

On the development of multi-instrument arrays for ionospheric studies over West Africa to support the implementation of SBAS

O. K. Obrou
Université Félix Houphouët Boigny (Ivory-Coast)

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Introduction

- ① Navigation and positioning is a key component of the Africa's space programme adopted by the African Union (AU) Member States to support the implementation of the Agenda 2063. It includes GNSS which supports gate-to-gate navigation and used for Performance-Based Navigation.
- ② The navigation strategies developed of the continent under the aegis of ICAO (International Civil Aviation Organization) provide a roadmap for the development of GNSS.
- ③ Satellite Based Augmentation System (SBAS) is a key element of these strategies to support all phases of flight from en-route down to precision approaches, which can be deployed at all runways ends, including in remote areas, without the need for local infrastructure.
- ④ SBAS operations enhance flight safety and efficiency, while reducing its environmental impact, and improves airports accessibility. They contribute to the objectives of the Single African Air Transport Market (SAATM).

Definition

SBAS - The Satellite Based Augmentation System

SBAS stands for satellite based augmentation system.

- It uses additional messages from GEO satellite broadcast to support signal augmentation.
- It makes additional satellites and signal corrections available at regional or continental level to end users, therefore improving integrity, accuracy, availability, and continuity of existing global navigation systems known as “core navigation constellations” (i.e. GPS, GLONASS, Galileo, Beidou)

SBAS's main application is in aviation industry, improving safety during approach and landing phases, and as well as in other domains that require improved accuracy and/or integrity (e.g., agriculture, maritime, land management, road etc.)

Existing SBAS

Several countries and regional organization have implemented their own Satellite-based Augmentation System.

- USA: Wide Area Augmentation System (WAAS)
- EU : European Geostationary Navigation Overlay Service (EGNOS)
- Japan: Michibiki Satellite Augmentation System (MSAS)
- India: GPS-aided GEO-Augmented Navigation (GAGAN)
- China: BeiDou SBAS (BDSBAS) (in development)
- South Korea: Korea Augmentation Satellite System (KASS) (in development)
- Russia: System for Differential Corrections and Monitoring (SDCM) (in development)
- ASECNA: Augmented Navigation for Africa (ANGA) (in development)
- Australia and New Zealand: Southern Positioning Augmentation Network (SouthPAN) (in development)

SBAS indicative aeria

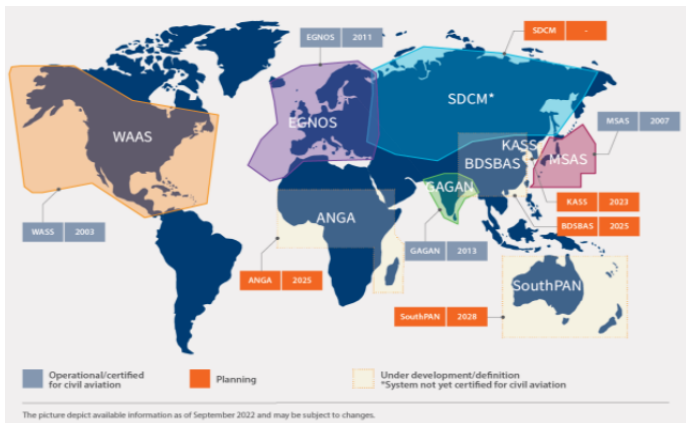
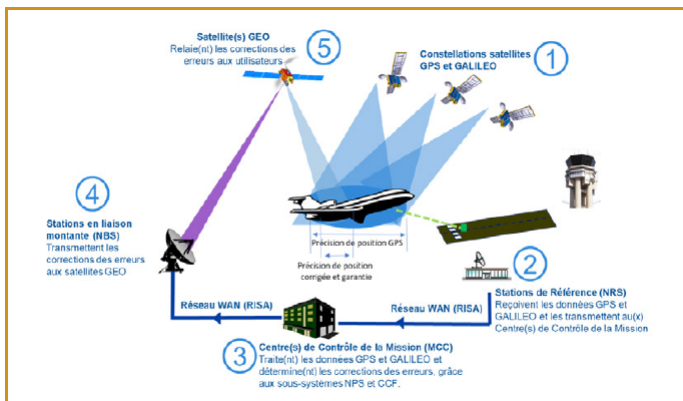


Figure: Courtesy of EUSPA

All of these systems are **compatible and Interoperable**

SBAS Architecture

It has a network of reference stations to observe GNSS performance, a communication network to transfer data to and from the different elements, a master station to aggregate the data and decide what information to send to the users, and an uplink station to send the data to communication satellites so that it can be relayed to the user.



GNSS infrastructure in support ANGA

SAGAIE Stand for **Stations ASECNA GNSS pour l'Analyse de l'Ionosphère Equatoriale** (ASECNA GNSS Stations for the Analysis of the Equatorial Ionosphere). The data collected have been used by Tales for the preliminary studies in the framework of the ANGA.



The area covered by the GEO satellite NigComSat-1R. In support of the preliminary test.

?

WHAT ARE THE INFRASTRUCTURES IN THE REGION

The West African region

- The region of West Africa is located west of north-south axis lying close to 10° east longitude.
- The Atlantic Ocean forms the western as well as the southern borders of the West African region.
- The northern border is the Sahara Desert, with the Ranishanu Bend generally considered the northernmost part of the region.
- The eastern border lies between the Benue Trough, and a line running from Mount Cameroon to Lake Chad.



Figure: ECOWAS members states

Colonial boundaries are still reflected in the modern boundaries between contemporary West African states, cutting across ethnic and cultural lines, often dividing single ethnic groups between two or more states

The first IGS stations in west Africa

Location	Country	Year	Partners
Cotonou	Benin	2008	UNAVCO-JPL/IGN
Dakar	Senegal	2011	CDDIC/DTGC
Toro	Nigeria	2011	UNAVCO-JPL/CGGN
Yakro	Côte d'Ivoire	1999	UNAVCO-JPL/CCT-BNETD



Partners

- 1 CCT-BNETD : Centre de Cartographie et de Télédétection
- 2 CGGN : Center for Geodetic and Geodynamics of Nigeria
- 3 DTGC : Direction des Travaux Géographiques et Cartographie

Observations

- The raw data are on RINEX Format and freely accessible
- Non of the Universities were involved in the project
- All of the stations were established for the Development of GIS and survey
- The station were established through partnership between National institution and International ones

The GNSS stations network in Ivory-Coast

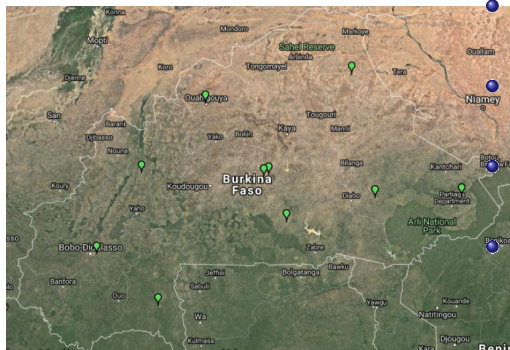
Location	Access	Year	Partners
Abidjan-Cocody	SCINDA	2006	BC/UFHB/CCT-BENETD
Korhogo	Monitor	2017	ESA/UFHB/UGPK
Man	UFHB	2018	UFHB/UMAN
Yakro	IGS	1999	UNAVCO-JPL/CCT-BNETD
Abidjan-Cocody	Not	2014	GLOBEESPACE/CCT-BNETD
Abidjan-Vridi	Not	2015	SEA PORT/CCT-BNETD
Abidjan-Cocody	Not	2018	OXYGEO (PC)
Abidjan-Yopougon	Not	2016	IVOIRTRAVAUX/CCT-BNETD

The CORS network in Benin



- This network is composed of 7 stations
- Data are stored under RINEX Format
- The data are freely accessible via (www.ign.bj)
- The network is managed by the Institut Géographique National (IGN) of Benin

The station network in Burkina Faso



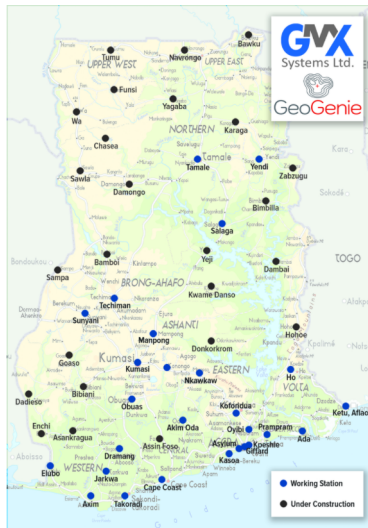
- This network is composed of 9 stations

- Data are stored under RINEX Format

- The data are accessible through an authorization

- The network is managed by the Institut Géographique du Burkina

The station network in Ghana



- This network is composed of 26 stations that are under operation
- Data are stored under RINEX Format
- The data are accessible through an authorization
- The network is owned, maintained and operated by Survey and Mapping Division of Ghana Lands Commission.

The station network in Nigeria

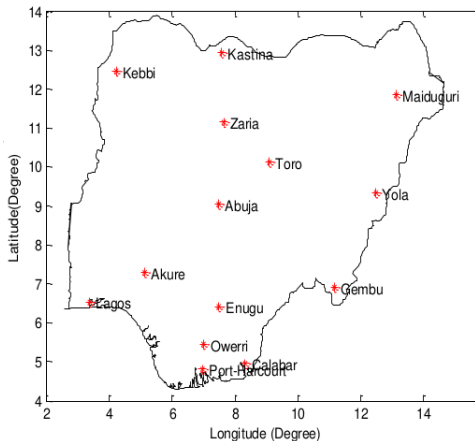
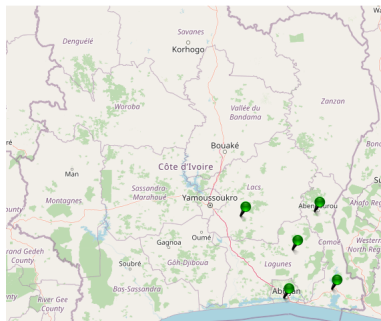


Figure: From Rabiou et al., (2014)

- This network is composed of 15 stations
- Data are stored under RINEX Format
- The data are accessible through an authorization grant by TERONET <https://teronet.nignet.net>
- The network is owned, maintained and operated by Office of Surveyor General of the Federal Government of Nigeria (OSGoF)

The CORS network of Ivory- Coast



- ① ABENGOUROU
- ② ABIDJAN
- ③ ABOISSO
- ④ ADZOPE
- ⑤ DIMBOKRO

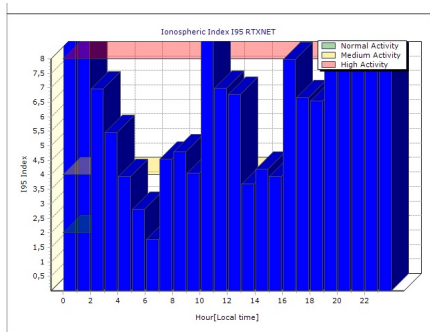
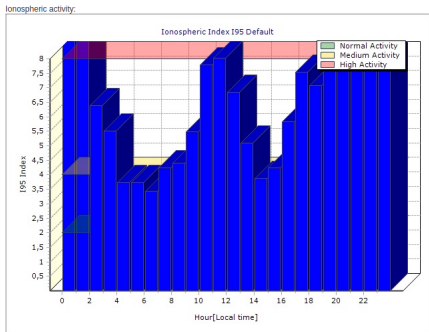
Figure: The 5 first stations of the network

Those stations are accessible through a permission granted by the CENTRE D'INFORMATION GÉOGRAPHIQUE ET DU NUMÉRIQUE

The Competence in Space Sciences in West Africa

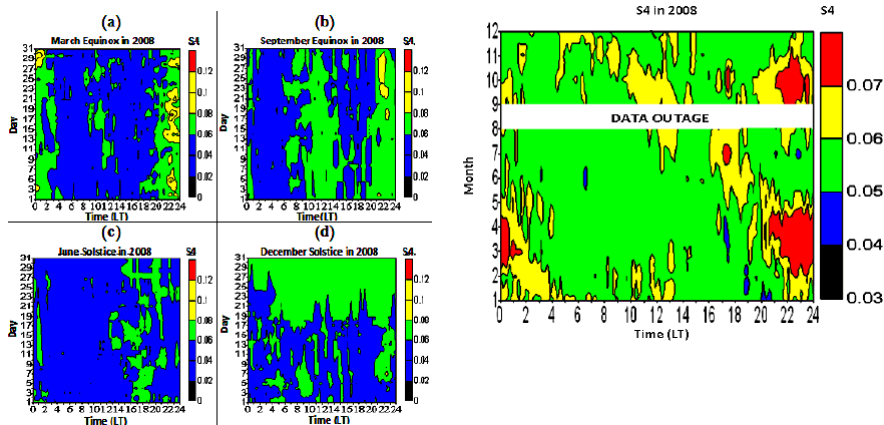
- ① BURKINA-FASO
 - University of Kodougou
- ② GHANA
 - University of Accra
 - Ghana Space Agency
- ③ COTE-D'IVOIRE
 - University FHB Cocody
- ④ NIGERIA
 - Space Agency
 - CAR
 - FUTA
 - University of Ilorin
 - University of Lagos

I95 Index variation over Abidjan



Variation of the I95 ionospheric index over Abidjan using the CORS network of Cote d'Ivoire data for september 8th, 2023

Scintillation activity over the city of Abidjan



Seasonal and annual variation of the S4 index over the city of Abidjan in 2008 (Ackah et al., 2011)

Preliminary studies of the ionosphere to support the deployment of SBAS through the agreement ASECNA /CNES.

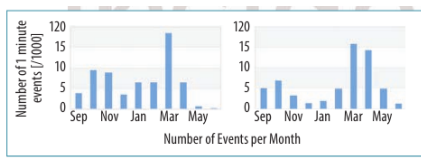


Figure: Number of events per month in Dakar (left panel) & Lomé (right) Secretan et al., (2014)

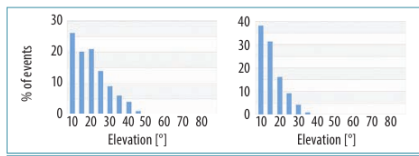
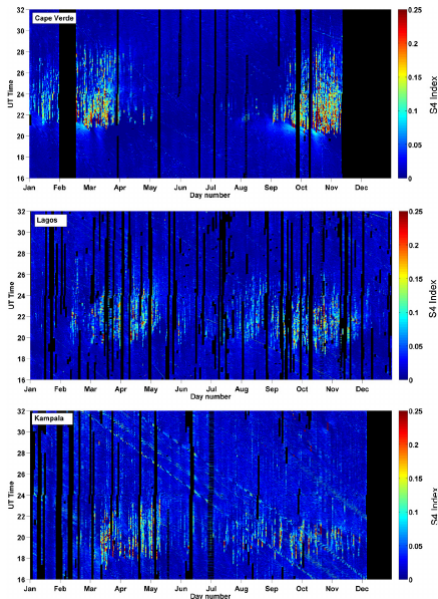


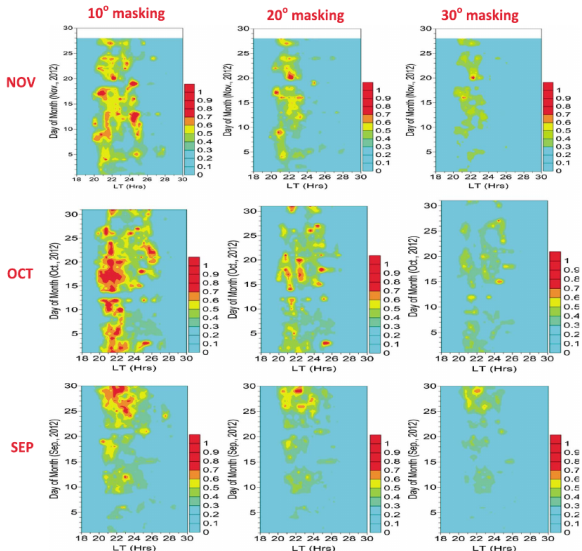
Figure: Repartition of the elevation of the LoS under scintillation in Dakar (left panel) & Lomé (right) Secretan et al., (2014)



S4 index measurements as function of day of the season and universal time. for the year 2010 from three regions: Cape Verde, Lagos, and Kampala. Black color has been used to indicate missing data.(Paznukhov et al., 2012)



Scintillation activity over Dakar



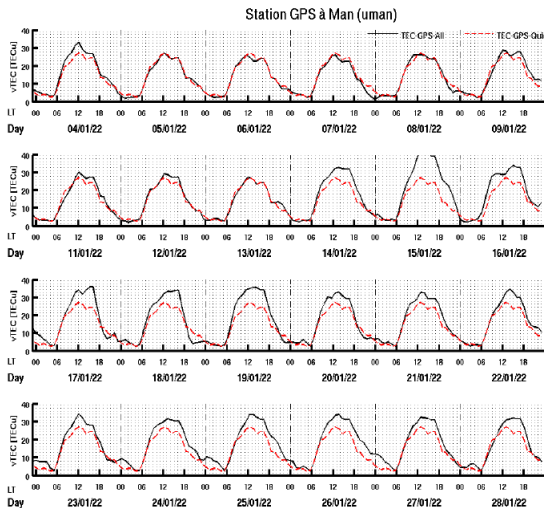
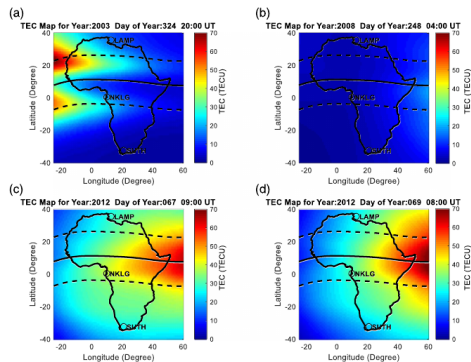


Figure: Diurnal variation of the TEC derived from GPS receiver installed at the University of Man (Lat :7.40 Long ; -7.55) (TWAS Grant # 12-100 RG/PHY/AC-I)

AfriTEC Model

This work by Okoh et al., (2020) presents the development of a storm-time Total Electron Content (TEC) model over the African sector. It is based on artificial neural networks which are used to learn the relationship between TEC and the corresponding physical/geophysical input parameters representing factors which influence ionospheric variability.



<https://www.mathworks.com/matlabcentral/fileexchange/69257-african-gnss-tec-afritec-model>

Summary

- Most of these existing networks are primarily established for survey and land management purposes.
- There is a need to strengthen our link with Surveyors.
- Most of this Networks results from collaboration in the framework of IHY and ISWI
- Keep on collecting data for science education and outreach on space weather
- Extending this Network to other countries in the region for a better coverage
- The creation of a regional network taking into account the objectives of scientist and Surveyors

THANKS FOR YOUR ATTENTION !

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