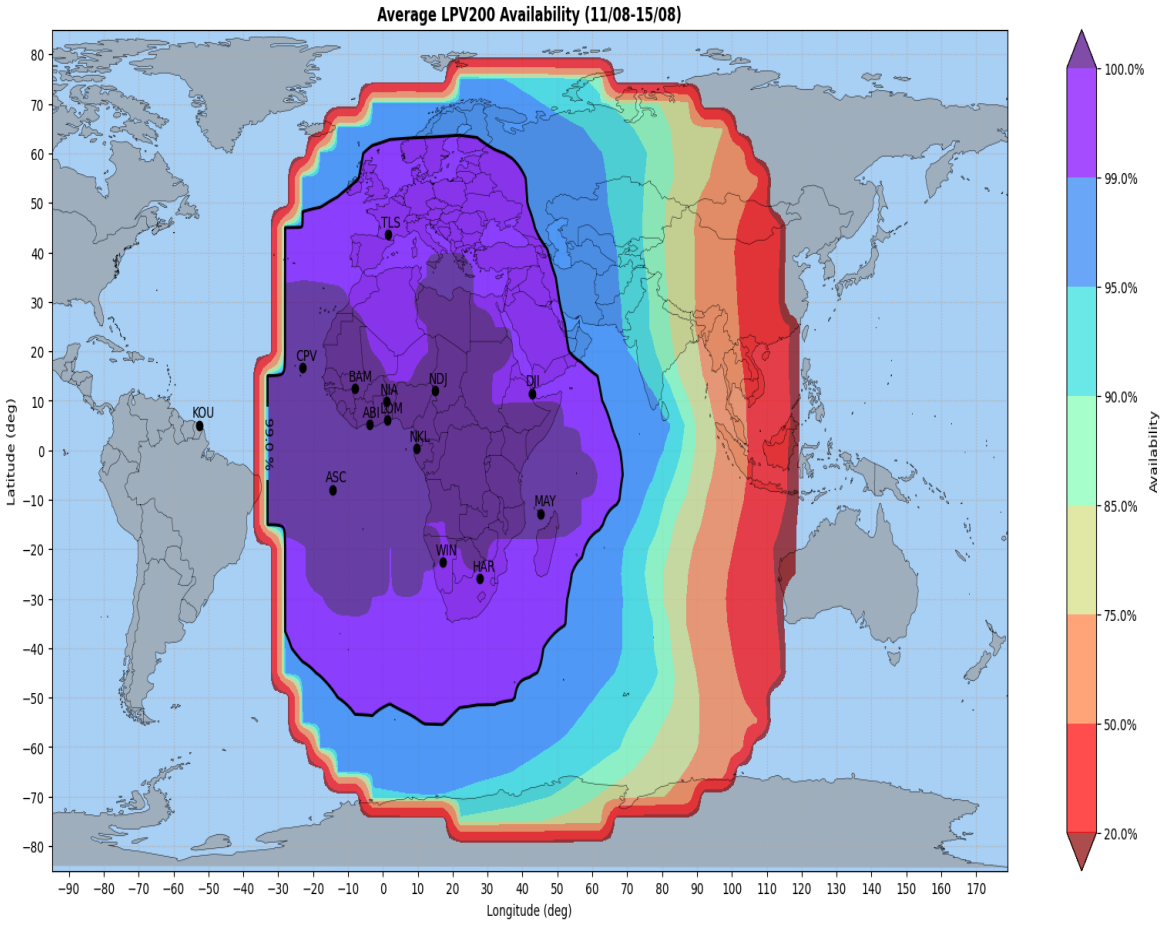




DFMC SBAS PROTOTYPE PERFORMANCE ANALYSIS

- **Global Availability performances**
  - **LPV200** service, combining both protection levels requirements, and NSE requirements, largely covers Africa and the South of Europe:
- **Integrity Performances**
  - The integrity performance, given by the safety index, is **even better** than with the deferred time scenarios:
    - GPS satellites: **SFI < 2.3**
    - Galileo satellites: **SFI < 2.0**

$$SFI = \frac{SREW}{\sigma_{DFRE} \cdot \delta DFRE}$$



DFMC SBAS PROTOTYPE: RESULTS AND PERSPECTIVES

Results

- Taking advantage of the already existing legacy SBAS demonstration service started jointly by NIGCOMSAT and ASECNA in 2021, the DFMC kernel has been successfully integrated into the ANGA testbed.
- The DFMC signal is available from June 2023 providing very good performances.

Perspective

- To improve the signal in space availability
- To improve the navigation kernel pre-processing of measurements, so as to enhance the robustness in view of African environmental conditions.

CONCLUSION

SBAS adoption in Aviation sector in Africa aligns with the Single African Air Transport Market (SAATM) agenda of African Union (AU); a flagship project of the AU agenda 2063 to advance the liberalization of civil aviation in Africa through a unified sky and acting as an impetus to the continent's economic integration agenda.

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