



# Present Status of Ionospheric and GNSS Research Infrastructure in Africa

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# Outline

- GNSS facilities and ionospheric monitors available in Africa
- Some opportunities for research visits at standard Laboratories across Africa
- Some Useful webpages and addresses

# Know Africa !



- A continent
- 54 Sovereign nations
- Multi-lingual structure
- English, French, Portuguese, Arabic, Spanish, over 1000 indigenous languages
- ~ 30.37 Million km<sup>2</sup>
- ~ 1.43 billion people
- ~16.72% World population



# Densification of GNSS in Africa

- IGS started deployment of GNSS receivers to Africa for geodetic purpose
- The United Nations – endorsed programs tagged International heliophysical Year IHY (2004-2009) and International Space Weather Initiative ISWI (2009 – date) combined with some other initiatives to expose the data gaps in ionospheric measurements in Africa
- These programs facilitated deployment of GNSS receivers from which TEC could be estimated to Africa from interested donor groups
- some African nations already established national networks of CORS, although for mapping purposes, but suitable for space weather studies

# GNSS Receivers Densification Programmes

-  IGS – AFREF - [igscb.jpl.nasa.gov](http://igscb.jpl.nasa.gov)
-  AMMA - [www.amma-international.org](http://www.amma-international.org),
-  National Reference Frames
-  IHY/ISWI
-  AfricaArray
-  ICTP-BC joint GNSS program
-  Scientific networks
-  National Institutions, Research Groups and Space agencies



Appreciable increase in the number of GNSS data points  
available for TEC derivation for ionospheric studies

# International Heliophysical Year 2007 (IHY, 2005-2009) & International Space Weather Initiative (ISWI, 2010 -).

## IHY/ISWI ANCHORS



[www.ihy2007.org](http://www.ihy2007.org)

- ✓ United Nations office for Outer Space Affairs UNOOSA, Vienna, Austria
- ✓ NASA



<http://www.iswi-secretariat.org/>

# IHY/ISWI

- Initiated in 1990, the United Nations Basic Space Science Initiative (UNBSSI) has led to the establishment of planetariums, astronomical telescope facilities, and IHY/ISWI instrument arrays worldwide, particularly in developing countries
- ISWI is envisioned to continue the tradition of IHY in the worldwide deployment of space weather monitoring instrument arrays including GNSS receivers
- To date, ISWI contributes to the observation of space weather through 14 instrument arrays with close to 1000 operating instruments in 97 countries

[www.ihy2007.org](http://www.ihy2007.org)

<http://www.spaceweather-eg.org/iswi/>



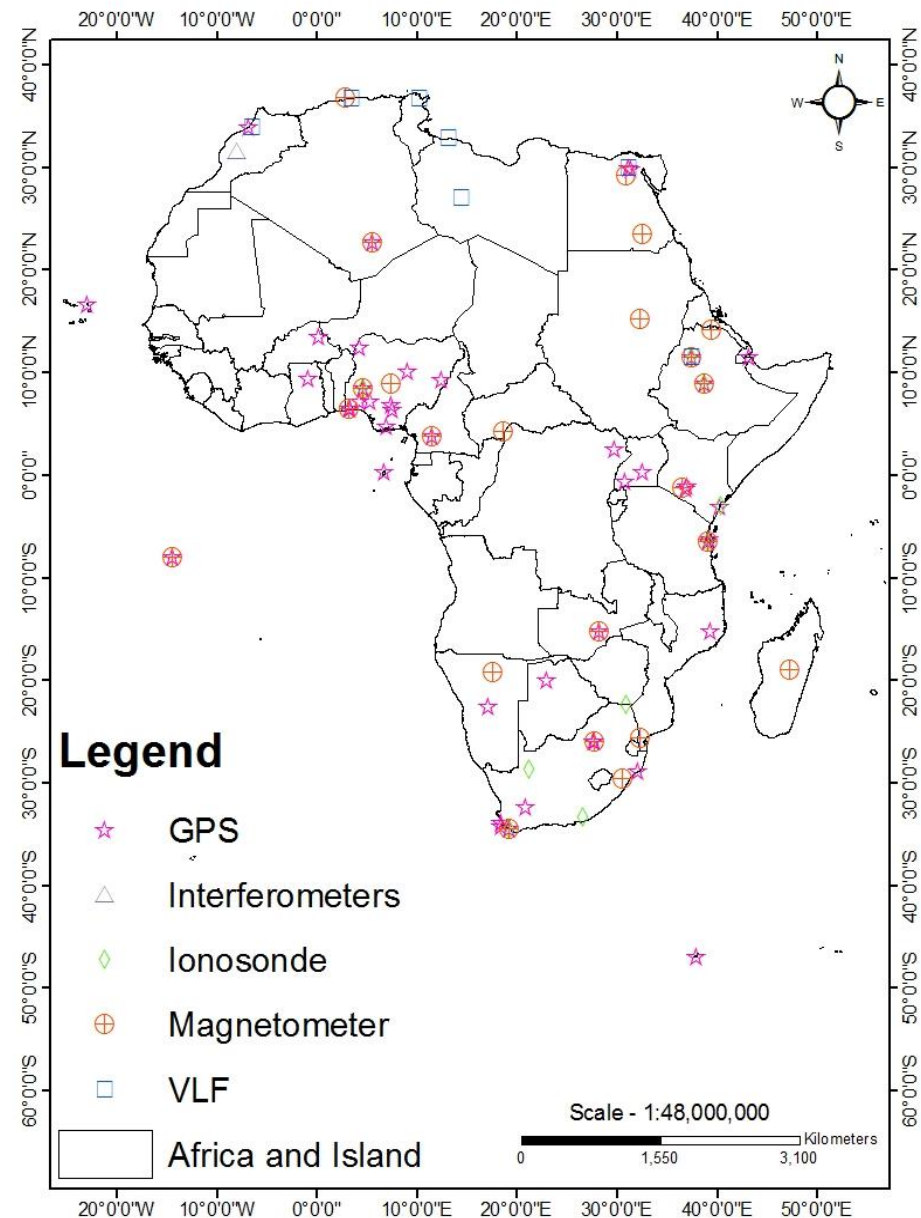
# IHY/ISWI

increase in # of  
stations that can serve  
as CORS in Africa in  
recent time

## SCintillation Network Decision Aid (SCINDA)

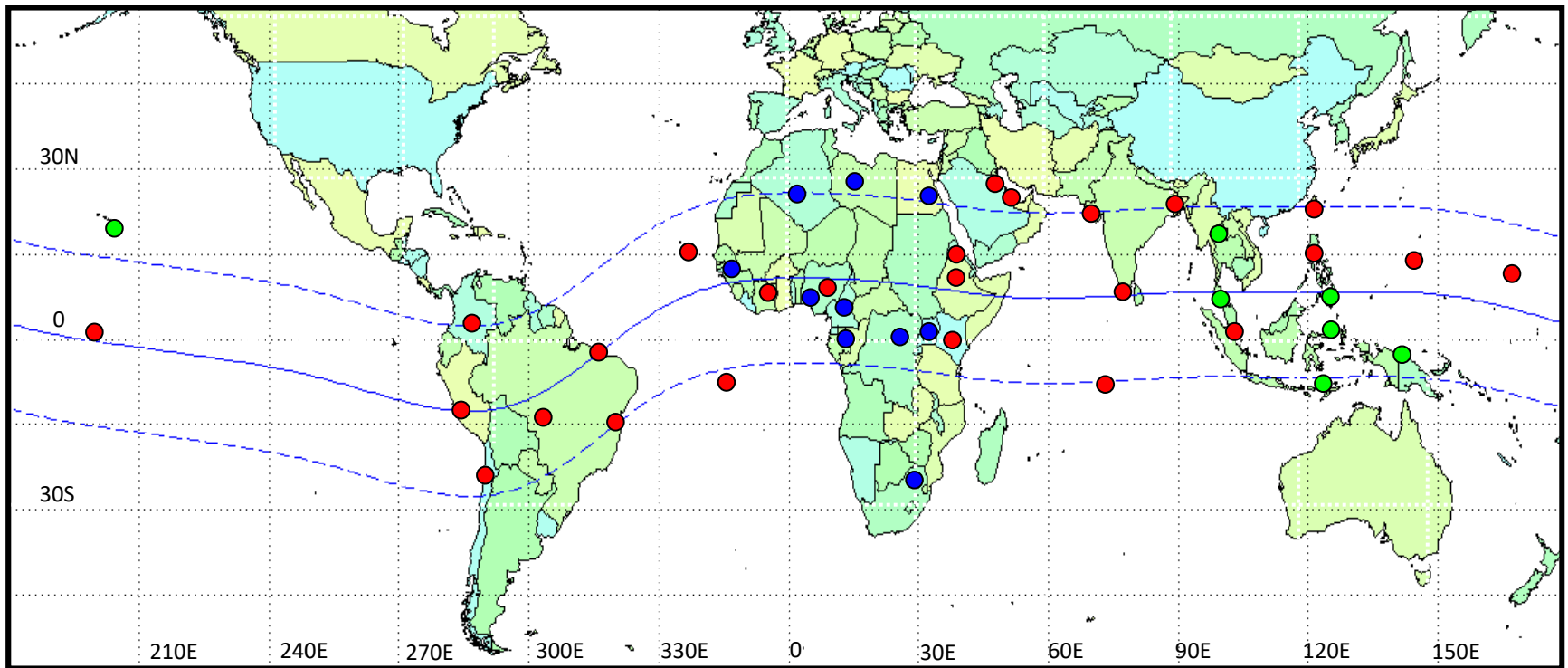
-US Air Force Research  
Lab Project  
– PI Keith Groves,

A regional nowcasting system to  
support research and users of  
space-based communication and  
navigation systems





# SCINDA Ground Stations



[Groves, 2010]

● Existing Sites

● UN IGY Sites

● Other/collaboration

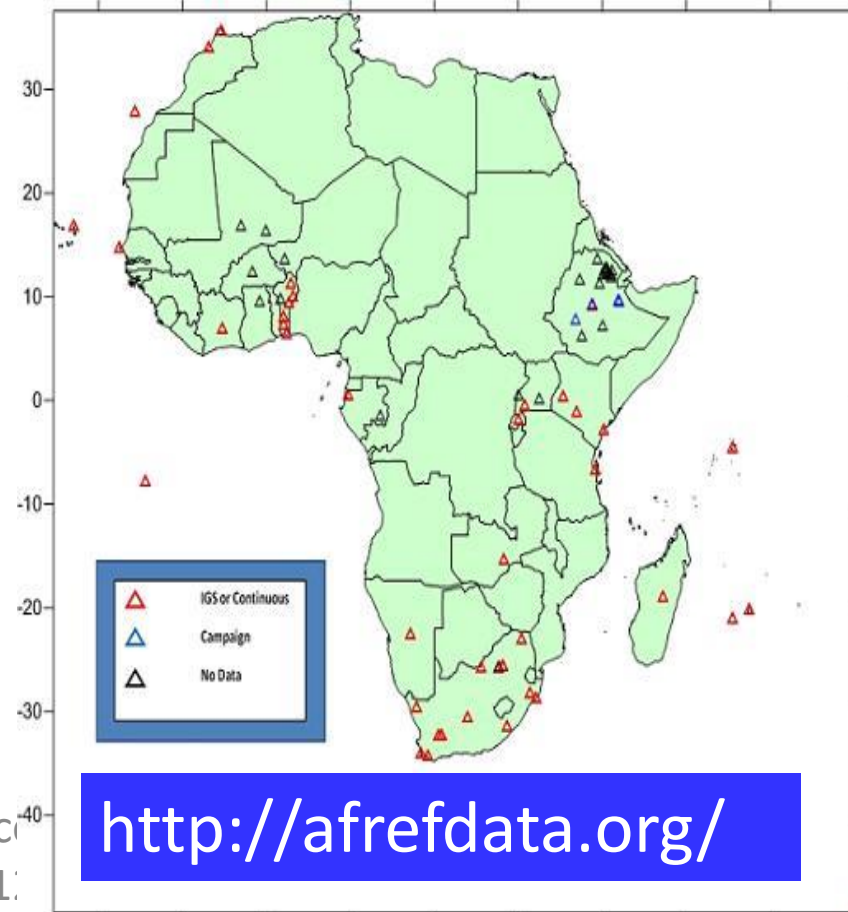
Eastern Africa Cap. Building Wkshop on Space Weather & Low-latitude  
Ionosphere, Malindi, Kenya, 03 - 12 October 2023

# International GNSS Service IGS

- The IGS global system produces high-quality GPS data and data products on line in near real time to meet the objectives of a wide range of scientific and engineering applications and studies
- improvement and extension of the International Terrestrial Reference Frame (ITRF),
- the monitoring of Earth deformations and movement
- for scientific satellite orbit determinations
- ionosphere monitoring etc

<https://igs.org/>

- ☐ a unified geodetic reference frame
- ☐ fundamental basis for the national & regional three-dimensional reference networks
- ☐ fully consistent and homogeneous with the International Terrestrial Reference Frame ITRF
- ☐ Densification of GNSS networks with its products in Africa
- ☐ Some countries have established a network of CORS
- ☐ AFREF has strong alliance with IGS



<http://afrefdata.org/>



# Solution

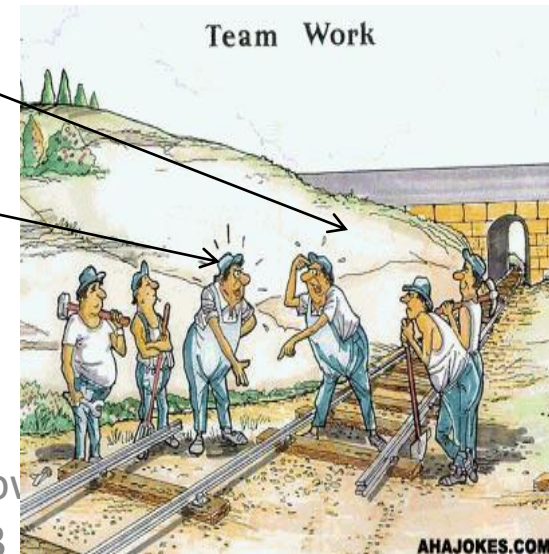
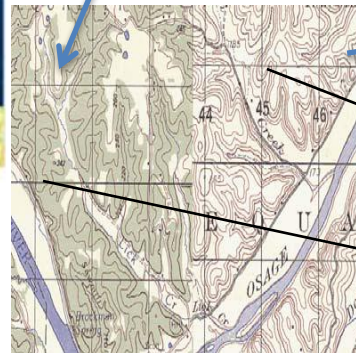
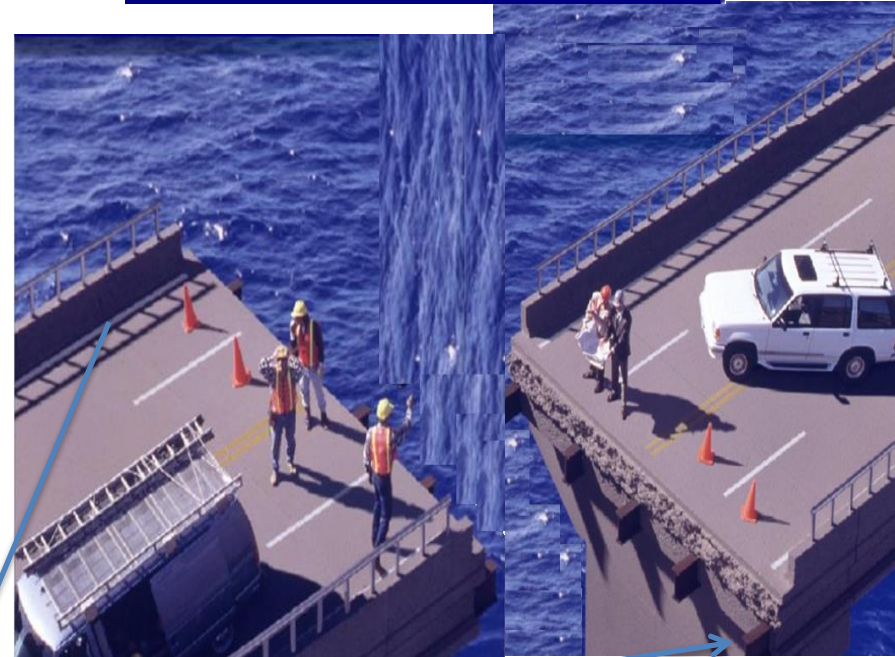
Non-uniform systems

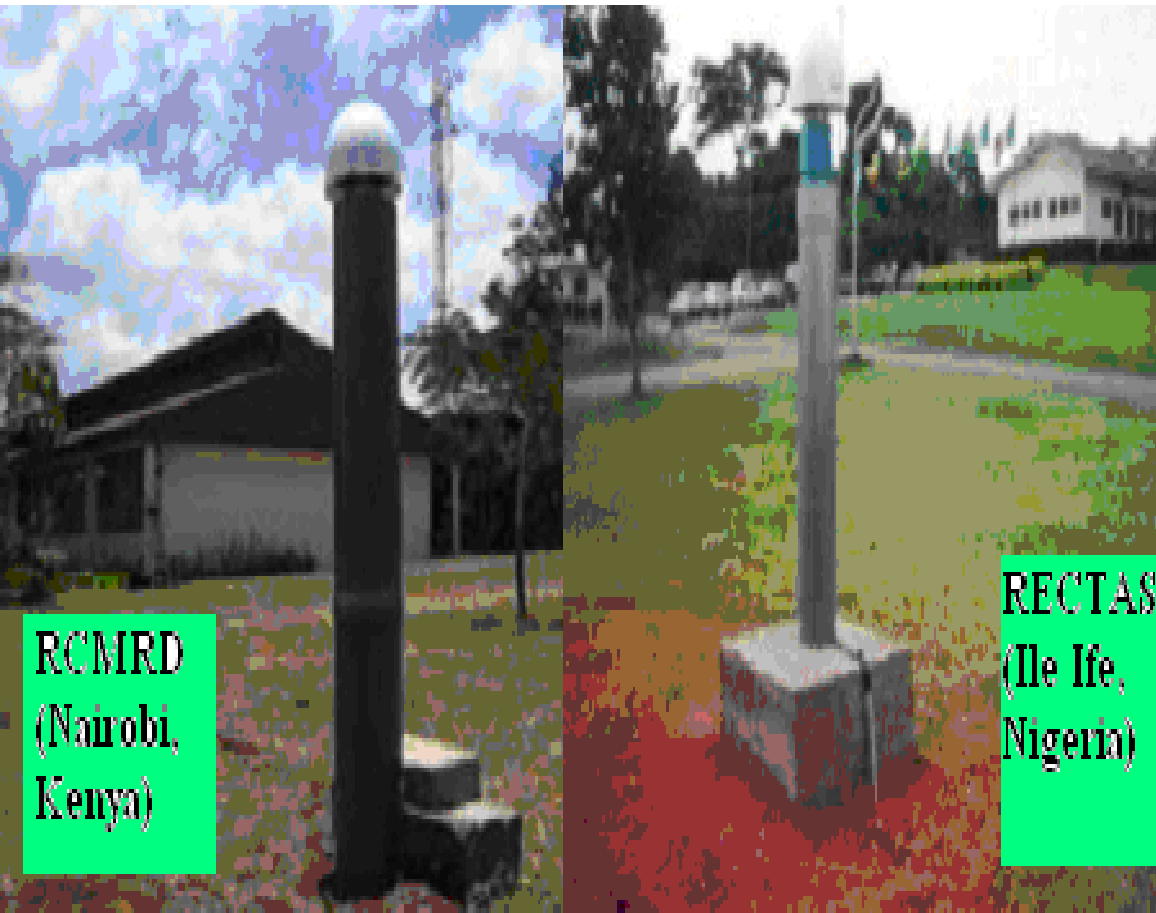
Uniform system

GNSS  
+  
ITRF

Reducing 54 Reference frames  
to 1

Consequences of using reference systems  
that are not consistent !





# Typical AFREF CORS



# AfricaArray: partners.

- *AfricaArray* grew out of a partnership of three organizations viz:
- University of the Witwatersrand (Johannesburg, South Africa)
- South African Council for Geoscience,
- Pennsylvania State University (University Park, PA, USA).



Council for Geoscience

<https://africaarray.net/>



# AfricaArray

- Launched in July 2004
- *AfricaArray* mission: To create new geoscientific research and training programmes and rebuild existing ones in Africa with Africans and for Africans
- While the long-term vision is to support training in many geoscience fields
- development of new geophysical training programmes and expand support of existing ones
- design and establishment of a network of geophysical observatories

<https://africaarray.net/>



- From August, 2010, many of the AfricaArray observatories were equipped with GPS receivers
- data are archived at the UNAVCO Data Management Facility
- UNAVCO originated as the University NAVSTAR Consortium
- a non-profit university-governed consortium, facilitates geoscience research and education using geodesy.
- network operations to support NSF-funded community GPS networks for Earth, atmospheric, and polar science applications, and the NASA's Global GNSS Network (GGN)

# ICTP-BC GNSS in Africa

- Partnership between Boston College, USA & Abdus Salam ICTP, Trieste, Italy.
- Series of annual Workshops since 2009
- Deployment of GPS stations in Africa
- Over 600 African scientists have been trained at ICTP
- Leading experts in GNSS teach at the annual workshops
- A training model



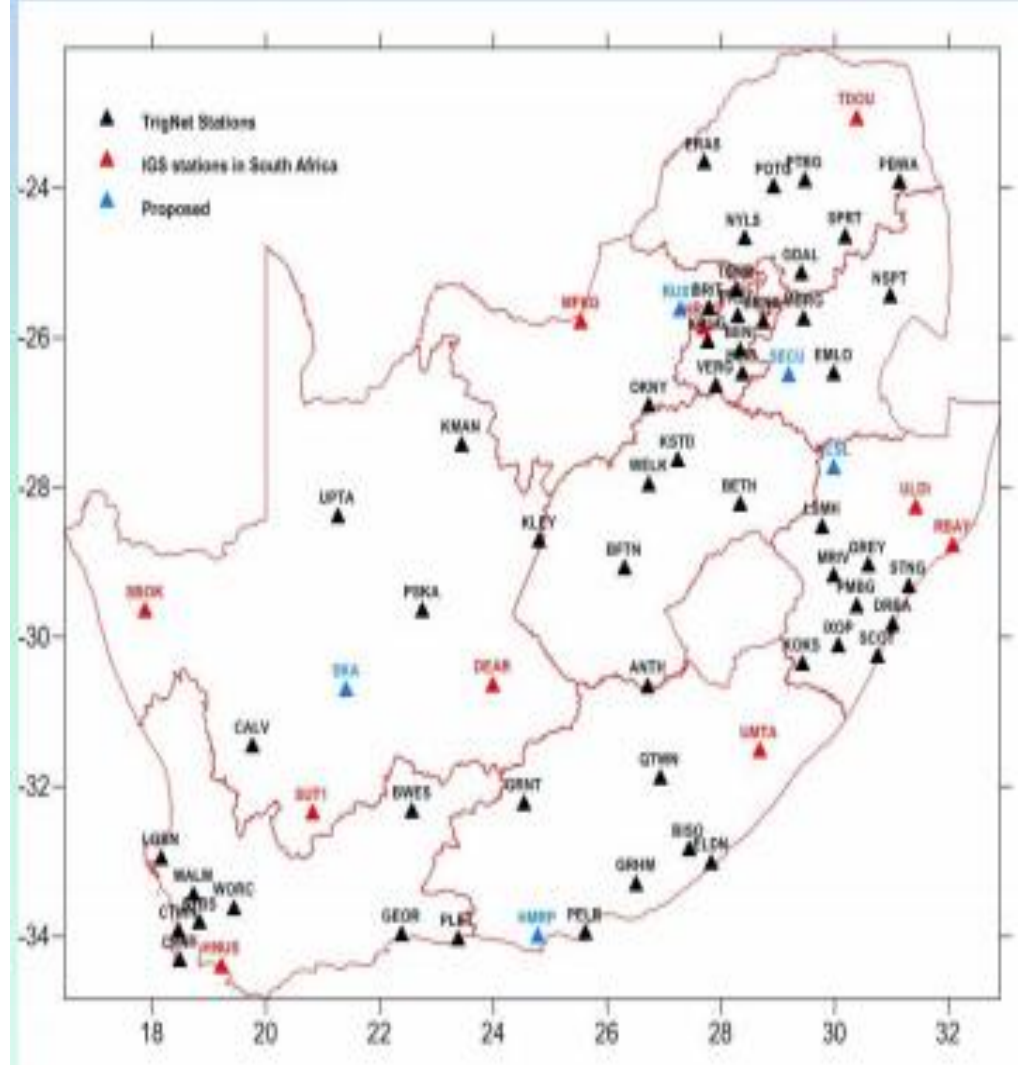
**installed GPS  
antenna at  
Sokoto, Northern  
Nigeria, 6<sup>th</sup> Nov  
2013**



# **SOME NATIONAL REFERENCE FRAMES**

# RSA: TrigNet network

- 67 base stations,
- maximum inter-station spacing distance of 300 km
- The data is streamed, via dedicated leased lines, to the National Geospatial Information NGI office in Cape Town
- where it is processed and made available, free of charge, to national & international users.

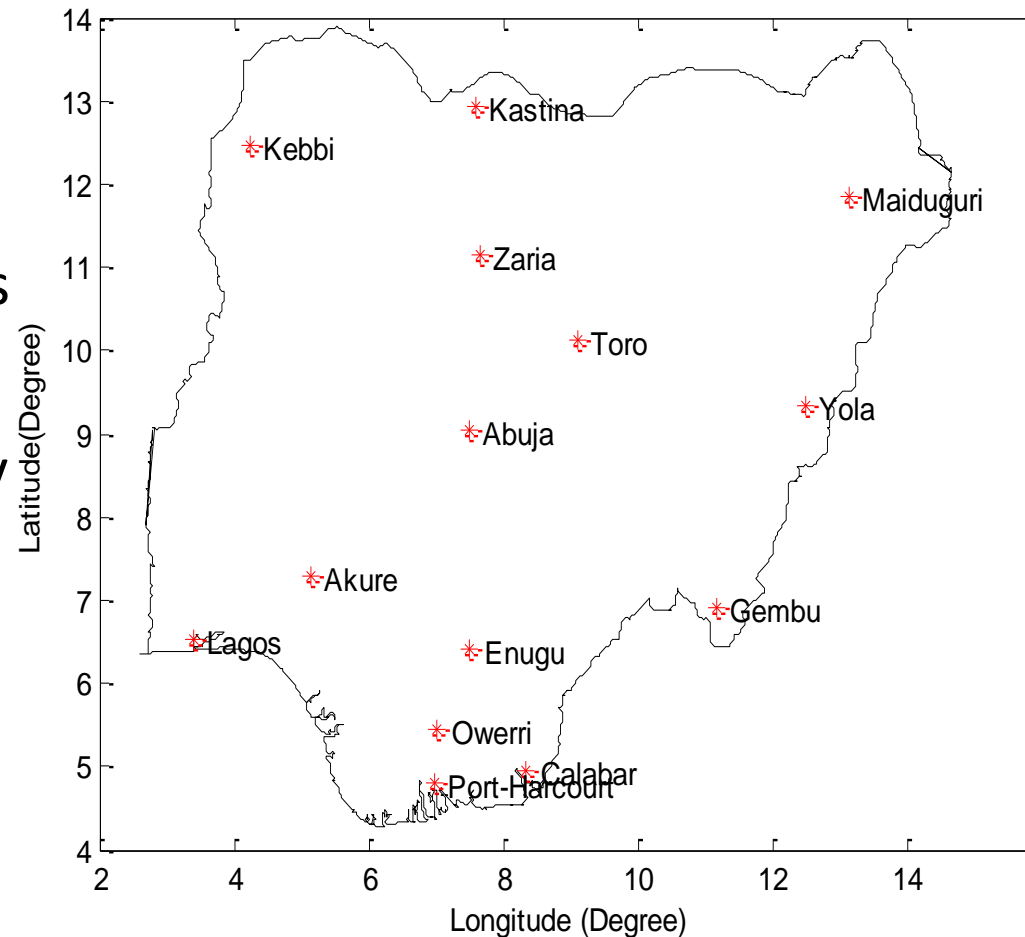


<http://www.trignet.co.za/>

[ Rubinov et al, 2012]

# NIGERIA: NIGNET - TERONET

- Primarily meant for land mapping and surveying
- RINEX files were accessed and 1<sup>st</sup> used for ionospheric studies by **Rabiu et al., (2014)**
- It's a project fully supported by the Office of Surveyor General of the Federal Government of Nigeria (OSGoF)
- CORS



**(Jatau et al, 2010)**

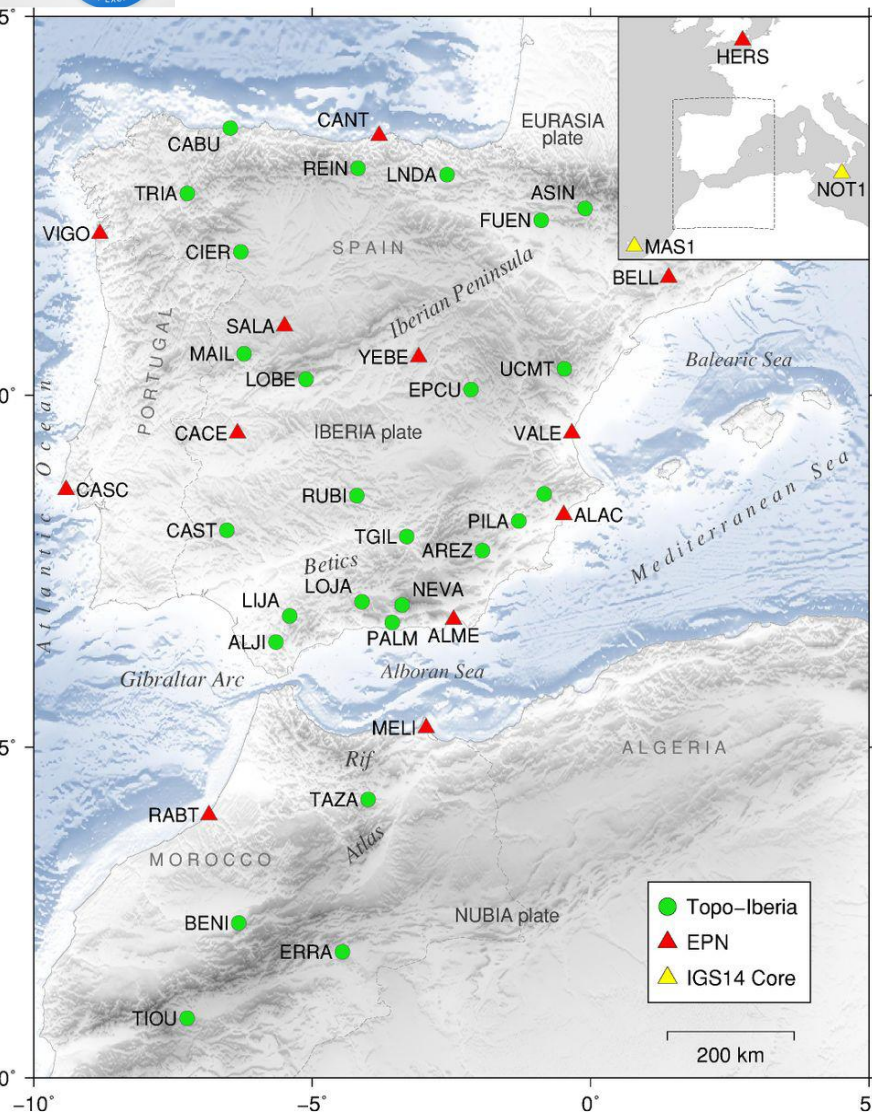
<https://teronet.nignet.net/>

# Ghana: Land Administration Project

- Ghana is adopting GNSS and GPS technology
- Govt of Ghana set out to implement Land Administration Project (LAP) by GPS based technology
- **LAP involves establishing an acceptable geodetic reference frame for Ghana.**
- A main objective for this was to recompute, adjust, and densify the existing national geodetic reference network
- The primary goal is to support surveying and national land information systems (LIS)



# Topo-Iberia CORS GPS



- Topo-Iberia GPS network was funded by the Spanish Ministry of Science and Innovation
- The project engaged 3 main techniques: seismology, magnetotellurics and GP
- The GPS network consists of 26 CORS located in the Spanish part of the Iberian Peninsula (22 stations) and northern **Morocco (4 stations)**
- The stations were installed between March and October 2008

<https://epncb.eu/ftp/obs/> and  
[https://epncb.eu/\\_networkdata/stationlist.php](https://epncb.eu/_networkdata/stationlist.php).



# Ethiopian Afar GPS campaign 2006-2009

- eastern Ethiopia
- A 60 km long dyke opened up in the Dabbahu segment in 2005 that marked the beginning of a continuing rifting episode.
- 14 permanent CORS GPS sites and over 20 campaign sites
- The majority of the CGPS stations were installed in 2006/2007
- UNAVCO supported the Afar Rift project, NSF funding terminated @ end of 2009

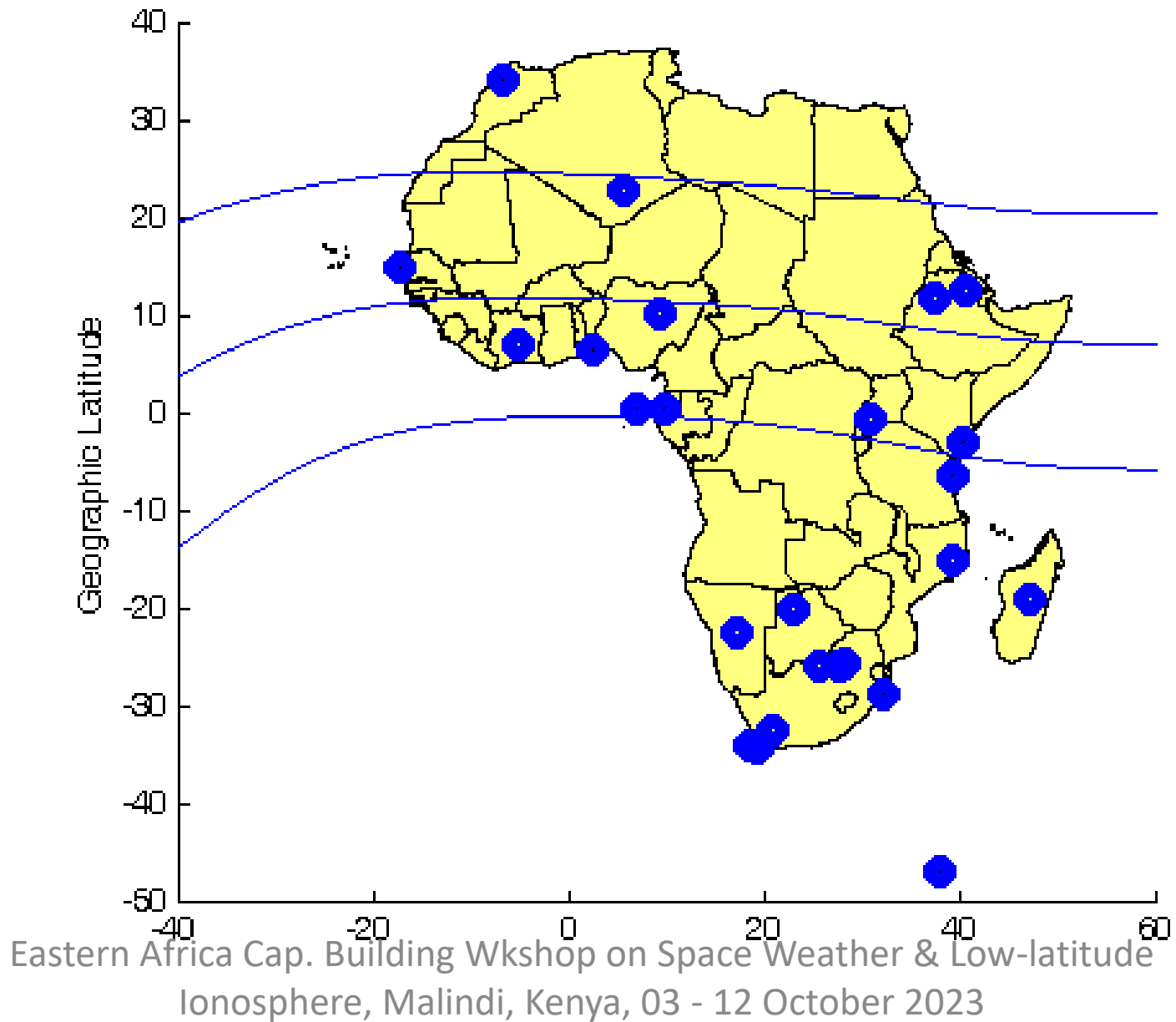
[www.unavco.org/highlights/2009/afar.html](http://www.unavco.org/highlights/2009/afar.html)



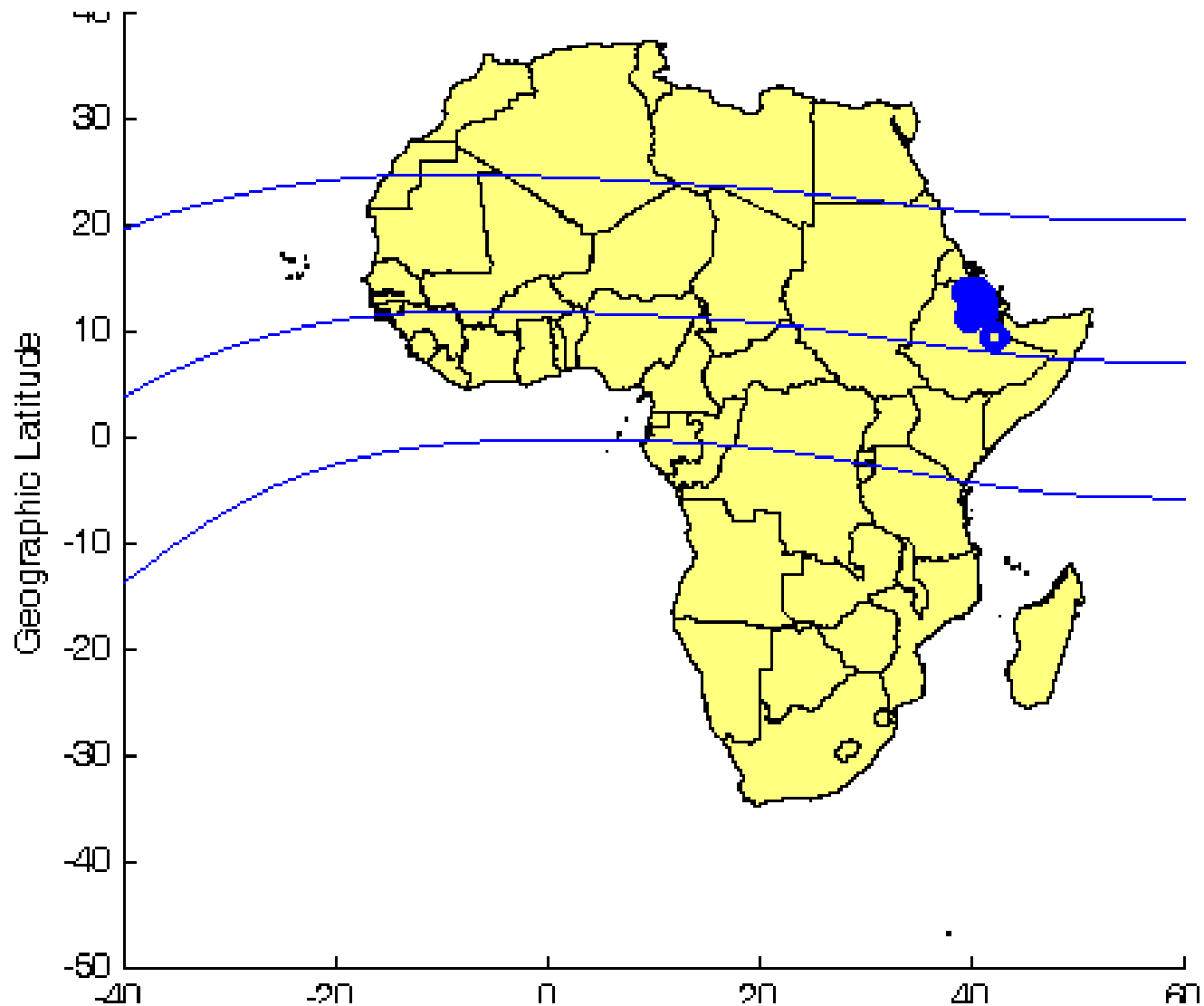
Map depicting the GPS network surrounding the Dabbahu Rift (black diagonal lines).

Continuous stations are in blue and permanent stations are in red

# IGS

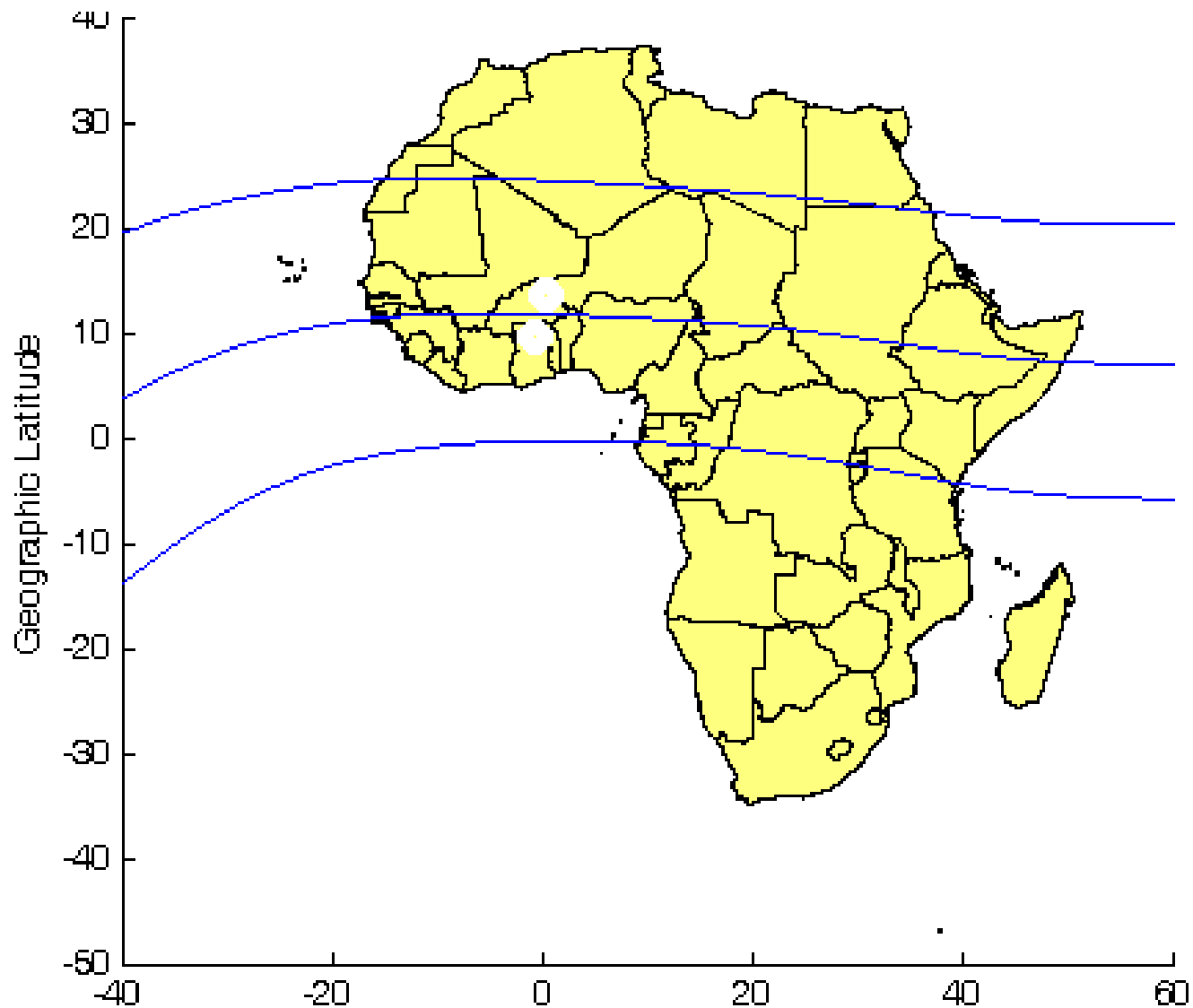


# AFAR



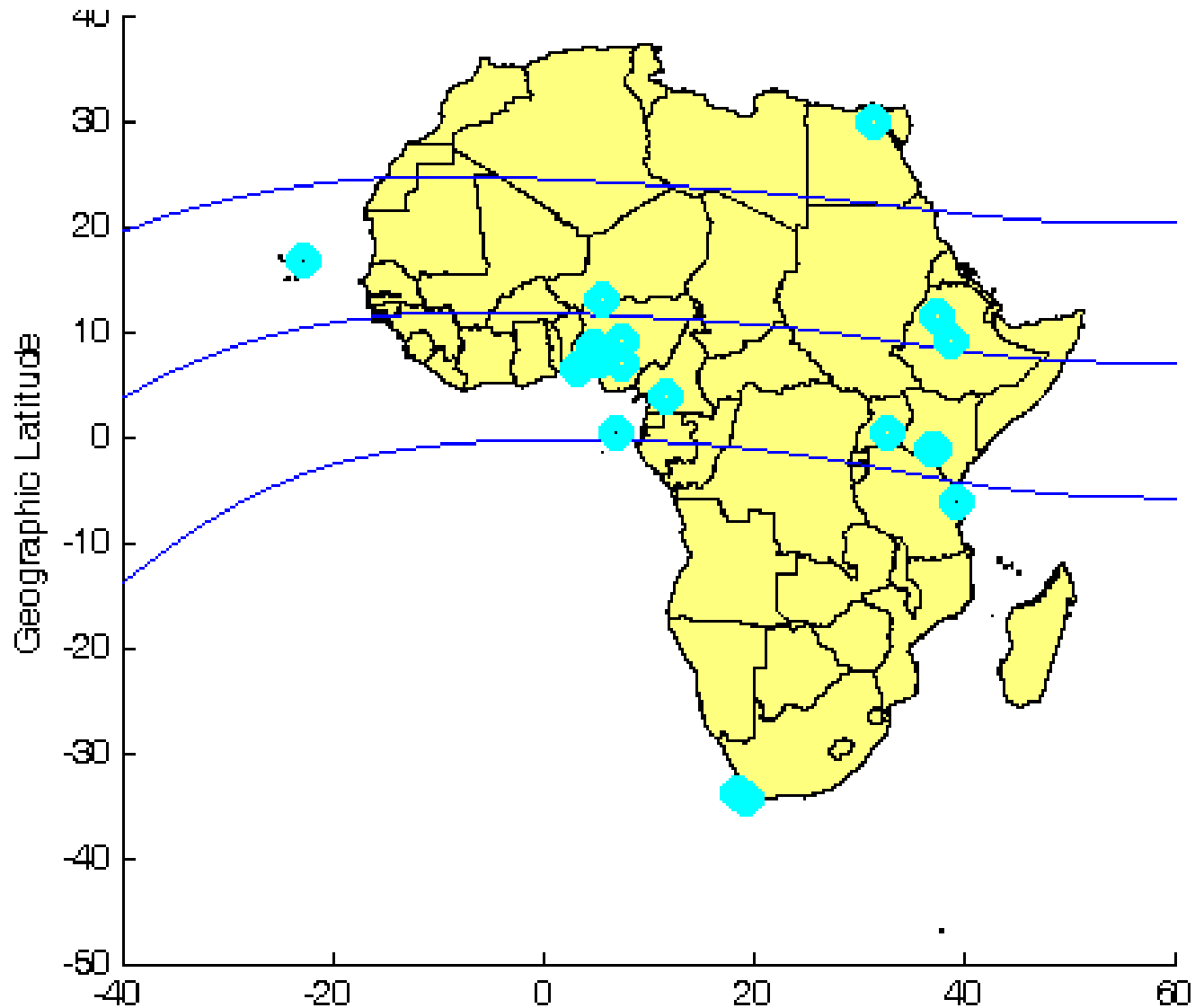
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# AMMA



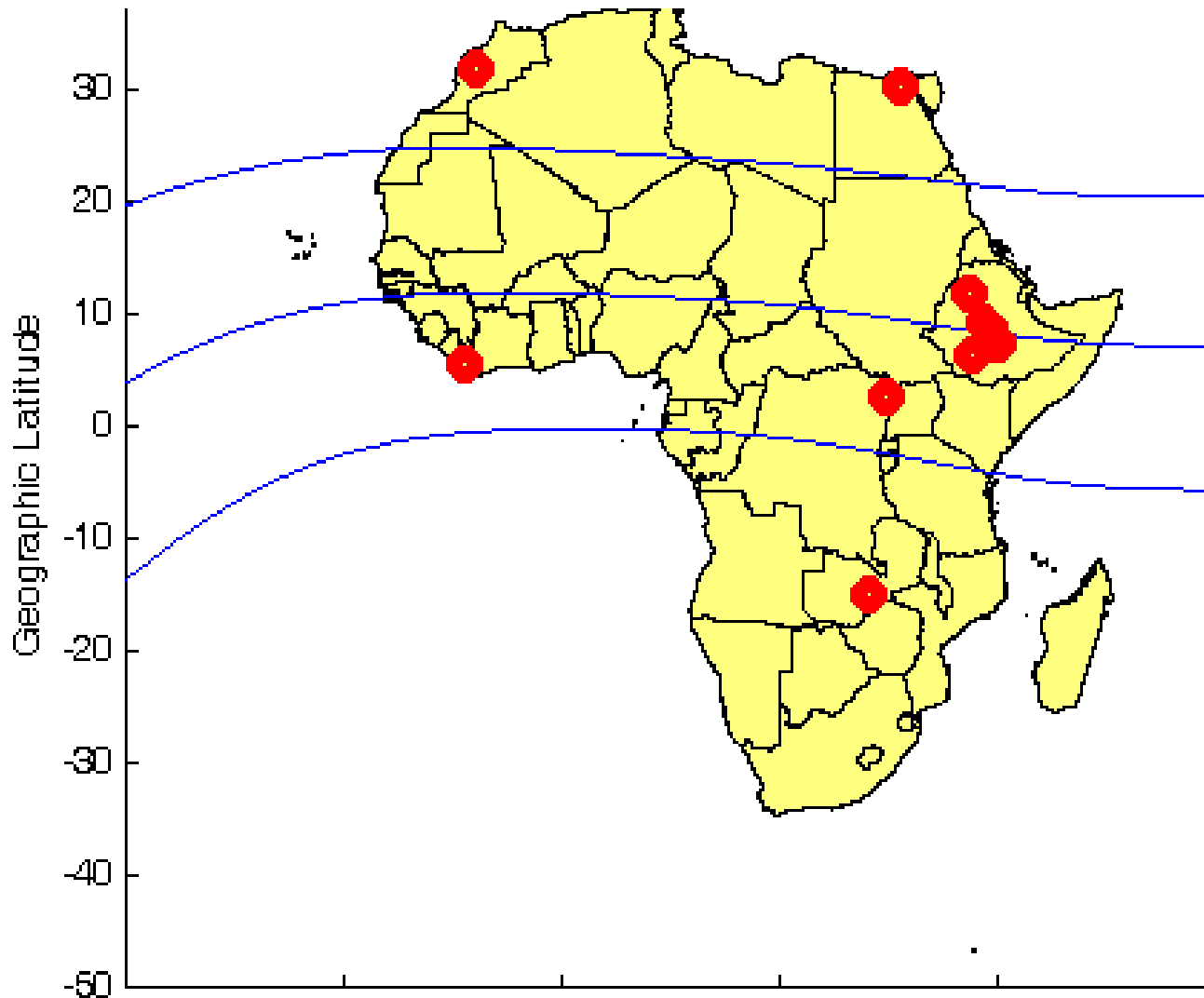
Eastern Africa Cap. Building Wkshop on Space Weather & Low-latitude  
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# SCINDA ICTP-BC



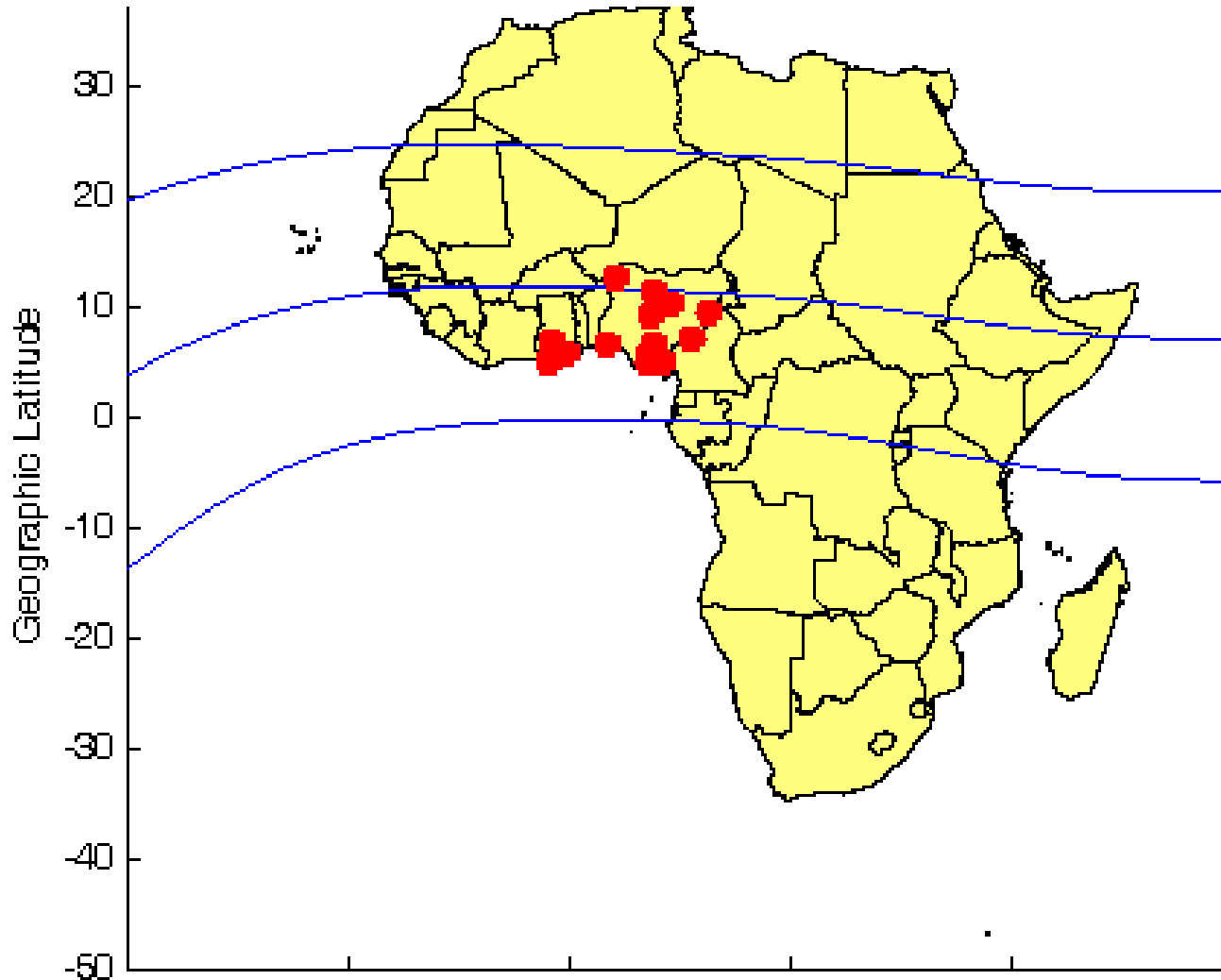
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# GALILEO & MISCELLANEOUS



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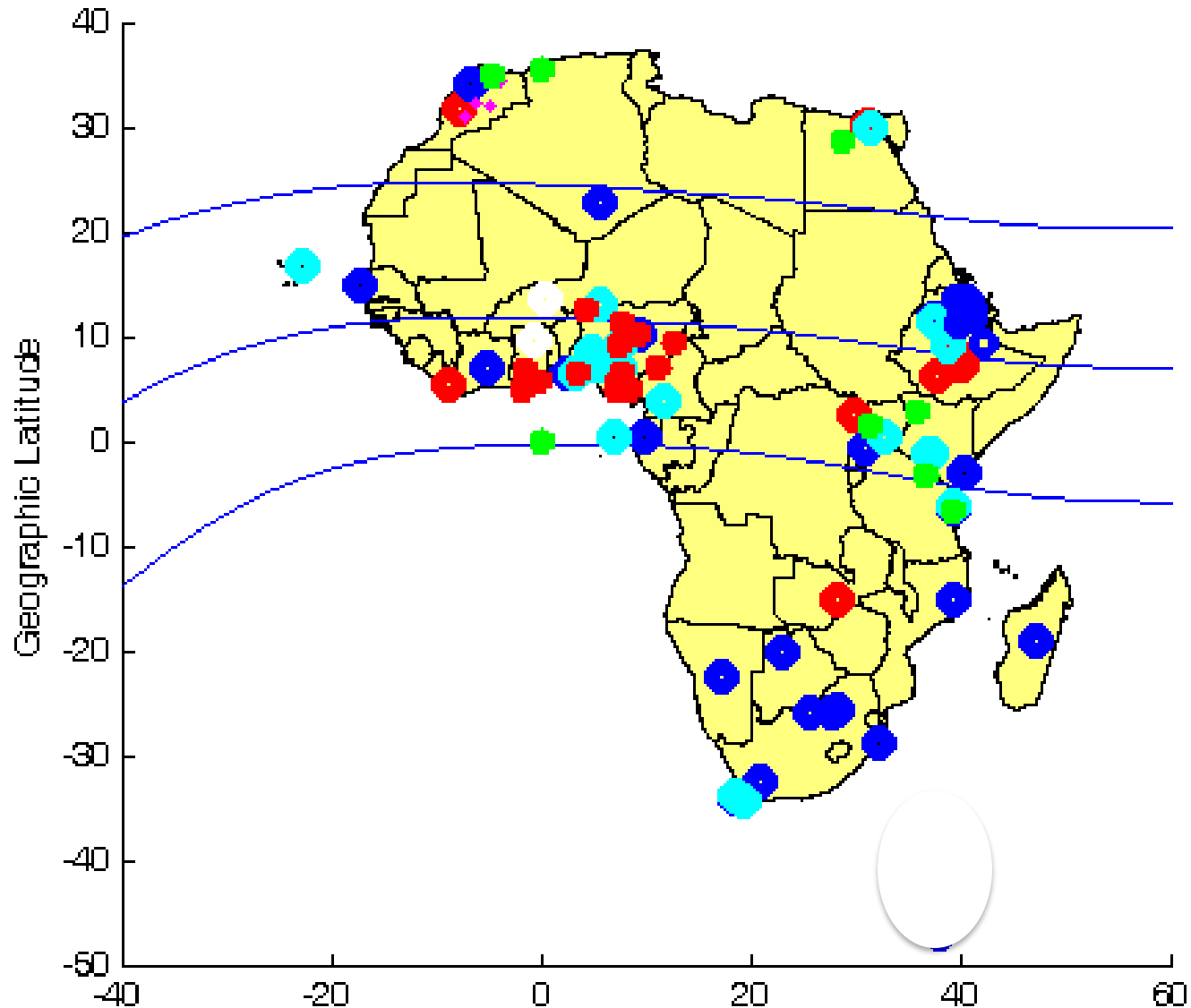
# NIGNET-LAP



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# ALL AVAILABLE CORS



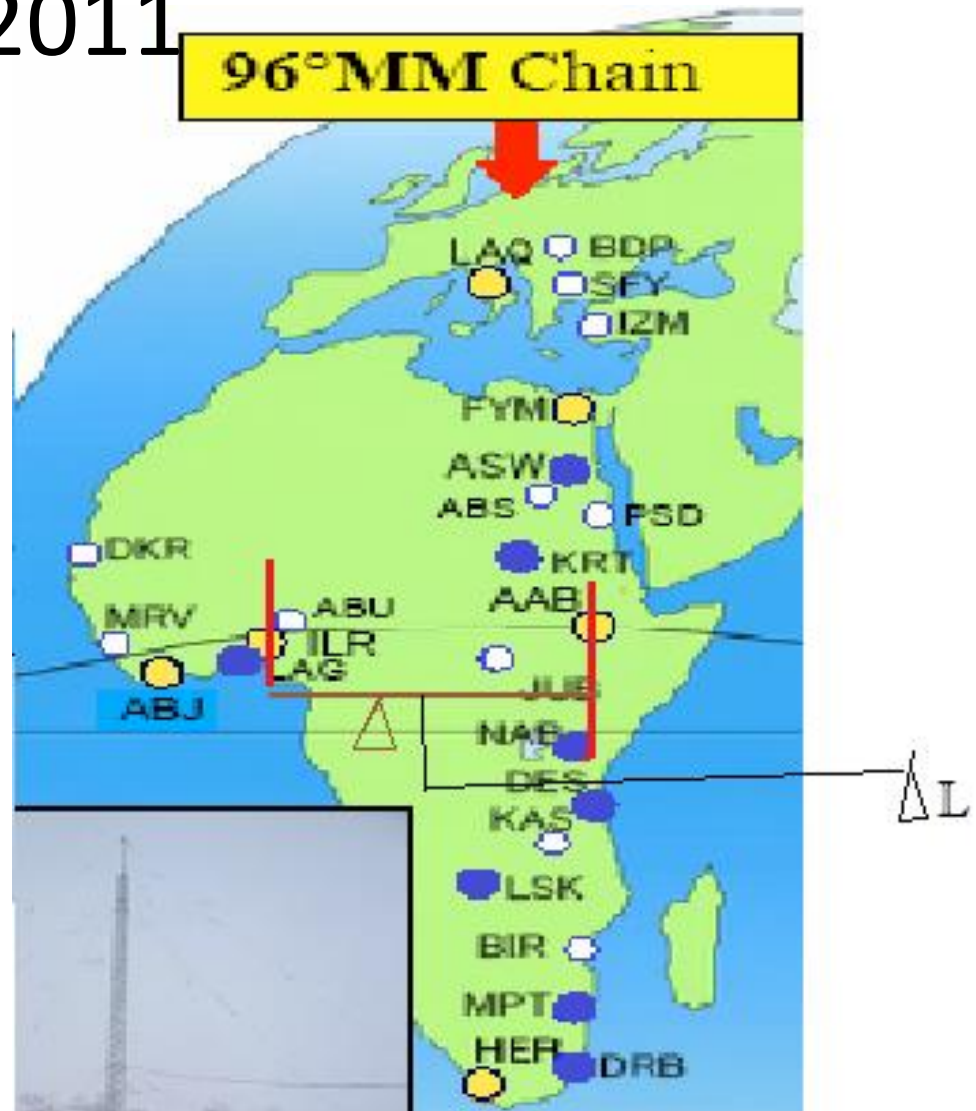


# **OTHER IONOSPHERIC MONITORS AND INFRASTRUCTURE**

# MAGDAS Magnetometers

## 2006 - 2011

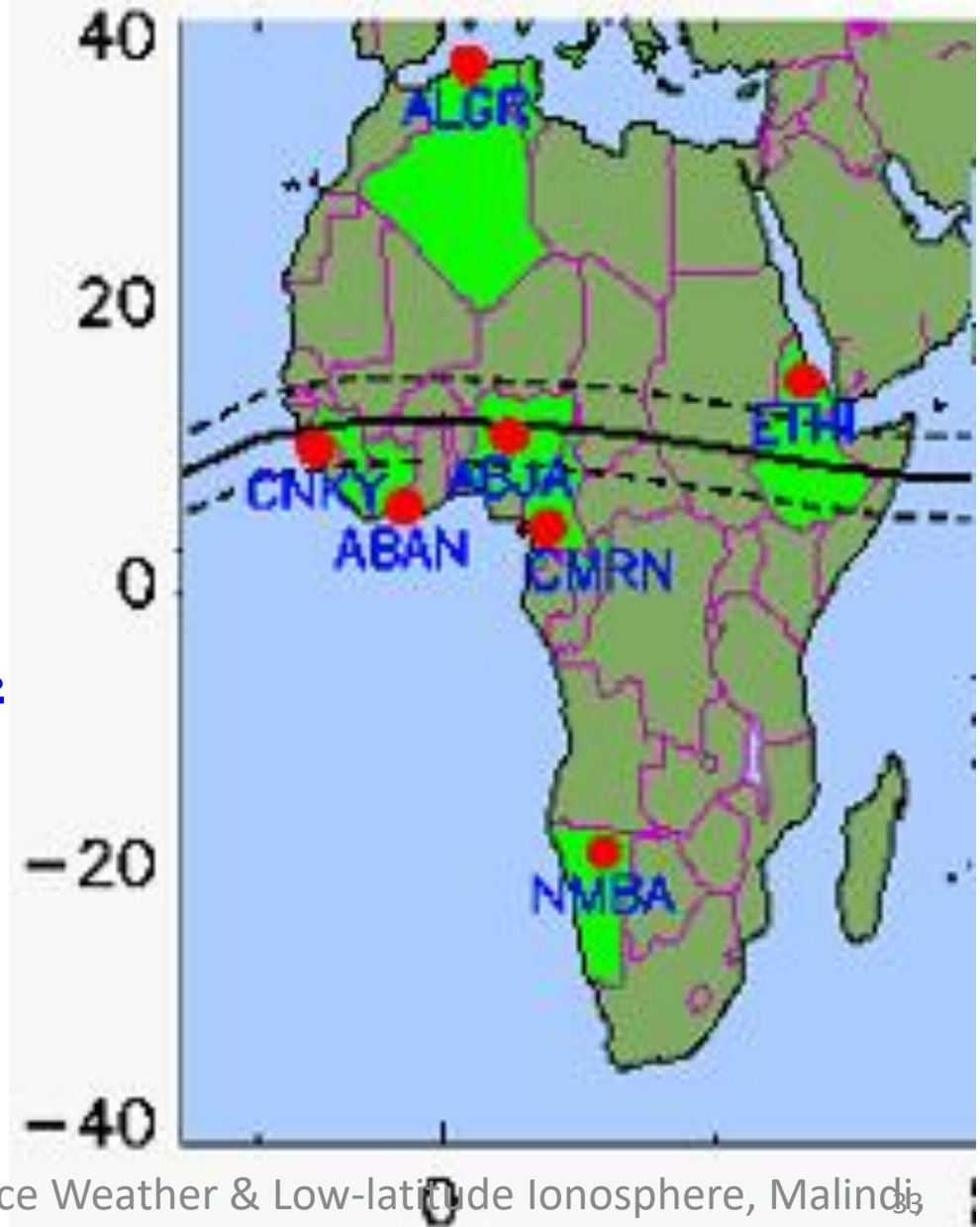
- Kiyohumi Yumoto initiated MAGDAS from, International Center for Space Weather Science and Education (ICSWSE), Kyushu University, Japan
- A worldwide Network ( 50 magnetometers)
- 14 in Africa
- Babatunde Rabiou – African Coordinator
- MAGDAS data is available on request from Akimasa Yoshikawa (yoshikawa.akimasa.254@m.kyushu-u.ac.jp)



# AMBER magnetometer Network

**PI: Dr Endawoke  
Yizengaw**

<http://magnetometers.bc.edu/index.php/amber2>





# Magnetometer Data Sets

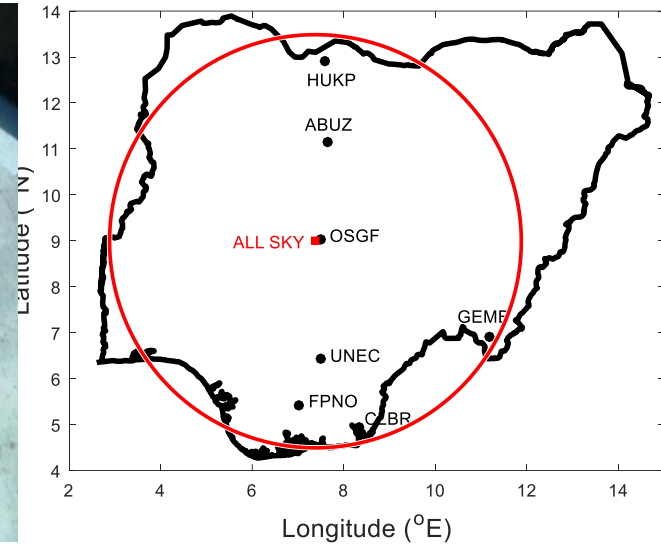
**Intermagnet magnetometer Network**

**<http://www.intermagnet.org/Welcome.php>**

**Supermag magnetometer Network**

**<http://supermag.jhuapl.edu/mag/>**

# Optical Observations



Nagoya University, Japan.

UN-ARCSSTE-E



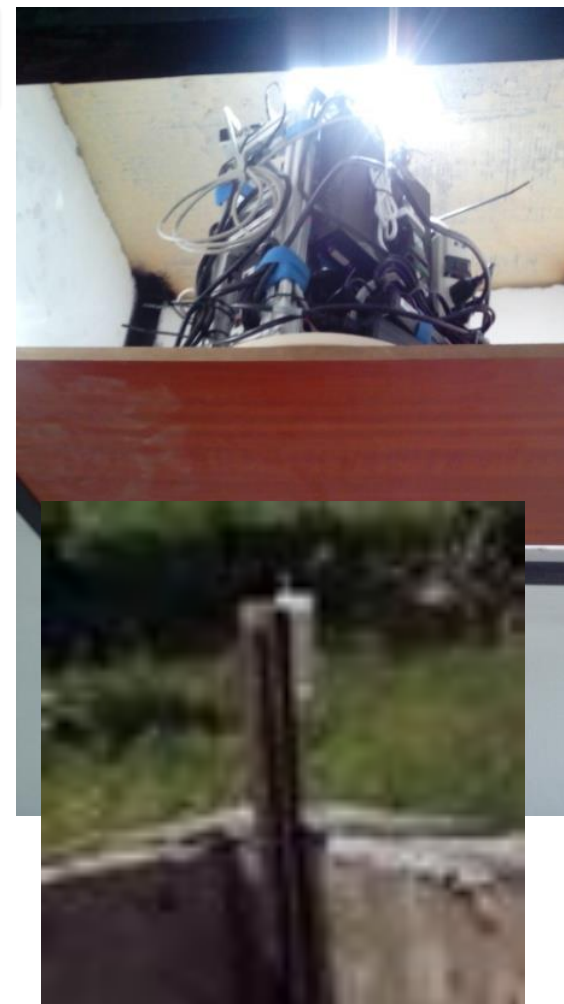
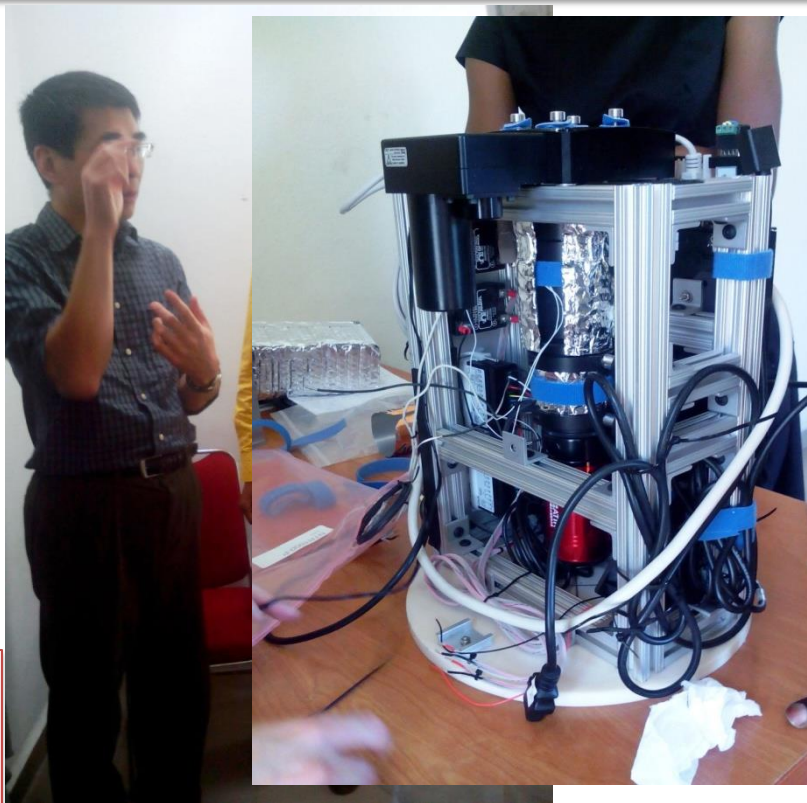
Nigeria & Ghana



# Fabry-Perot Interferometer (FPI)

**Installed November 2015**

**PI:  
Dr Qian  
Wu**

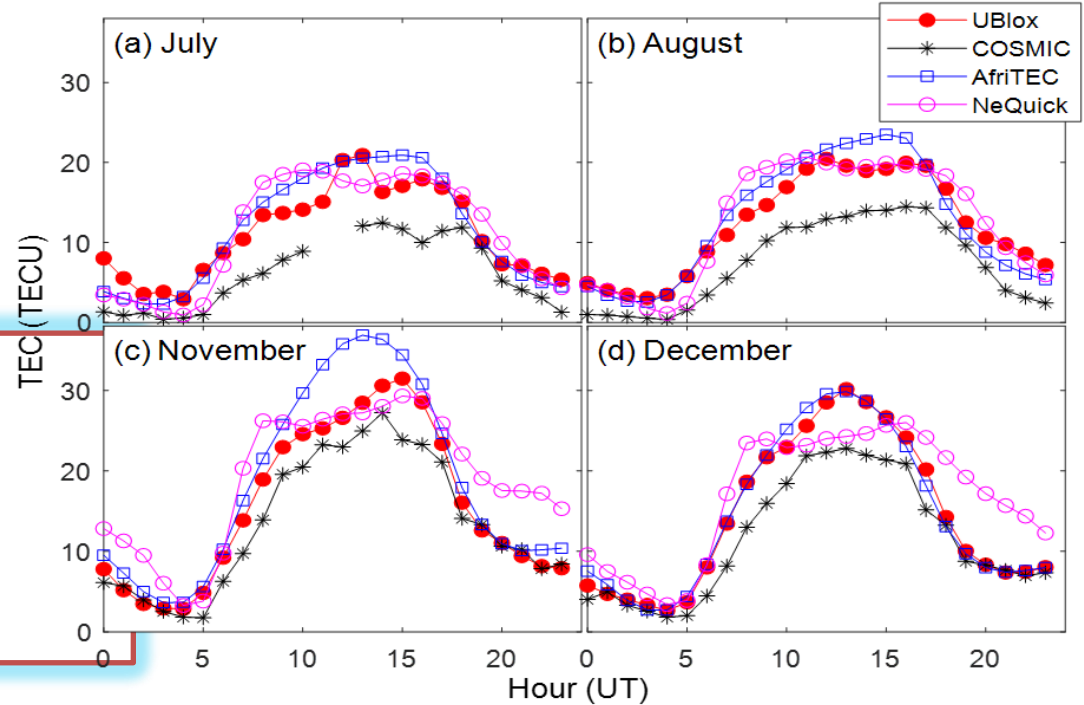


**National Center for Atmospheric  
Research, Boulder, USA**

**Cloud  
detector**  
Weather & Low-  
level clouds  
October 2025



# Nigerian GNSS Initiative 'CARGI'



Advances in Space Research

Volume 68, Issue 9, 1 November 2021, Pages 3835-3845

New results of ionospheric total electron content measurements from a low-cost global navigation satellite system receiver and comparisons with other data sources



# Nigerian space weather monitoring facilities

- GPS stations for Space Weather monitoring
- all-sky Optical Imager,
- magnetometers
- scintillation monitor,
- Fabry Perot Interferometer,
- SOFIE.
- HF Doppler Radar
- CARGI – low cost GNSS receivers
- Digisonde – University of Ilorin only



South African National Space Agency, Hermanus

As presented

Pierre Cilliers

# Space Weather impacts on Geodesy

***Pierre Cilliers, PrEng, PhD***

***Stefan Lotz, PhD***

***South African National Space Agency (SANSA), Hermanus***

IAG Symposium Commission 4: Positioning and Applications  
**5-8 September 2022**

Eastern Africa Cap. Building Wkshop on Space Weather & Low-latitude Ionosphere, Malindi,  
Kenya, 03 - 12 October 2023



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## Welcome to Space Weather at SANSA

SANSA Space Science is host to the only Space Weather Regional Warning Centre in Africa which operates as part of the International Space Environment Service (ISES). The Space Weather Centre provides an important service to the nation by monitoring the sun and its activity to provide information, early warnings and forecasts on space weather conditions. The space weather products and services are required primarily for communication and navigation systems, in the defence, aeronautics, navigation and communication sectors.

### Current Conditions

2022-09-23 08:13

Solar wind speed: N/A km/s  
IMF Bz: -6.4 nT  
Hermanus T-index: 47  
Hermanus K-index: 3  
Hermanus hmF2: 232.968 km  
Hermanus foF2: 7.500 MHz  
Dcx Index: 12.3 nT





*SANDIMS is the repository of all Geomagnetic, Ionospheric and Magnetospheric data gathered from SANSA Space Science's instrumentation network.*

## Instrumentation Network

Instruments in the network are grouped into the above three classes, and further sub-classed by **Instrument Type**, each of which is represented by one or more **Instrument Models**. Specific instruments so classified are the **Field Instruments** of the network, which extends throughout **South Africa** and **Namibia**, as well as **Gough** and **Marion** islands in the southern oceans and the **SANAE IV** research base in Antarctica. The SANDIMS Metadata Model includes GPS location, manufacturer and Principal Investigator information, as well as technical parameters of the instruments (most importantly sampling interval) and their

antennae. Metadata associated with a data bundle may be exported and shared using NASA's DIF v10.0 interchange format.

## Search and Download Facility

The metadata are searchable by instrument site, type and sampling interval. Datasets are archived per Field Instrument, File Type and Processing Level and may be filtered by date ranges. Data selected for download is compressed and bundled and made available via an FTP site with a temporary login.

<https://sandims.sansa.org.za/>

# Instrumentation in Africa

## Current Partners:



### **Zimbabwe**

Zimbabwe National Geospatial and Space Agency (ZINGSA)



### **Nigeria**

University of Lagos (UNILAG)



### **Ethiopia**

Bahir Dar University



### **South Africa**

- South African National Space Agency (SANSA)
- National Geospatial Information (NGI) TRIGNET



### **Zambia**

Kwame Nkrumah University (KNU)



### **Namibia**

Ministry of Mines and Energy (MME)



### **Uganda**

Busitema University (BU)



### **Kenya**

Pwani University (PU)  
Kenyan Space Agency (KSA)



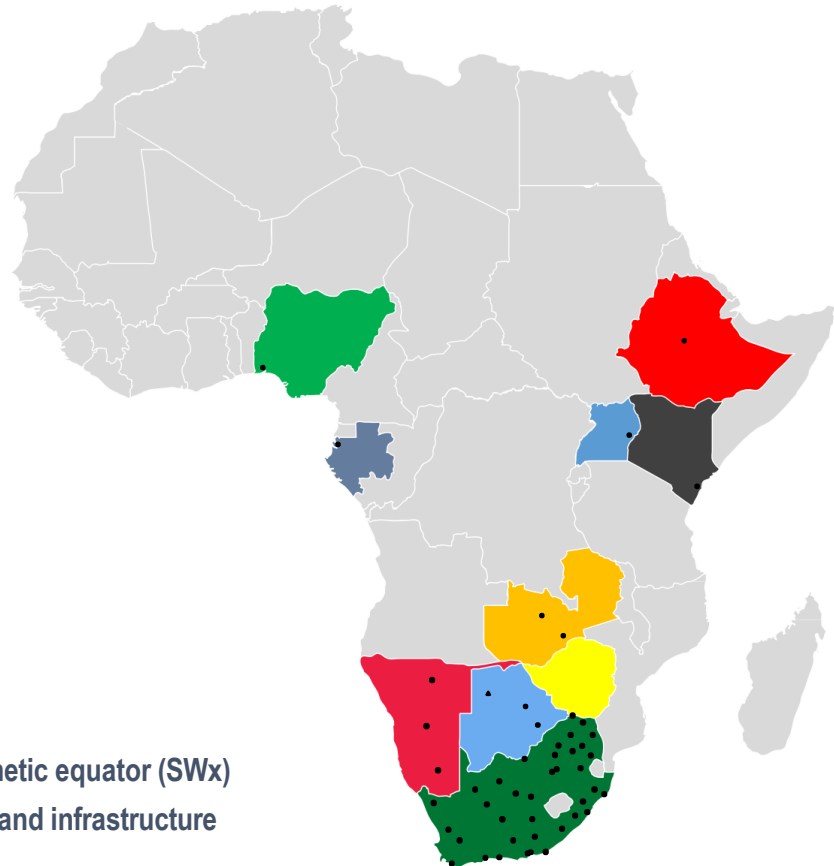
### **Gabon**

L'Agence Gabonaise d'Etudes et d'Observations Spatiales (AGEOS).



### **Botswana**

Botswana International University of Science and Technology (BIUST)



## More to come!

Focus is currently on the SADC region (SBAS + SWx) and the magnetic equator (SWx)

Focus is currently on the deployment of GNSS stations as the cost and infrastructure requirements offer the best value in terms of the outputs gained.

The African Instrumentation Network







## Operationalise Space Weather

*Provide 24/7 operational space weather services to the African region from November 2022*

- ✓ develop capability
- ✓ derive economic benefit
- ✓ provide a national platform
- ✓ ensure credibility
- ✓ fill the expertise gap
- ✓ provide quality services
- ✓ contribute to the knowledge economy
- ✓ create opportunities & partnerships
- ✓ increase the value proposition of space science



## Explore the SANS Space Weather Centre



<https://www.youtube.com/watch?v=eICp6XEWoVo>



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# Some Other Known Research Groups with Multiple SW Monitoring facilities

- Space Weather Monitoring Centre, Helwan University, Egypt
- Bahir Dar University, Ethiopia
- Universite Felix Houphouet-Boigny, Abidjan, Cote D'ivoire
- Pwani University, Kenya





# GNSS RINEX databases

## SOPAC GPS RINEX Database

<http://sopac-old.ucsd.edu/dataBrowser.shtml>

## NASA GPS RINEX Database

[https://cddis.nasa.gov/Data\\_and\\_Derived\\_Products/GNSS/RINEX\\_Version\\_3.html](https://cddis.nasa.gov/Data_and_Derived_Products/GNSS/RINEX_Version_3.html)

## Nigerian GNSS RINEX Database

<https://teronet.nignet.net/>

## South Africa GPS RINEX Database

<http://geodesy.hartrao.ac.za/site/en/data-and-products.html>

## UNAVCO GPS RINEX Database

[http://facility.unavco.org/data/gnss/perm\\_sta.php](http://facility.unavco.org/data/gnss/perm_sta.php)







# Calculated GPS TEC

**Madrigal data base (MIT)**

<http://millstonehill.haystack.mit.edu/>

**ICTP data base**

*<https://arplsrv.ictp.it/>*

<https://t-ict4d.ictp.it/nequick2/gnss-tec-calibration>



# Model outputs

***Community Coordinated Modeling Center (CCMC)***

**<http://ccmc.gsfc.nasa.gov/>**

The African GNSS TEC (AfriTEC) Model

**<https://arcsstee.org.ng/african-gnss-tec-models/>**

NeQuick

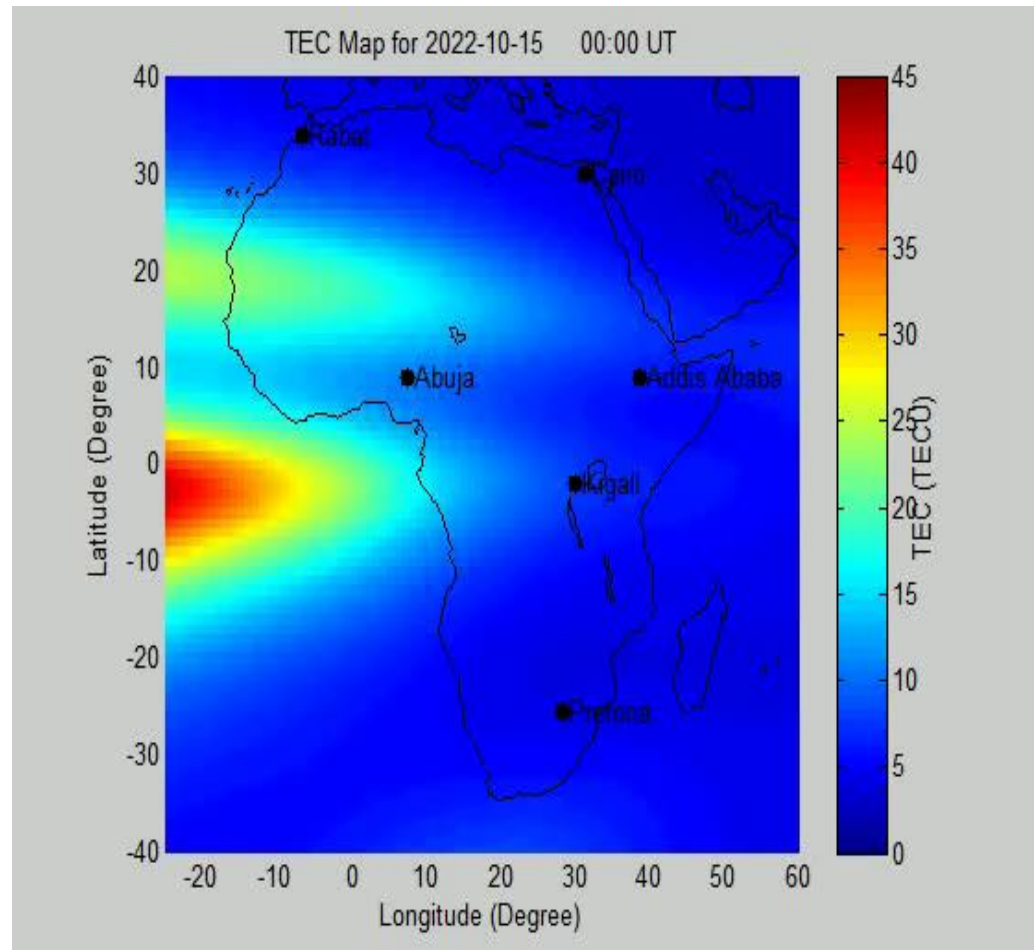
**<https://t-ict4d.ictp.it › nequick2>**



# AfriTEC Model

## The African GNSS TEC (AfriTEC) Model

- a model of the ionospheric GNSS TEC over the entire African region
- used to obtain the ionospheric GNSS TEC at all locations over the African continent.
- The model is developed by the method of artificial neural networks.



<https://arcsstee.org.ng/african-gnss-tec-models/>



# OPPORTUNITIES

Eastern Africa Cap. Building Wkshop on Space Weather & Low-latitude Ionosphere, Malindi, Kenya, 03 - 12 October 2023



# Some opportunities for research visits at standard research facilities/laboratories across Africa



UN-ARCSSTE-E

- ✓ Short/long term research visits
- ✓ SCOSTEP Visiting Scholar Fellowship
- ✓ Virtual interactions

# University Support Program (USP) & SCOSTEP Visiting Scholar (SVS) Program @ UN-ARCSSTEE



**Kebbi State Univ**



**OAU, Ile-Ife**



**Univ of Ilorin**



**Addis Ababa Univ, Ethiopia**



**George, Kenya SCOSTEP SVS**



<https://scostep.org/svs/>

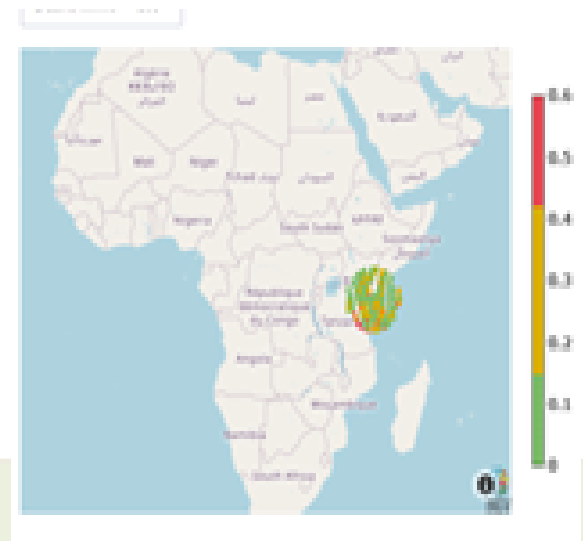


# New ionospheric observatory in Luigi Broglio Malindi Space Center (Kenya)

Courtesy : Claudio Cesaroni, INGV

## Collaboration

- ✓ Istituto Nazionale di Geofisica e Vulcanologia (INGV)
- ✓ Italian Space Agency (ASI)



- ☐ ASI ionosonde
- ☐ GNSS receiver for scintillation monitoring.

Data are freely available in real time @ eSWua webportal.  
For more details on the project <http://norisk.rm.ingv.it/>

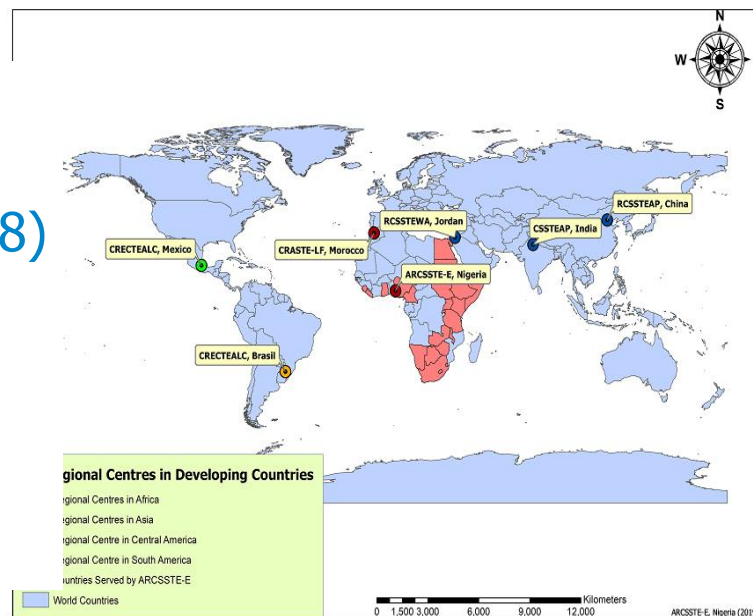
# Regional Centres for Space Science and Technology Education (affiliated to the United Nations)

## African Centres

ARCSSTE-E (Anglophone – NIGERIA (1998)  
CRASTE-LF (Francophone - MOROCCO) (1998)

## Other Centres

India (inaugurated 1995)  
Mexico/Brazil (inaugurated 2003)  
Jordan (inaugurated 2012)  
China (inaugurated 2014)



## Core Activities

### 1. Education

- Post Graduate Diploma (PGD)
- M.Sc, PhD
- Space Education and Outreach Programme (SEOP)

### 2. Research & Development

### 3. Short Term Training in SST

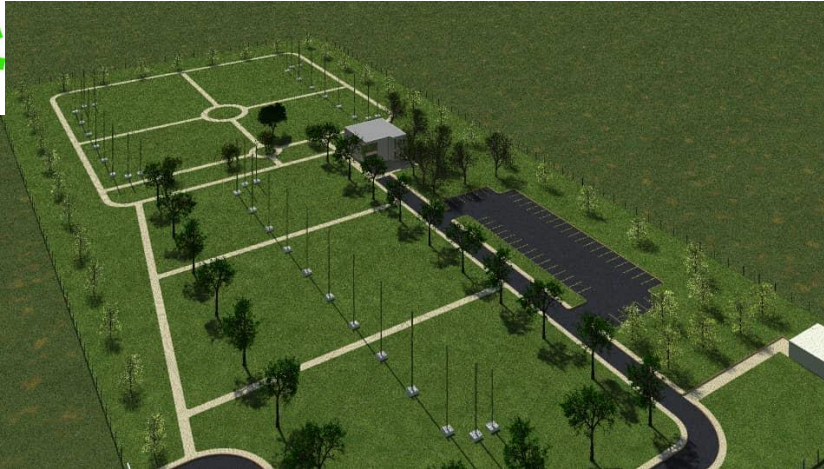
## 6 Thematic Areas of Space S & T

- Remote Sensing/ GIS
- Satellite Communication
- Satellite Meteorology/Global Climate
- Space Science/Space Weather/Atmospheric Physics
- Global Navigation Satellite Systems (GNSS)
- Space Law



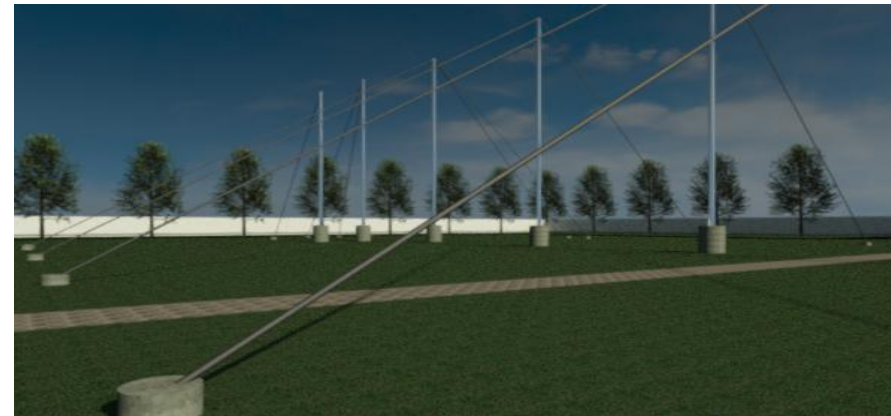
# VT-Nigerian Bowen Equatorial Aeronomy RADAR

## VT-NigerBEAR



BOWEN UNIVERSITY - VIRGINIA TECH -  
NASRDA COLLABORATION

Equivalent of SuperDARN in low latitude



- Domiciled at Bowen University, Iwo, Nigeria
- 1<sup>st</sup> of its kind in low latitudes
- enhancement of research capability
- new science results that could improve our understanding of the equatorial ionosphere and space weather
- multi-technique approach to study the ionosphere

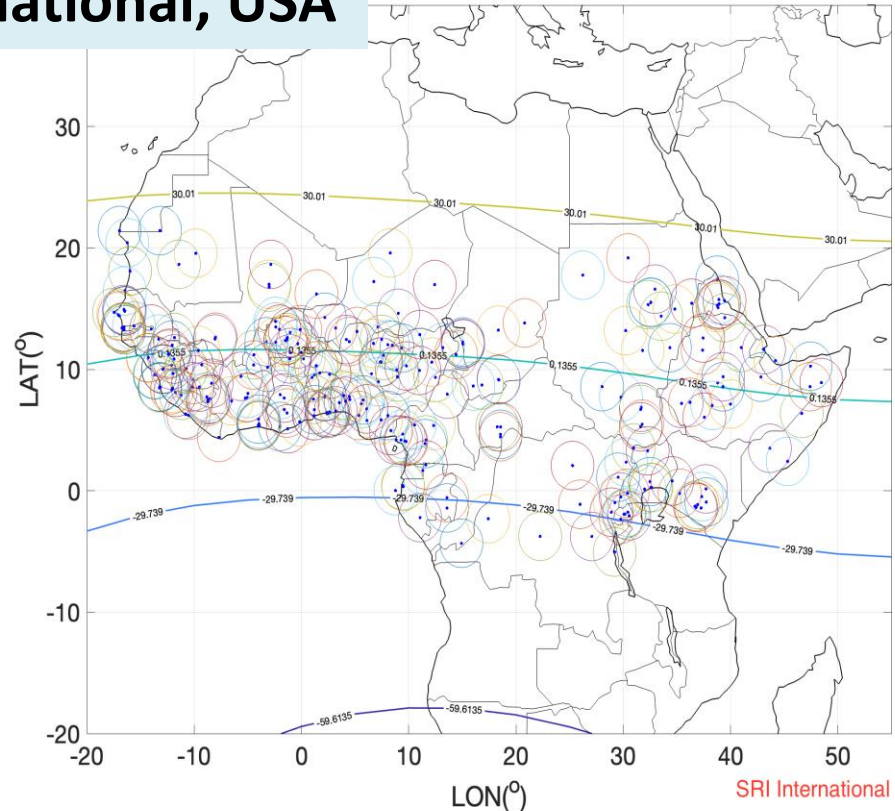
**PI: Dr. O. S. Bolaji**  
**[oloriebimpjch2002@yahoo.co.uk](mailto:oloriebimpjch2002@yahoo.co.uk)**



# Continuous Network of GNSS Receivers over Africa (CONGA)

PI: Dr Olusegun Jonah, SRI International, USA

- A proposal
- About 281 GNSS Rx
- Solar powered units
- About 28 countries
- Interested participants should email:  
***olu.jonah@sri.com***



<https://forms.gle/g3XHKARPwkwBbjGH6>

# Some EXTRA Useful Data Sources

Hourly  
geomagnetic data



- World Data Center for Geomagnetism, Kyoto  
<http://wdc.kugi.kyoto-u.ac.jp/hyplt/index.html>
- World Data Center for Geomagnetism, Edinburgh  
<http://www.wdc.bgs.ac.uk/catalog/master.html>

Hourly solar wind  
data



- OMNIWeb (NASA/GSFC's Space Physics Data Facility)  
<http://omniweb.gsfc.nasa.gov/ow.html>

Kp index and IQDs



- GFZ German Research Centre for Geosciences  
<http://www.gfz-potsdam.de/en/kp-index/>

Ionospheric  
conductivity model



- World Data Center for Geomagnetism, Kyoto  
[<http://wdc.kugi.kyoto-u.ac.jp/ionocond/exp/icexp.html>]

# Some EXTRA Useful Data Sources

NCAR TIE-GCM



- High Altitude Observatory, NCAR, Boulder  
<http://www.hao.ucar.edu/modeling/tgcm/>

Hourly Dst index



- World Data Center for Geomagnetism, Kyoto  
<http://wdc.kugi.kyoto-u.ac.jp/dstae/index.html>

Sunspot number



- Sunspot Index and Long-term Solar Observations  
<http://www.sidc.be/silso/datafiles>

F10.7 solar activity index



- OMNIWeb (NASA/GSFC's Space Physics Data Facility)  
<http://omniweb.gsfc.nasa.gov/form/dx1.html>

# Some EXTRA Useful Data Sources

MgII solar activity  
index



- University of Bremen  
<http://www.iup.uni-bremen.de/gome/gomemgii.html>

Solar EUV flux



- Space Science Center, University of Southern California  
[http://www.usc.edu/dept/space\\_science/sem\\_data/sem\\_data.html](http://www.usc.edu/dept/space_science/sem_data/sem_data.html)



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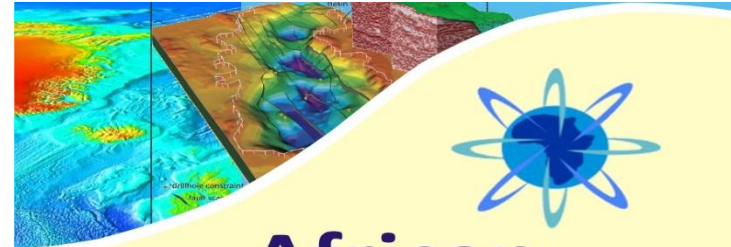
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Telephone: +234 803 0705787**



# Last words: Growing your Career

## Self motivation

- Be determined
- Have a focus
- Identify a scientific problem
- Literature review
- Set out objectives
- Find a guide/mentor
- Stay mentor-able

## Stay enterprising

- Networking
- Newsletters
- Workshops and conferences announcements
- Be productive
- Check your email regularly
- Check relevant webpages

**Obey data rules and rules of cooperation anywhere**



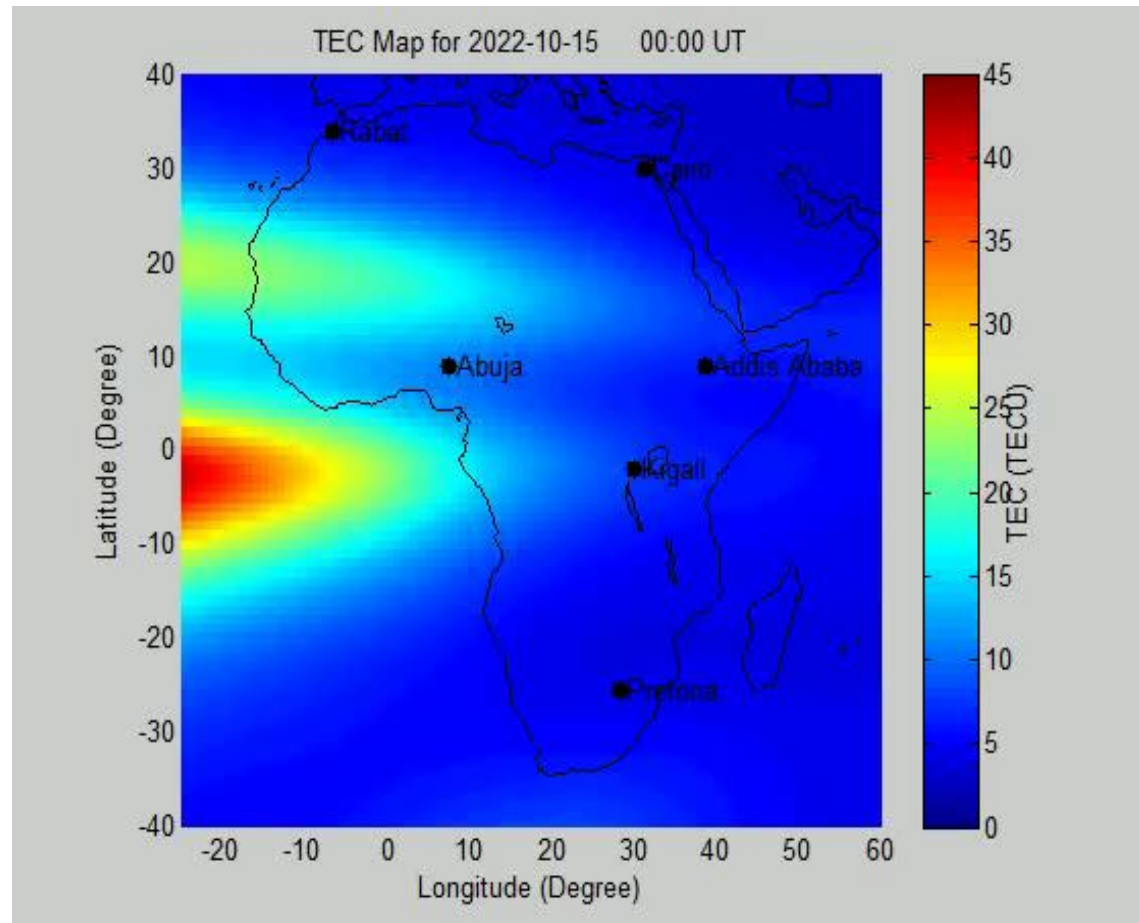
# Summary

- ☐ There is a growing interest in densifying the GNSS ground infrastructures in Africa
- ☐ Some facilities and optimal size of experts are available for ionospheric and space weather research in Africa
- ☐ Networking and consistency remain critical keys in progressive research





# Thank You



<https://arcsstee.org.ng/>



Eastern Africa Cap. Building Wkshop on Space Weather & Low-latitude Ionosphere, Malindi, Kenya, 03 - 12 October 2023