An updated vision of availability of TEC GNSS derived ground observations in Africa

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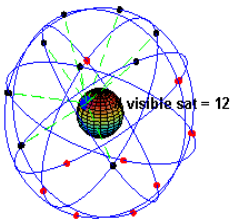


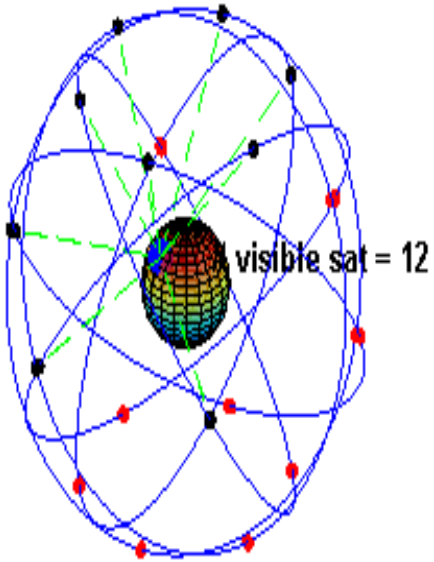
Outline

- Chronological evolution of GNSS ground infrastructure
- GNSS infrastructure densification programs
- Analysis of TEC derived from ground based GNSS observations offered corrective contributions to existing models
- National governments participation
- Some results from GNSS derived TEC.
- Summary

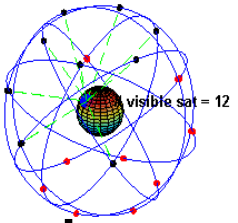
Know Africa !

- A continent
- 54 Sovereign nations
- Multi-lingual structure
- English, French, Portuguese, Arabic, Spanish
- ~ 30 billion km^2
- ~ 1.19 billion people
- ~17% World population

Applications of GNSS Technology in Africa



Science with GNSS



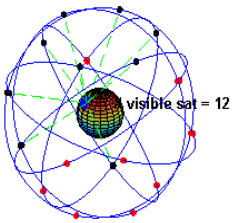
➢ Atmospheric & Geophysical research

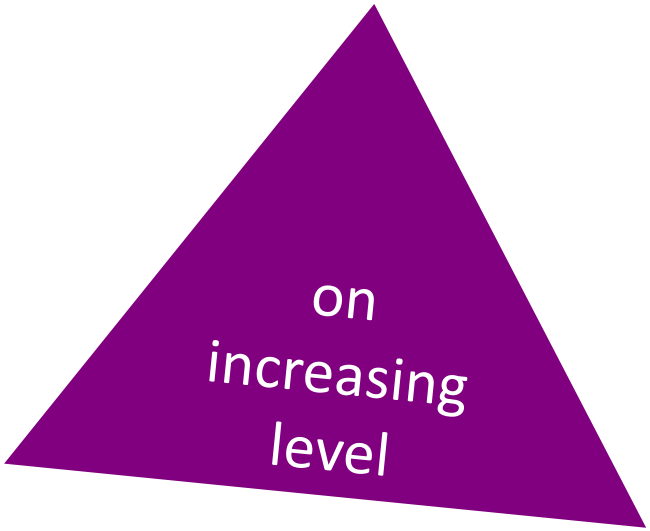
- Characterization of ionosphere using TEC
- Space weather studies
- Scintillation studies
- Atmospheric delay
- TIDs
- Validation/improvement of existing atmospheric models
- Water vapour estimation
- Climate change studies
- Seismic studies

Output ⇒

- ✓ PhDs
- ✓ M.Sc
- ✓ Research publications

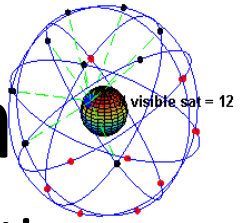
Social-Economic Applications of GNSS





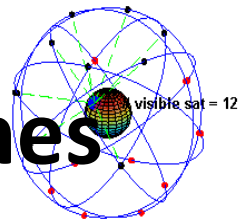
- positioning services,
- surveying & mapping,
- Boundary mapping
- food security,
- disaster management,
- air, land & sea navigation,
- Land administration
- emergency response
- Wild life management

Densification of GNSS in Africa



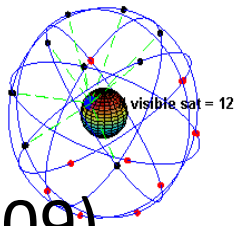
- IGS started deployment of GPS receivers to Africa for geodetic purpose
- The United Nations – endorsed programs tagged International heliophysical Year IHY (2004-2009) and International Space Weather Initiative ISWI (2009 – date) combined with some other initiatives to expose the data gaps in ionospheric 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
- AMMA - www.amma-international.org,
- National Reference Frames
- IHY/ISWI
- AfricaArray
- ICTP-BC joint GNSS program

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



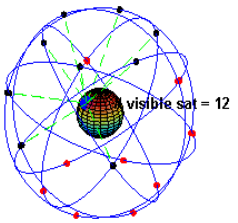
International Heliophysical Year 2007 (IHY, 2005-2009) & International Space Weather Initiative (ISWI, 2010 -).

IHY/ISWI ANCHORS

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

www.ihy2007.org

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



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

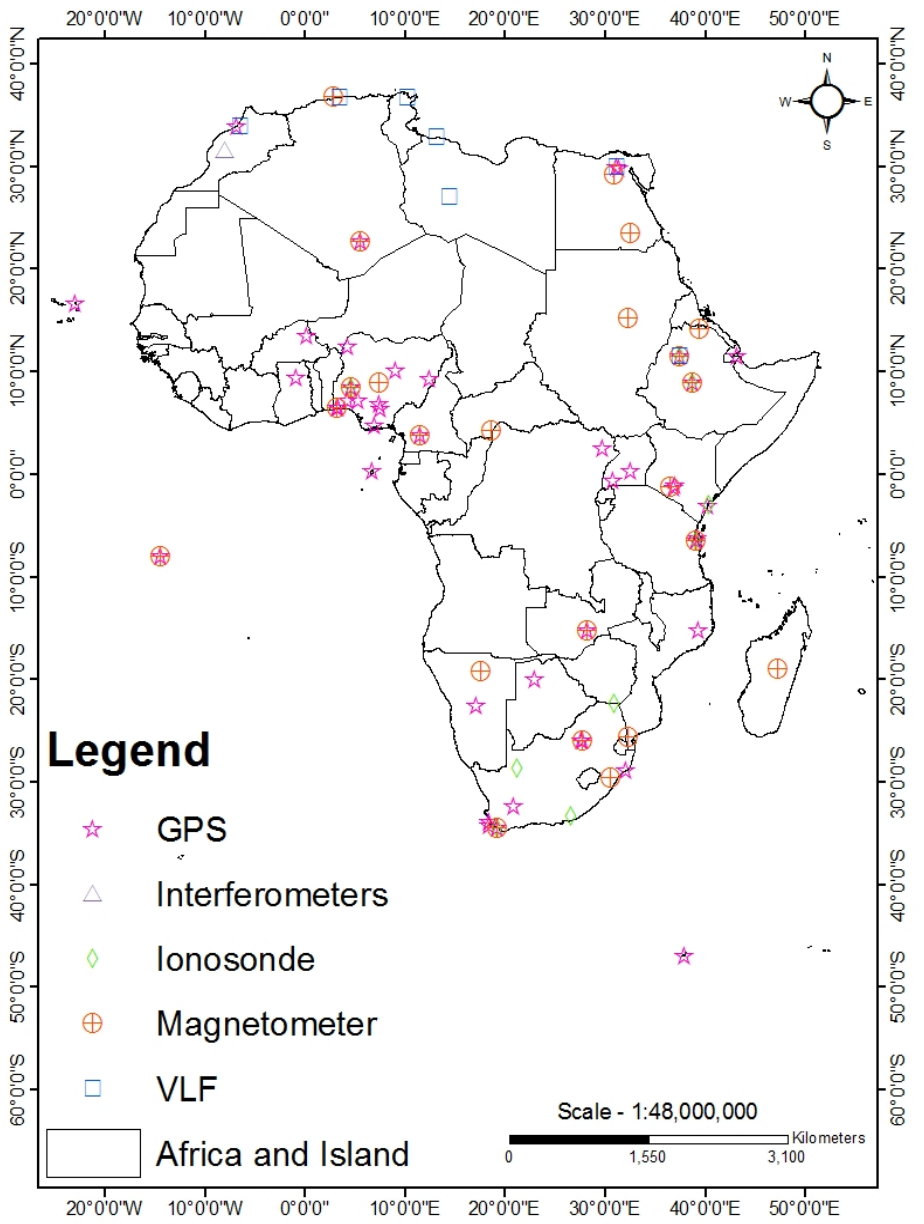
http://www.spaceweather-eg.org/iswi/

IHY/ISWI

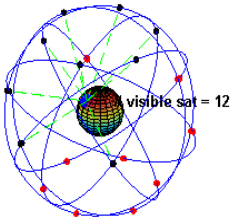
increase in # of stations that can serve as CORS in Africa in recent time

SCintillation Network Decision Aid (SCINDA) -US Air Force Research Lab Project – PI Keith Groves,

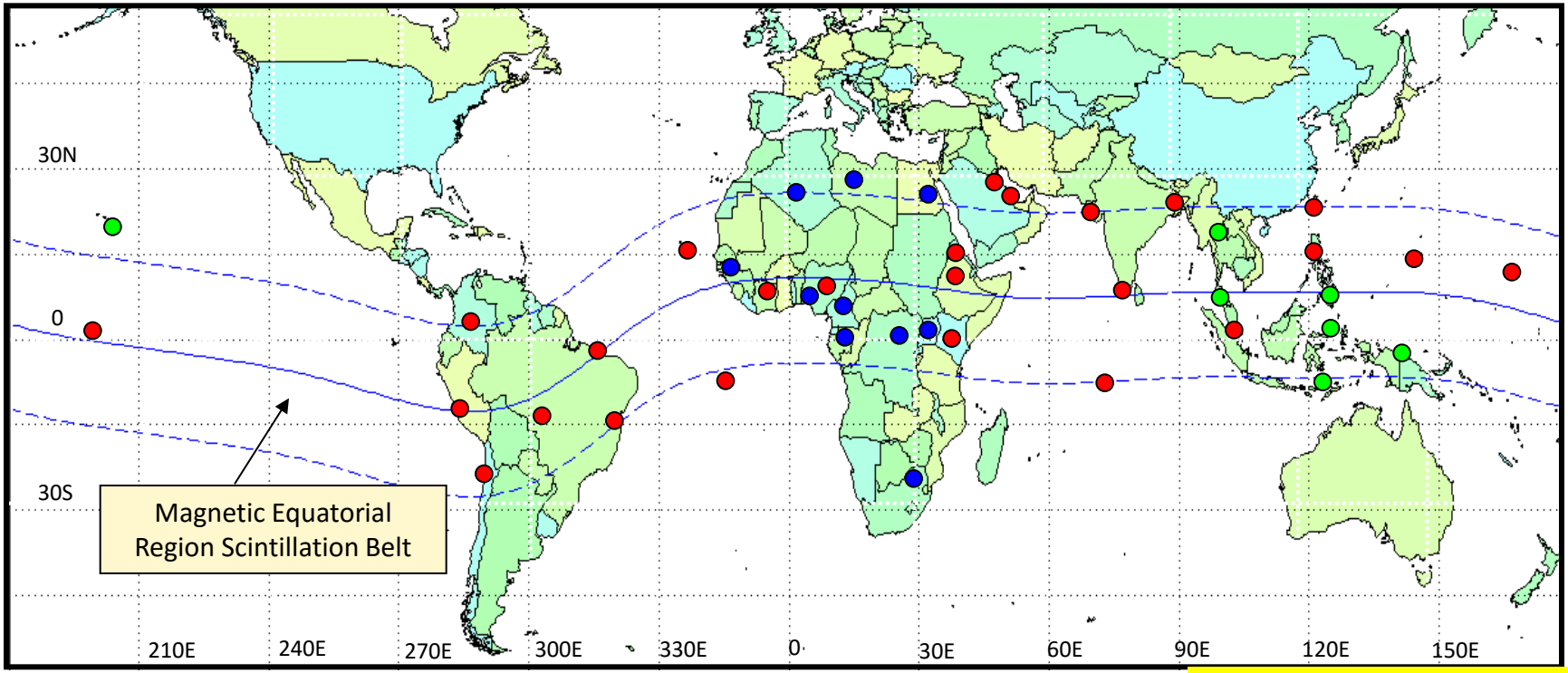
A regional nowcasting system to support research and users of space-based communication and navigation systems



SCINDA Ground Stations

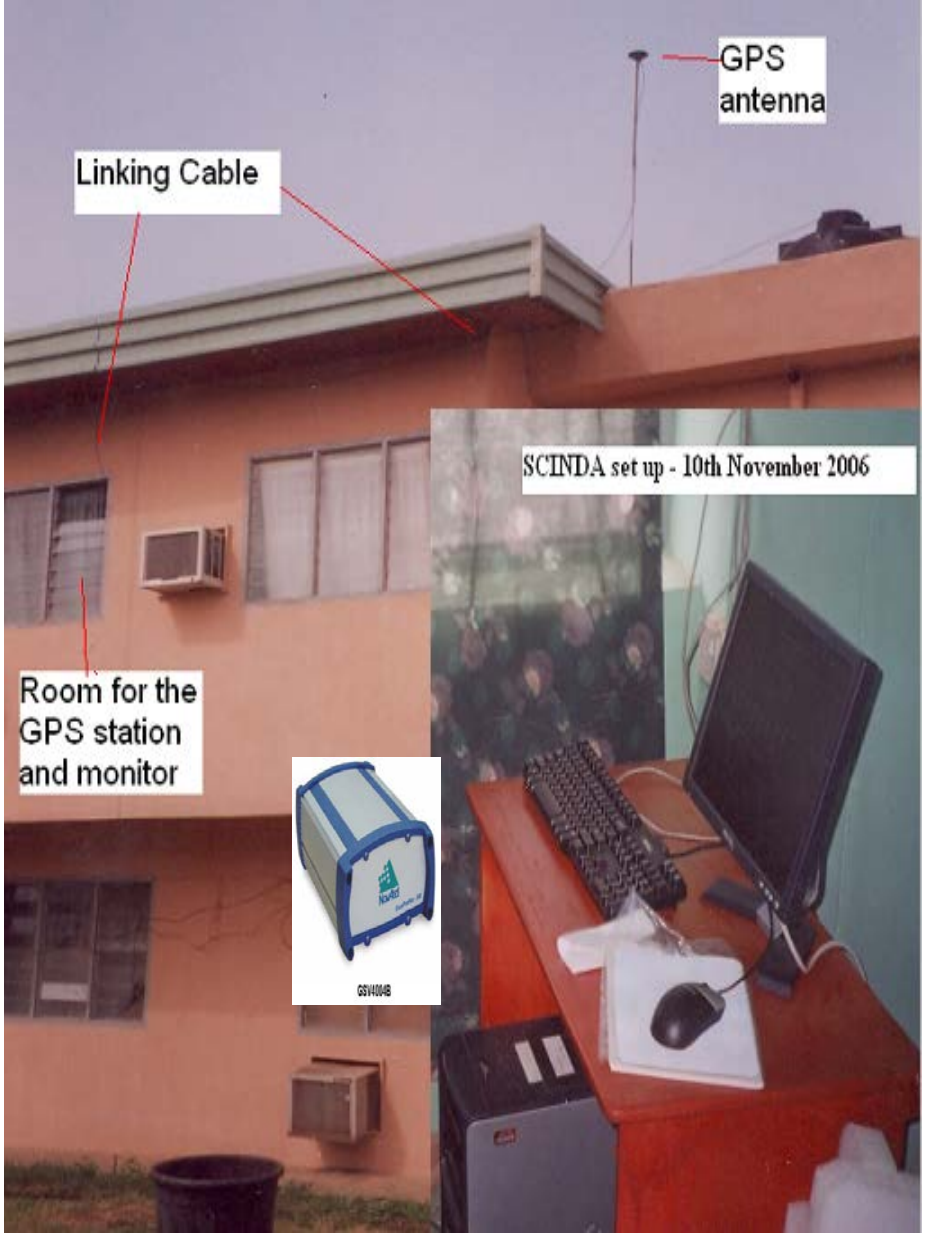


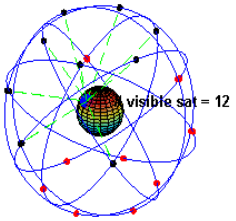
- Broad range of magnetic equator over land
- EIA width



[Groves, 2010]

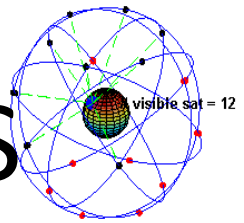
Existing Sites UN IHY Sites Other/collaboration





SCINDA facility at Akure, Nigeria

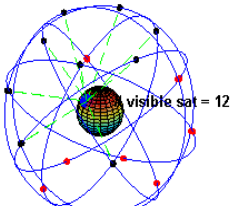
International GNSS Service IGS



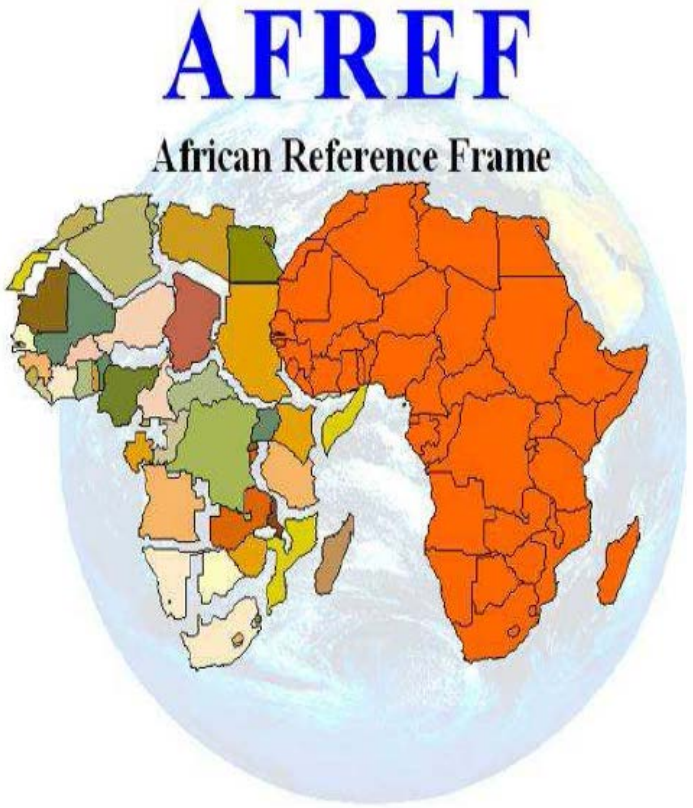
- The IGS global system produces high-quality GPS data and data products on line in near real time to meet the objectives of a wide range of scientific and engineering applications and studies
- improvement and extension of the International Terrestrial Reference Frame (ITRF),
- the monitoring of Earth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

https://igscb.jpl.nasa.gov/overview/viewindex.html

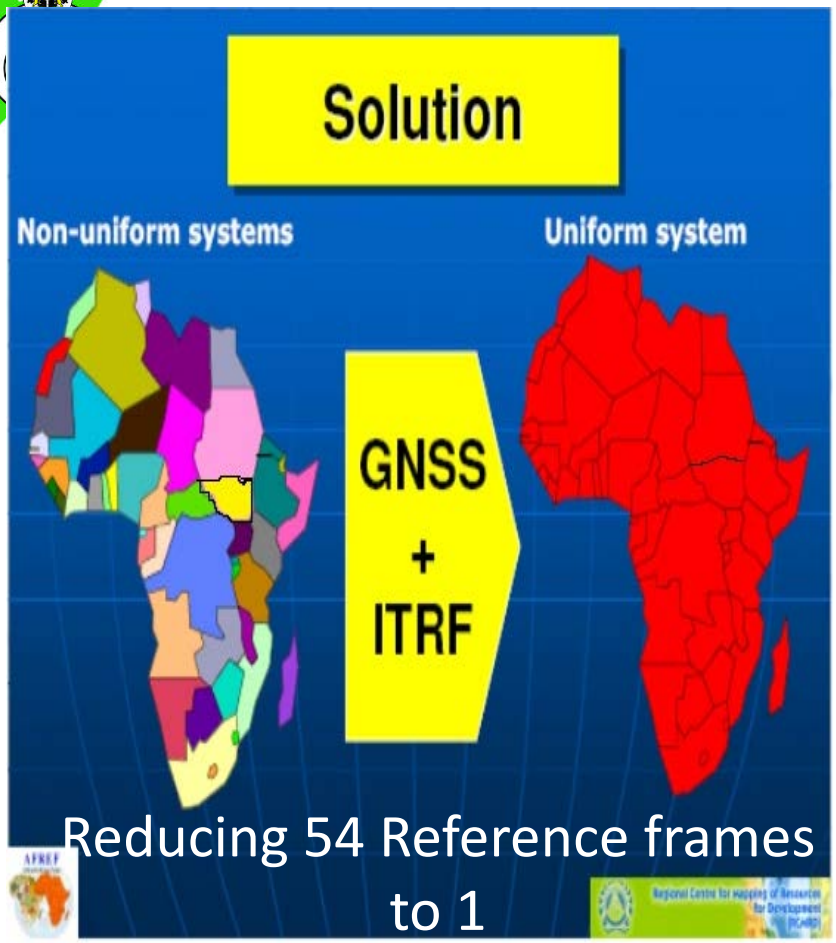
The African Geodetic Reference Frame



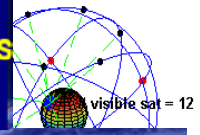
- a unified geodetic reference frame
- fundamental basis for the national & regional three-dimensional reference networks
- fully consistent and homogeneous with the International Terrestrial Reference Frame ITRF
- Densification of GNSS networks with its products in Africa
- IGS has strong alliance with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

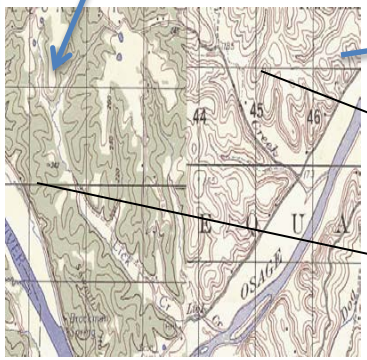


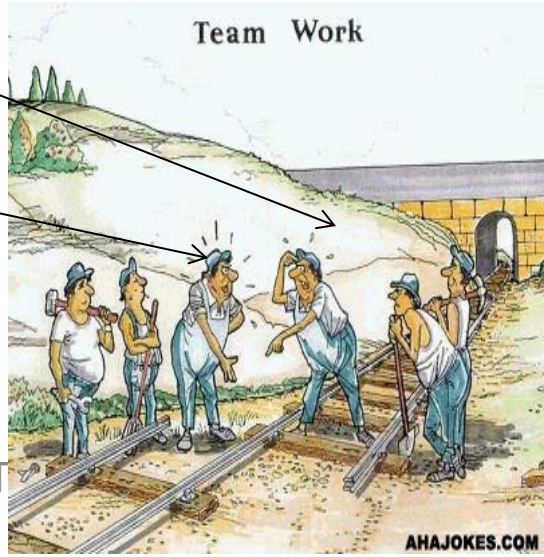
http://geoinfo.uneca.org/afref/



Consequences of using reference systems that are not consistent !

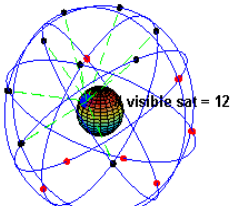




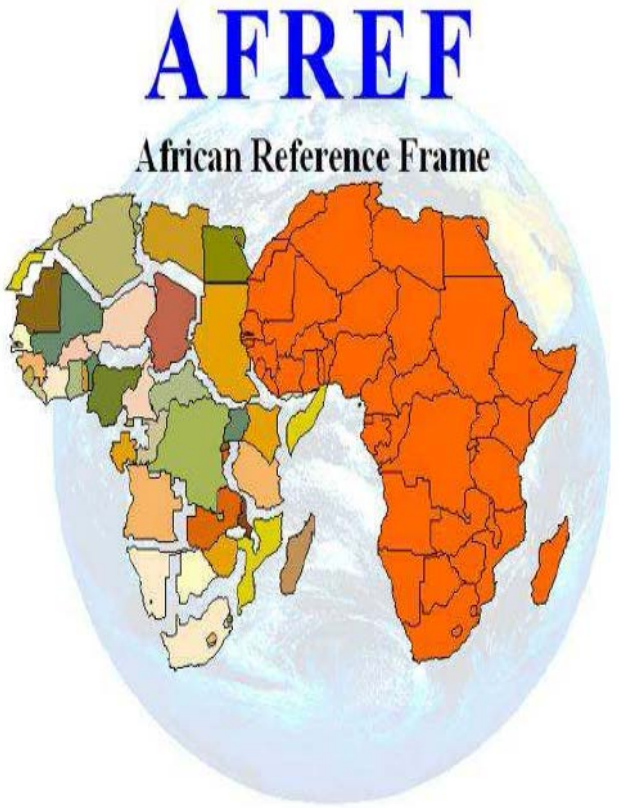


Combrinck (AFREF Presentation Berlin GNSS 2008)

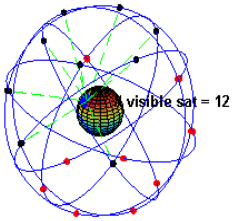
The African Geodetic Reference Frame

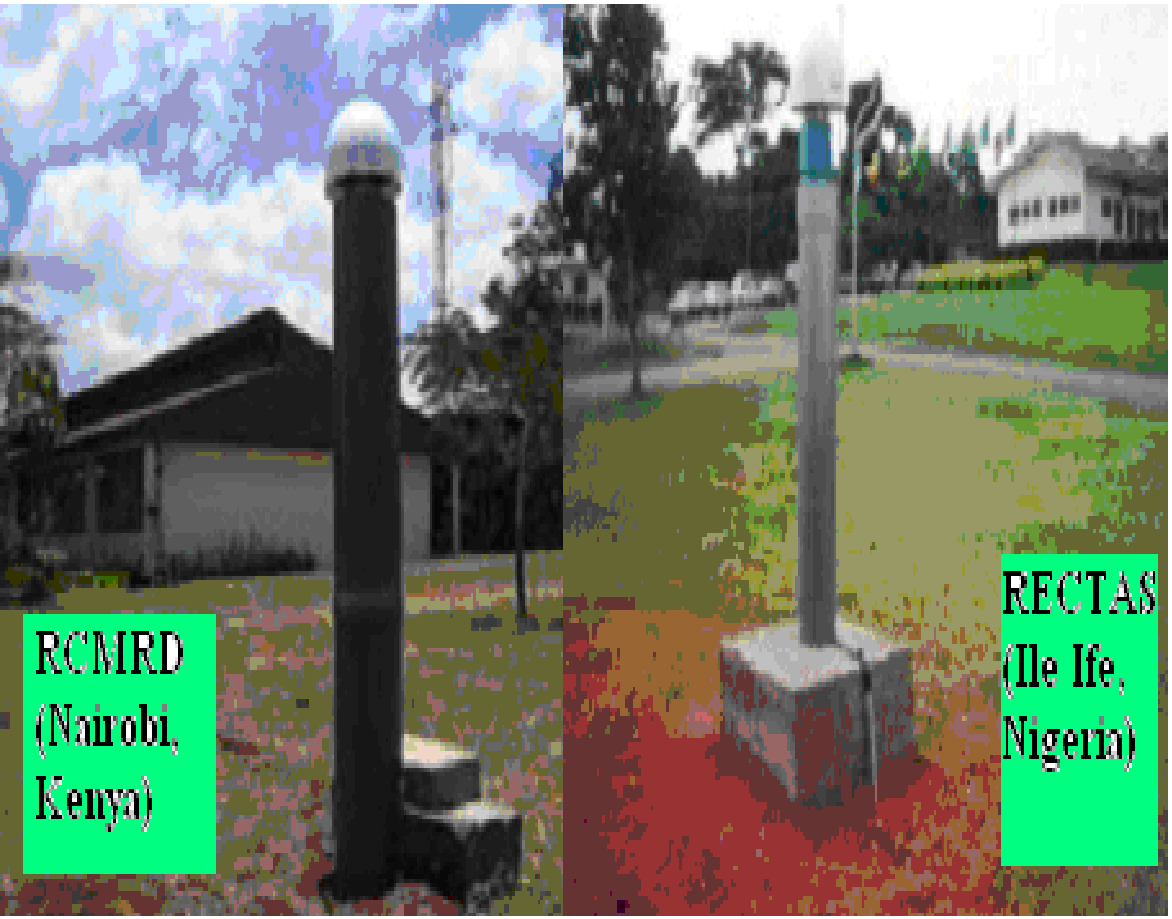


- Full implementation will include a unified vertical datum and support for efforts to establish a precise African geoid
- More than 5 countries have established a network of CORS: Ghana, Tanzania, South Africa, Nigeria and Egypt. About 20 countries now have at least one CORS. AFREF CORS are linked to IGS .
- Nigeria has 14 CORS in her network.
- RSA has 67 CORS

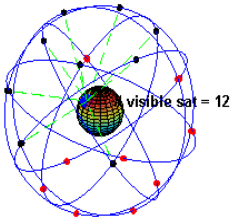


http://geoinfo.uneca.org/afref/





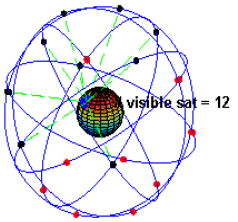
Typical AFREF CORS



AfricaArray: partners.

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

http://www.africaarray.psu.edu

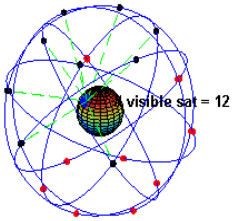


AfricaArray

- 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

http://www.africaarray.psu.edu

AfricaArray: Operations

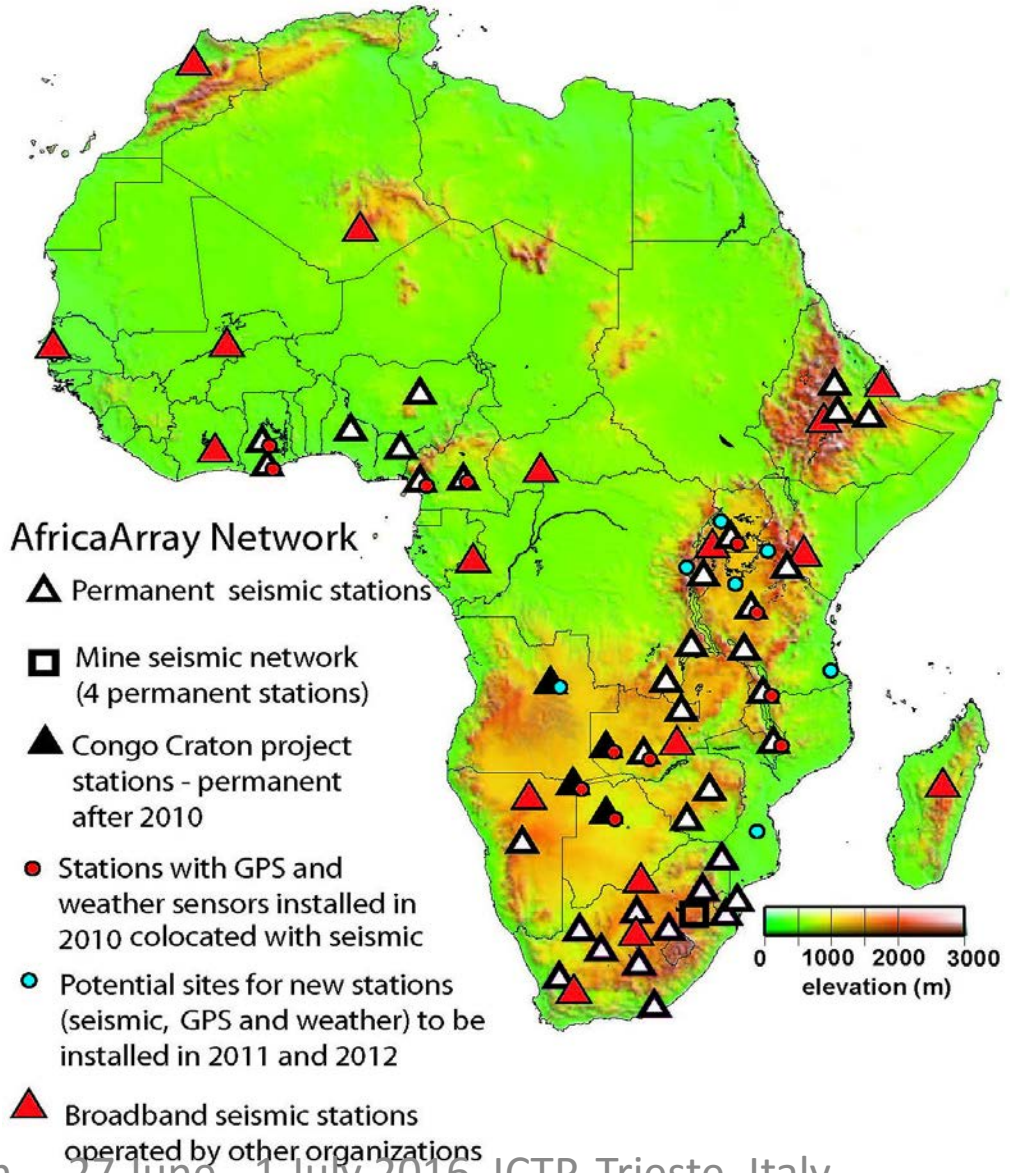


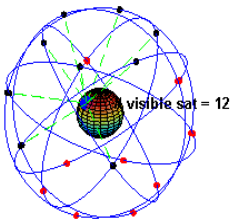
- A network of shared scientific observatories across Africa linked through common instrumentation, data access, and operation
- Data from the observatories provide the underpinning for much of the science supported by *AfricaArray.* Some of the observatories are permanent, while others are installed and operated on a temporary basis
- The first phase of *AfricaArray* (2005-2007) established a network of 20 to 30 permanent observatories spanning much of southern and eastern Africa
- the second phase of *AfricaArray* (2008-2010), the network of permanent observatories was expanded into other parts of Africa

AfricaArray stations

- starting in August, 2010, many of the observatories are being equipped with GPS receivers and automated weather stations.
- data are archived at the UNAVCO Data Management Facility

UNAVCO



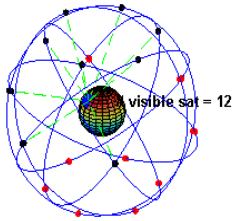


UNAVCO

- originated as the University NAVSTAR Consortium
- 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)

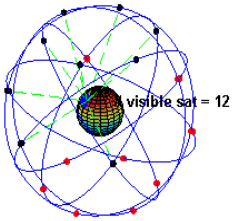
www.unavco.org

ICTP-BC GNSS in Africa



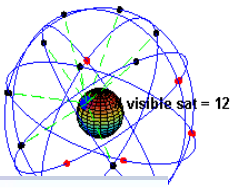
- Partnership between Boston College, USA & Abdus Salam ICTP, Trieste, Italy.
- Series of annual Workshops since 2009
- Deployment of GPS stations in Africa
- Over 400 African scientists have been trained at ICTP
- Leading experts in GNSS teach at the annual workshops
- A training model

installed GPS antenna at Sokoto, Northern Nigeria, 6th Nov 2013

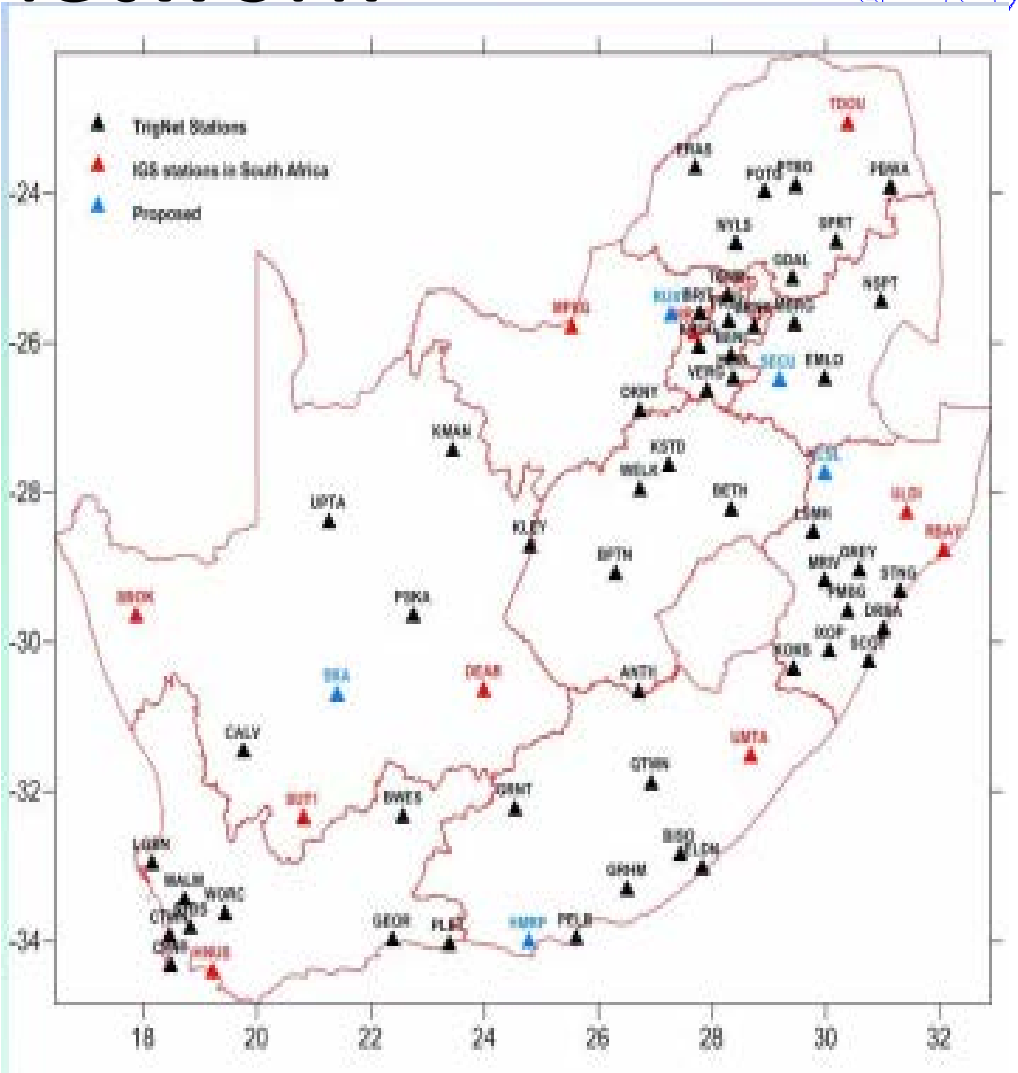


SOME NATIONAL REFERENCE FRAMES

RSA: TrigNet network



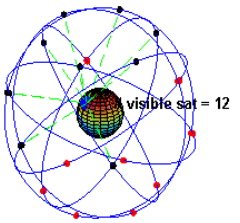
- 67 base stations,
- maximum inter-station spacing distance of 300 km
- The data is streamed, via dedicated leased lines, to the National Geospatial Information NGI office in Cape Town
- where it is processed and made available, free of charge, to national & international users.



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

[Rubinov et al, 2012]

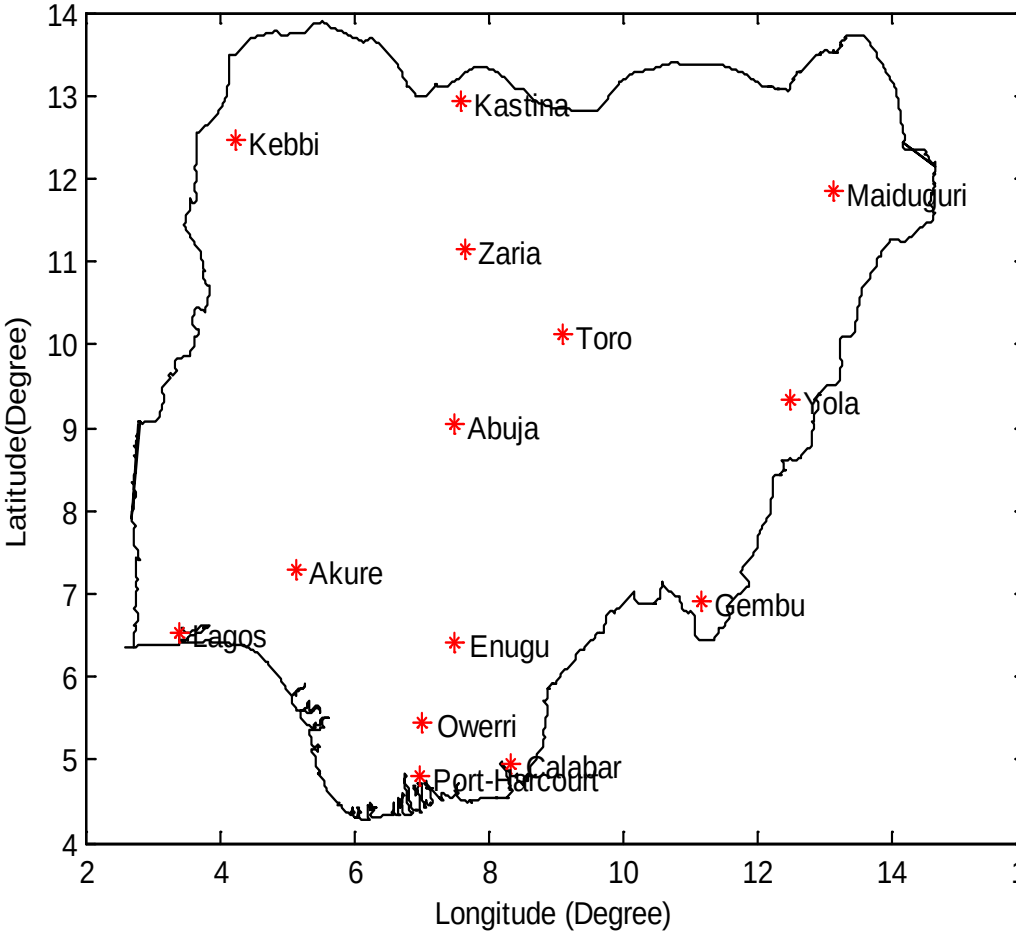
NIGERIA: NIGNET



- Primarily meant for land mapping and surveying
- RINEX files were accessed and 1st 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)
- 14 CORS

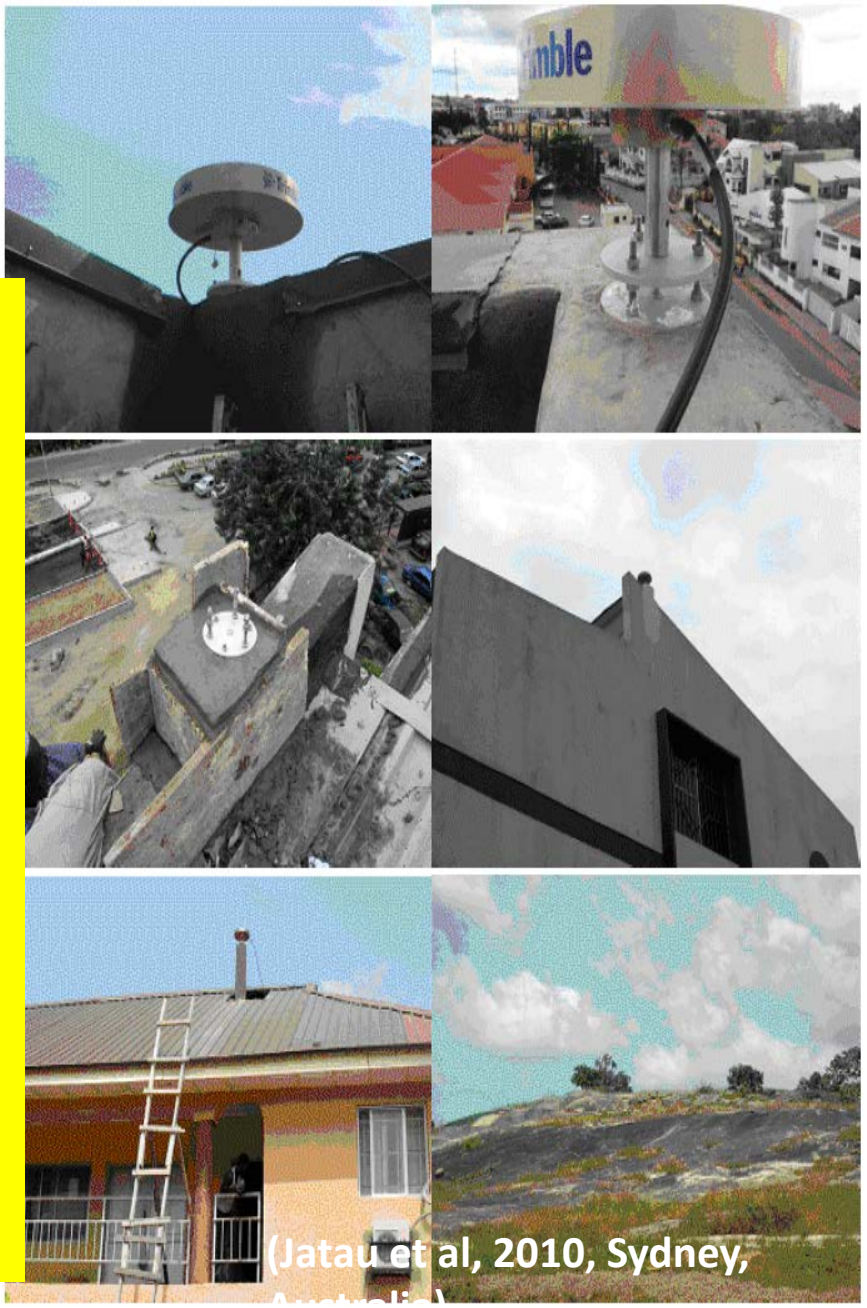
http://server.nignet.net/data/

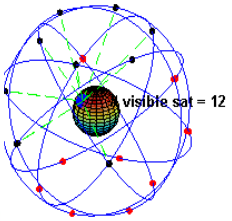
(Jatau et al, 2010)

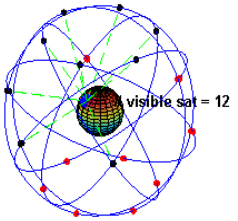


NIGNET

- **Top – OSGF station installed at OSGoF headquarters, Abuja**
- **Middle – UNILAG station installed at the campus of University of Lagos.**
- **Bottom Left –FUTY station installed at Federal University of Technology of Yola**
- **Bottom Right - location at Toro.**





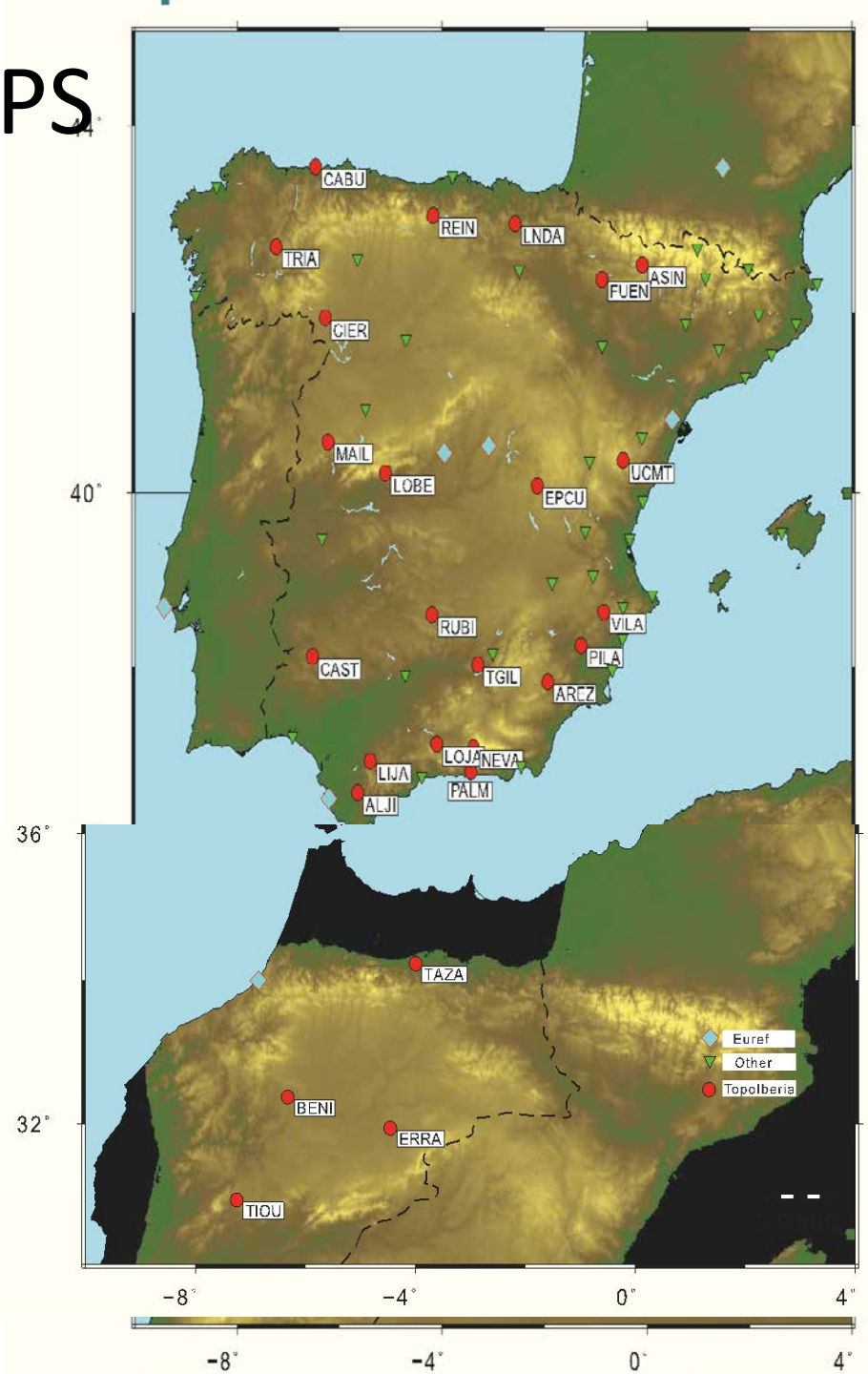


Ghana: Land Administration Project

- 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



Ethiopian Afar GPS campaign 2006-2009

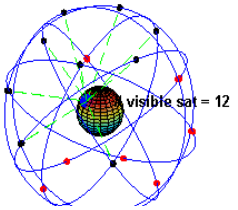
- eastern Ethiopia
- A 60 km long dyke opened up in the Dabbahu segment in 2005 that marked the beginning of a continuing rifting episode.
- 14 permanent CORS GPS sites and over 20 campaign sites
- The majority of the CGPS stations were installed in 2006/2007
- UNAVCO supported the Afar Rift project,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

www.unavco.org/highlights/2009/afar.html

Map depicting the GPS network surrounding the Dabbahu Rift (black diagonal lines). Continuous stations are in blue and permanent stations are in red

PI Eric Calais: Purdue University

IGS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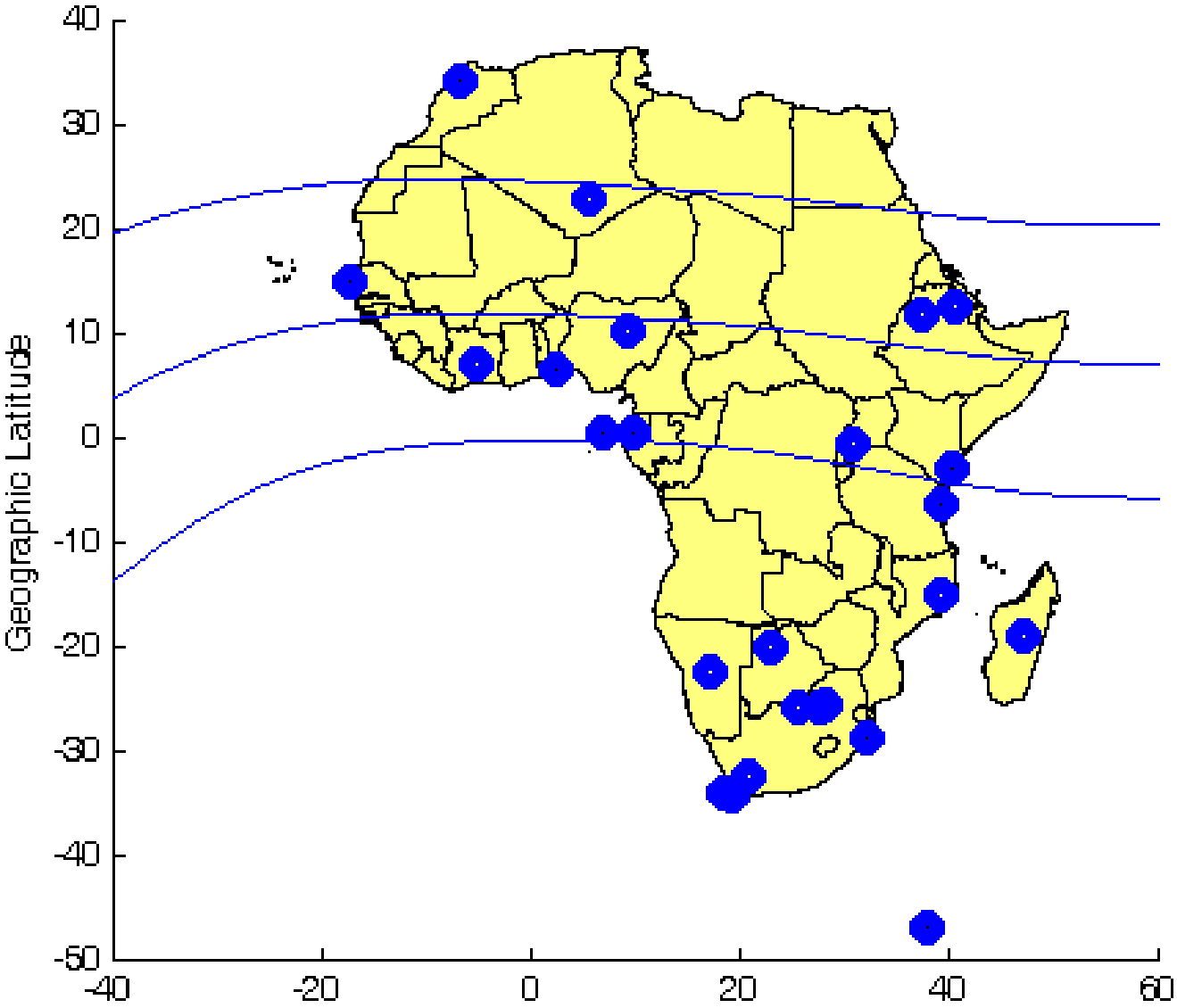
Geographic Latitude
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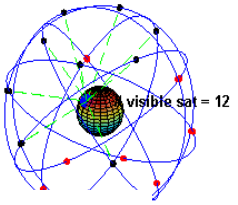
-40
-20
0
20
40
60

AFAR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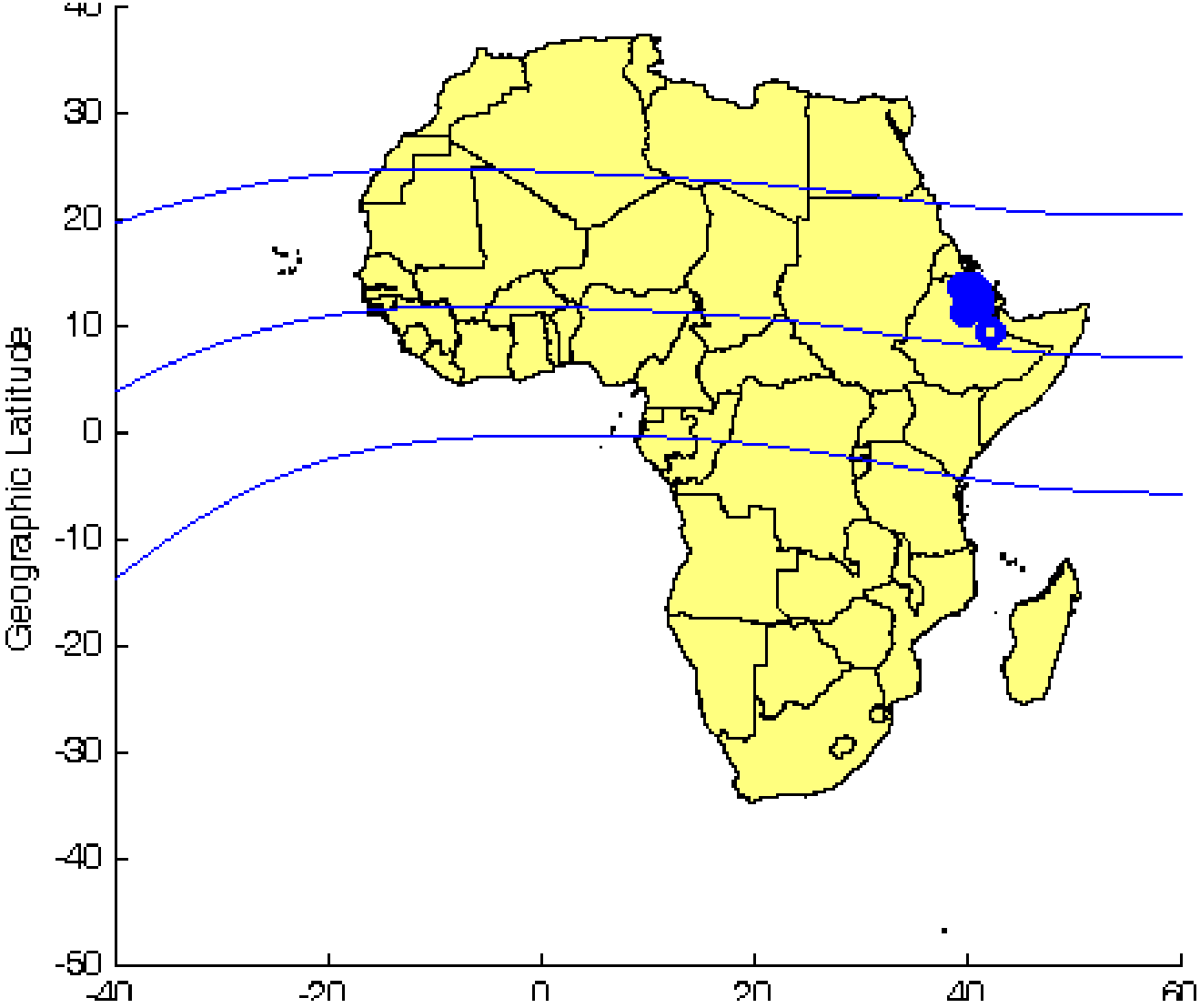
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0
20
40
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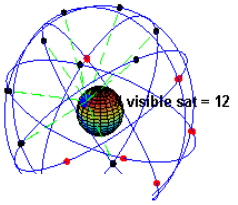
AMMA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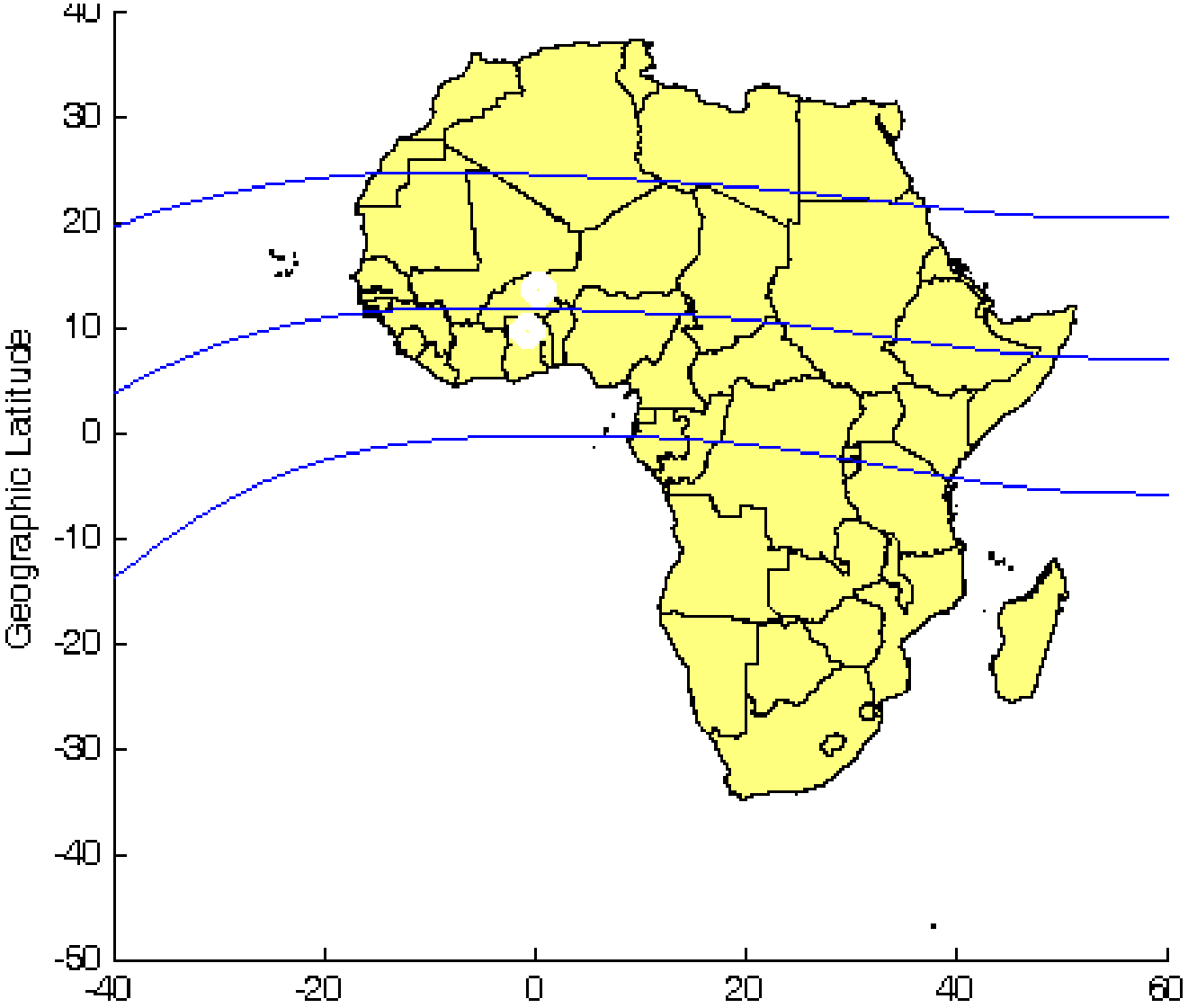
Geographic Latitude
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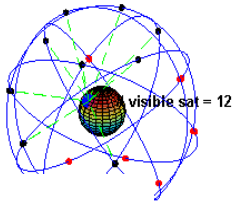
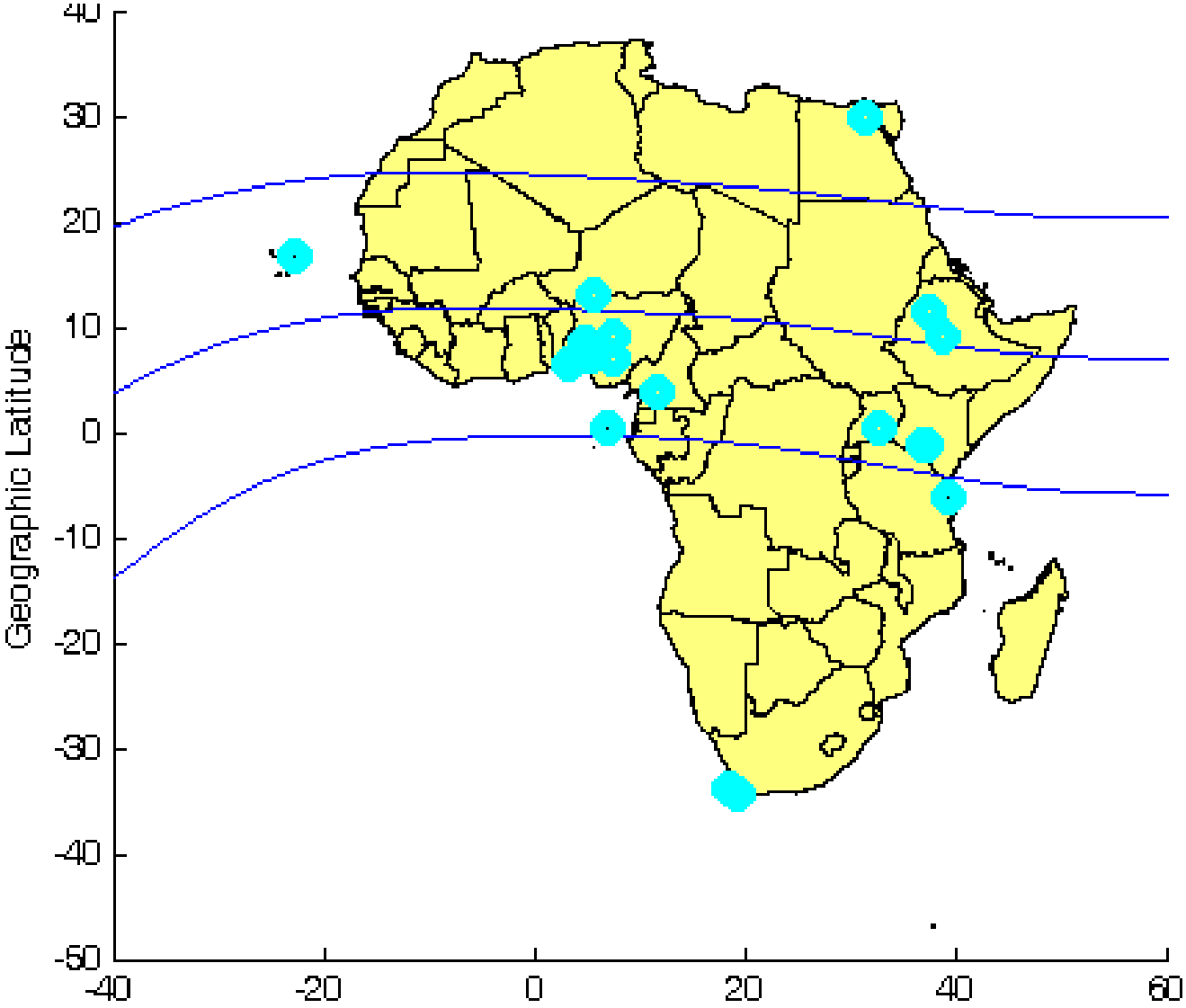
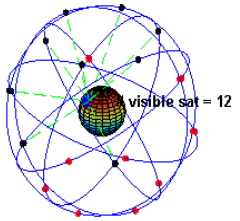
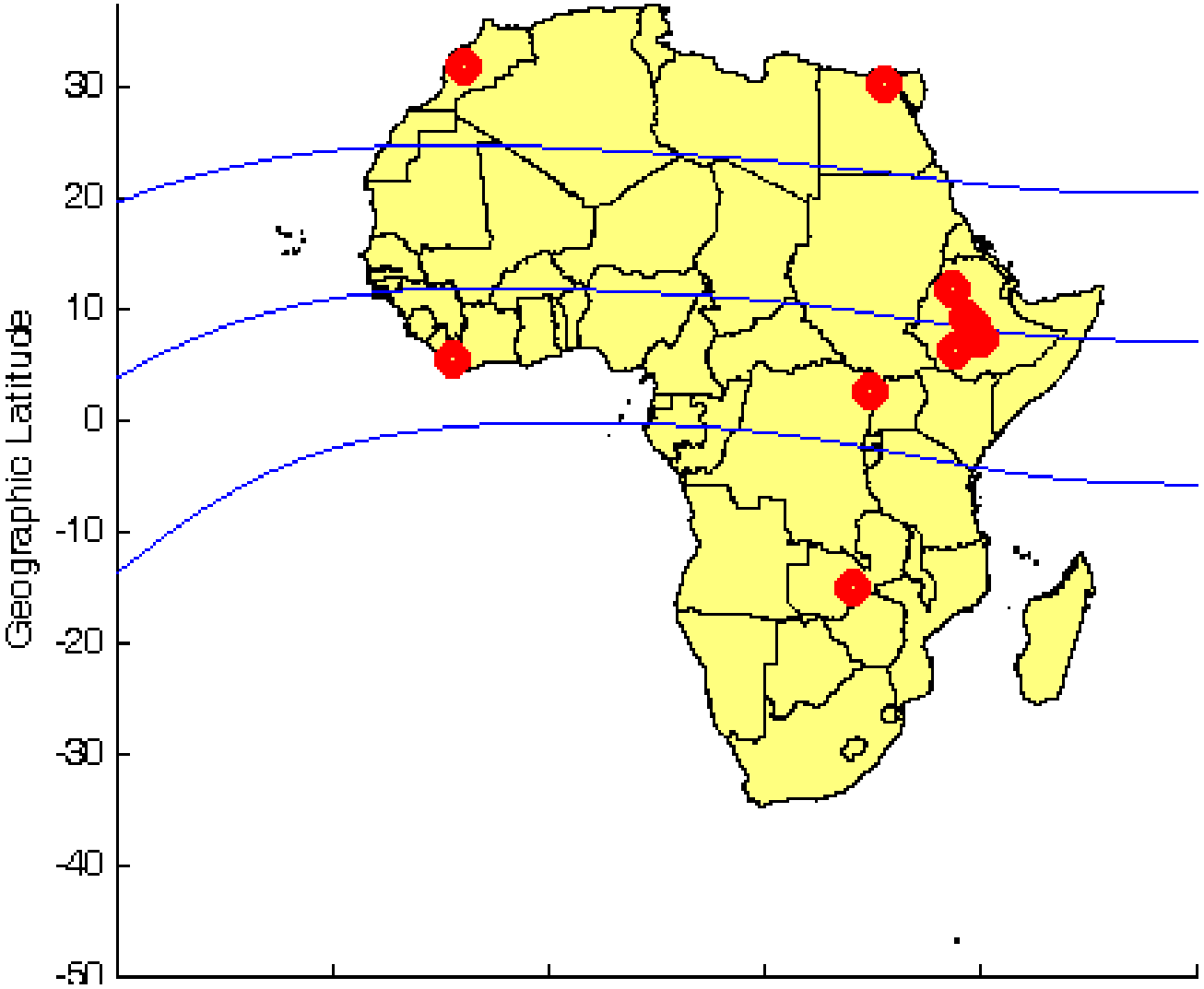
SCINDA ICTP-BC



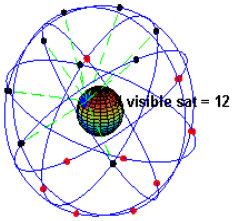


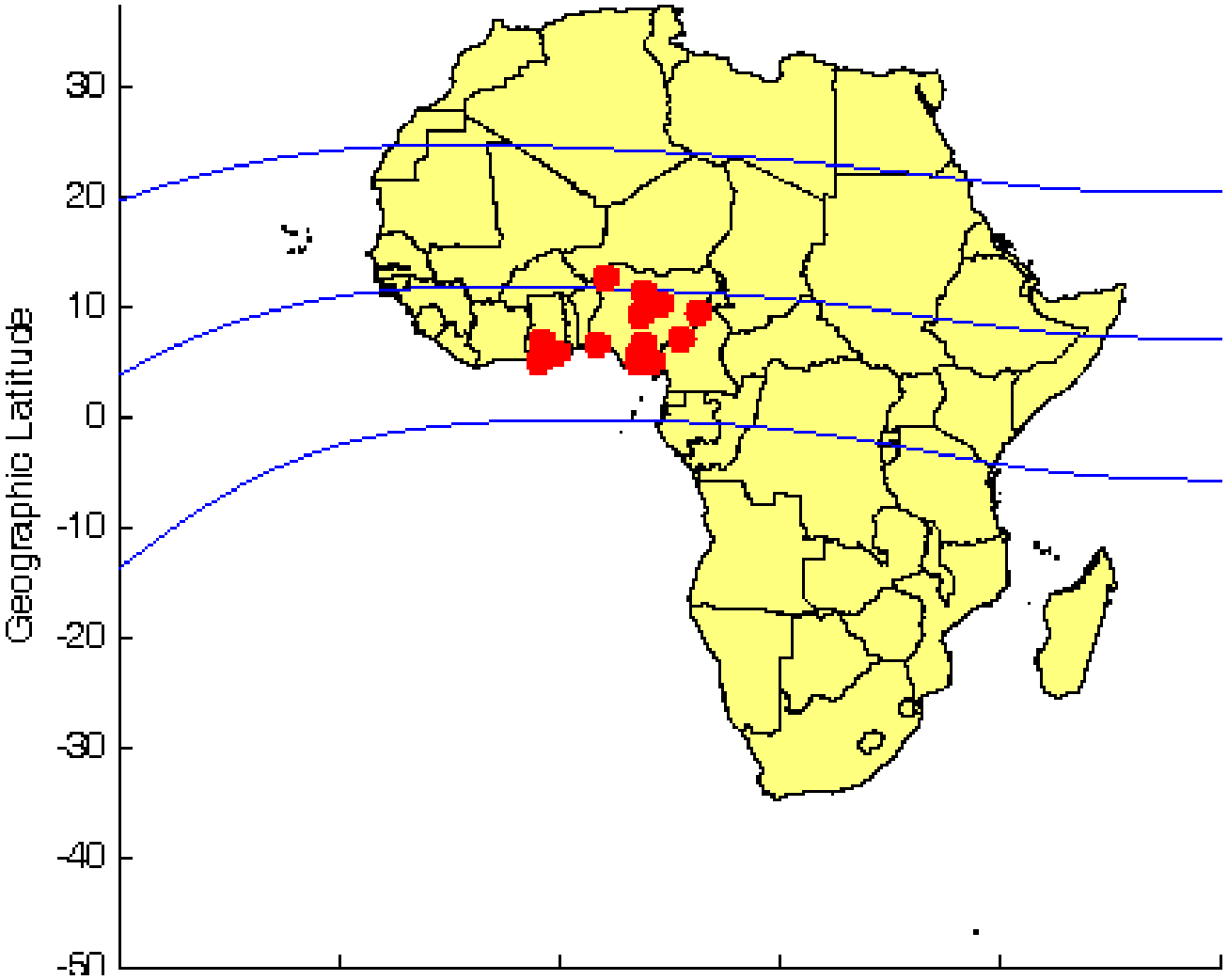
GALILEO & MISCELLANEOUS



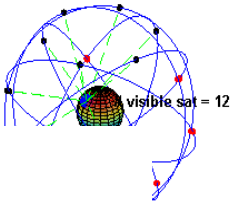


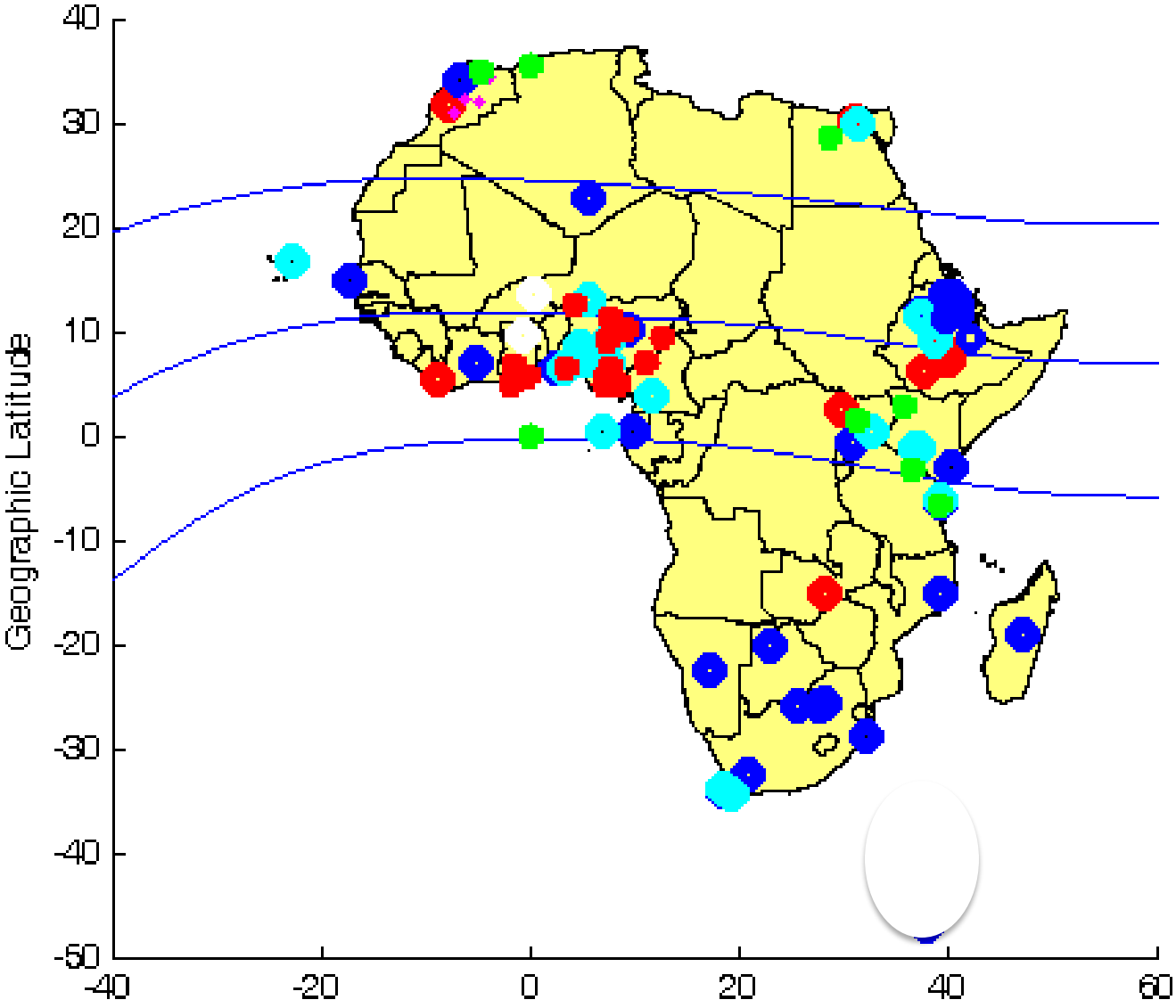
NIGNET-LAP

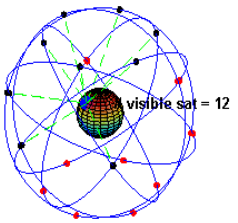




ALL AVAILABLE CORS

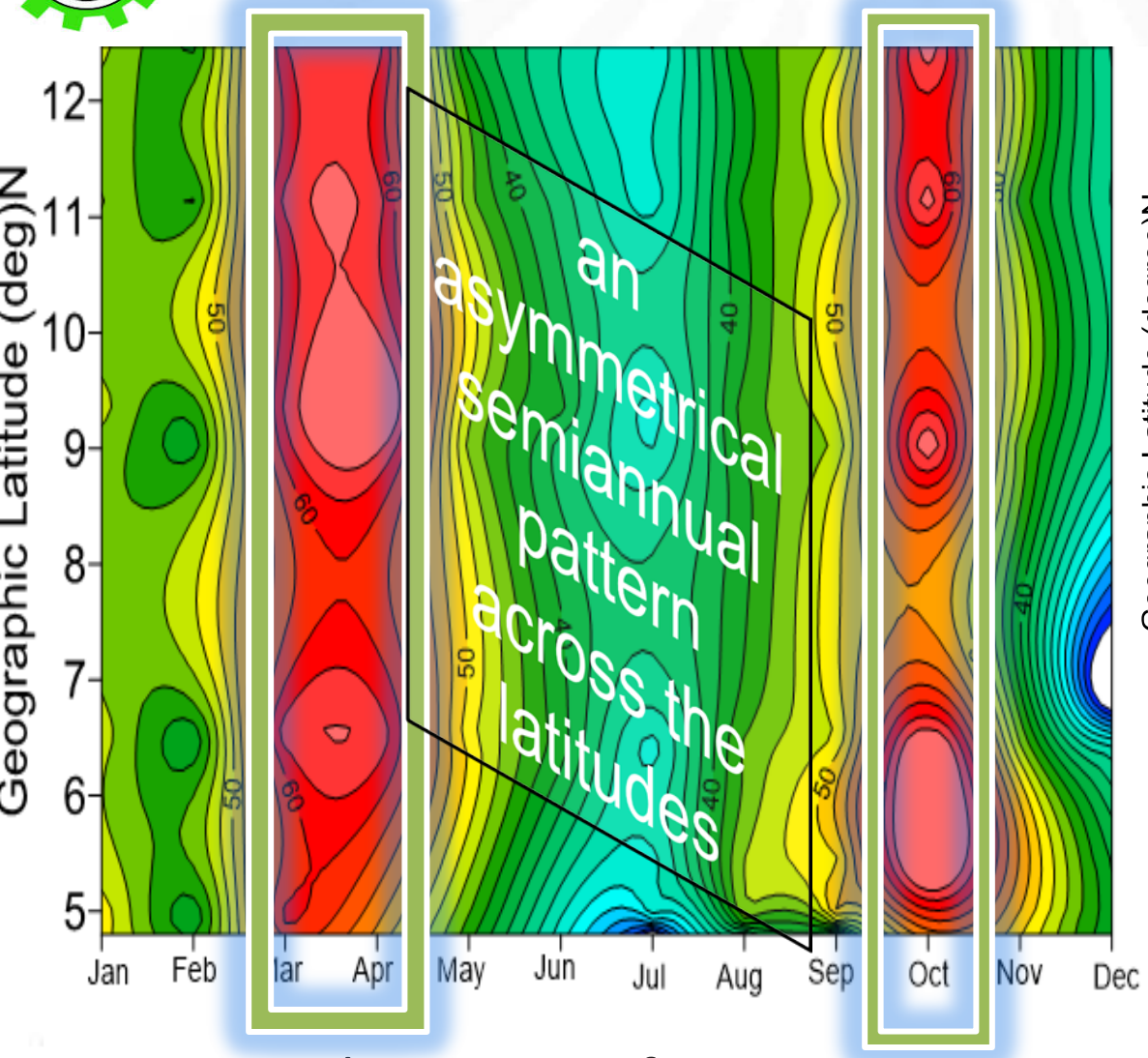


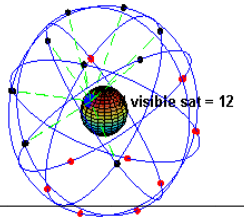


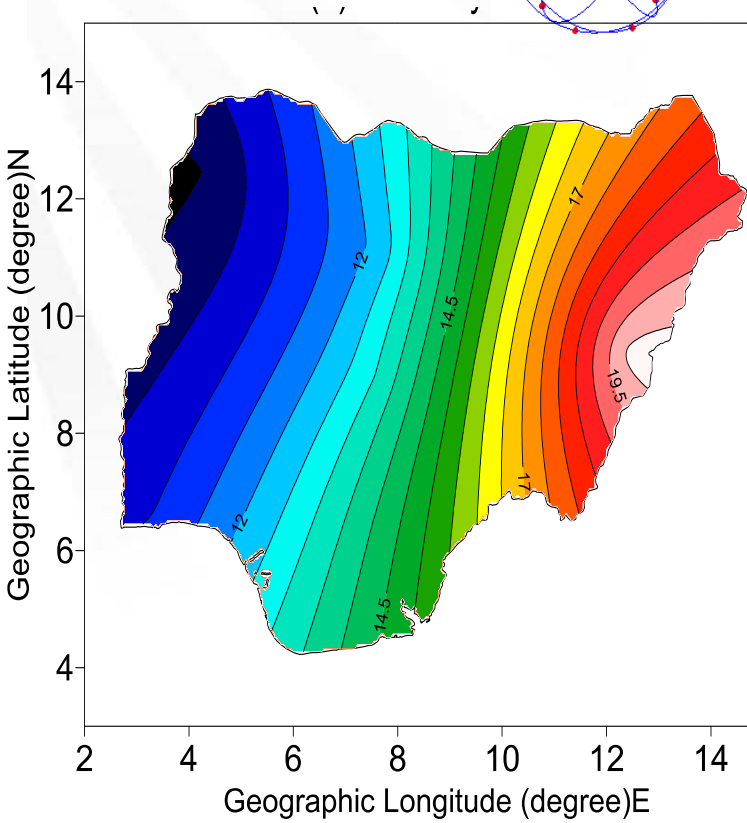


Some GPS-Derived TEC Studies

Total Electron Content TEC Studies



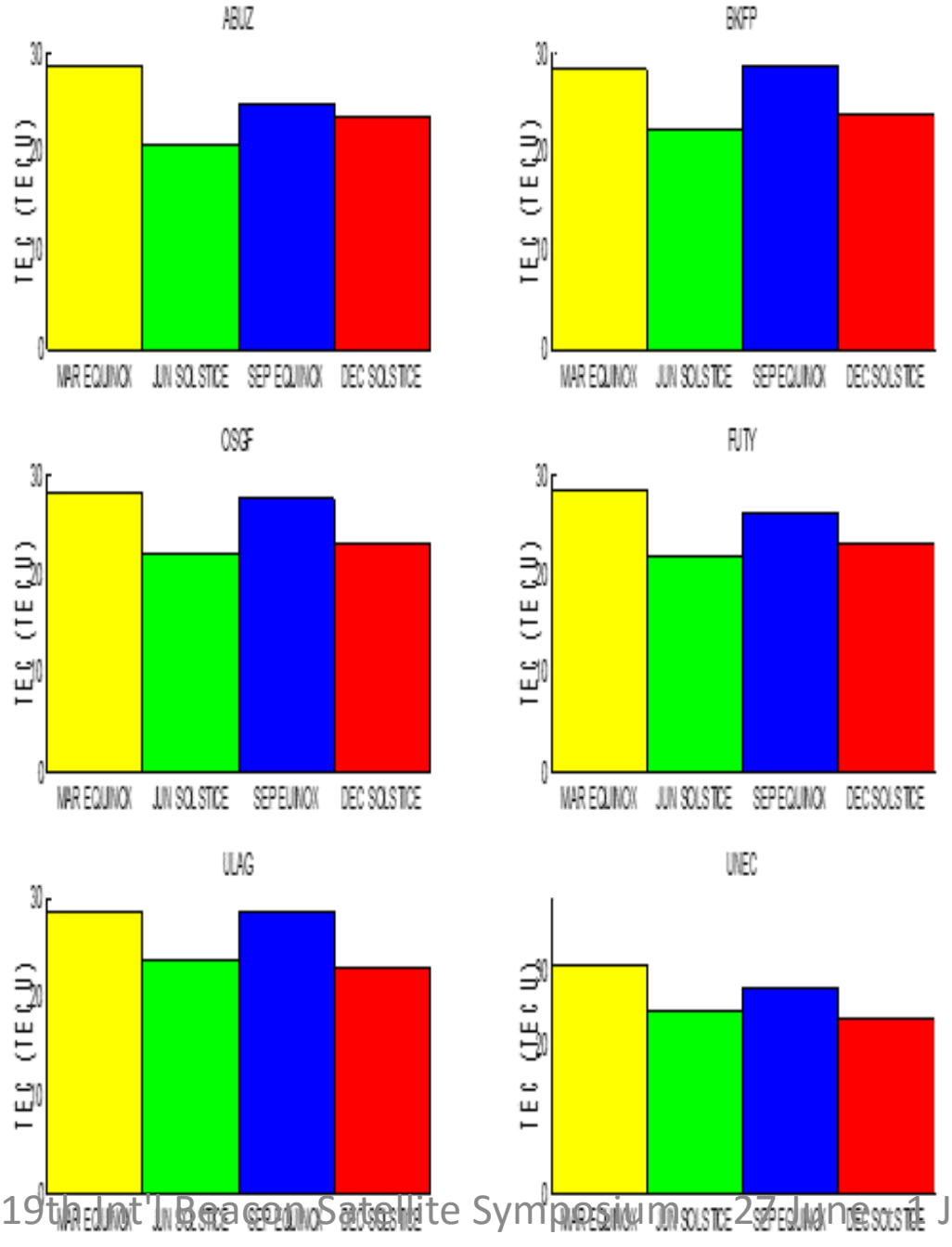




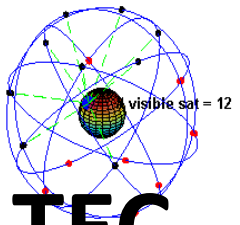
Spatial @ 0700LT

semiannual variation of noon time TEC over Nigeria

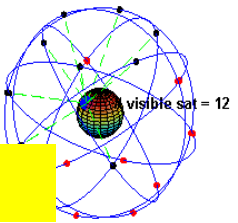
[Eyelade, 2014]



Semiannual Variation of TEC



- Uniform pattern at all stations irrespective of distance from the magnetic equator
- Equinoctial maximum with minimum in solstices
- Asymmetrical equinoctial maximum as March Equinox has greater value than September

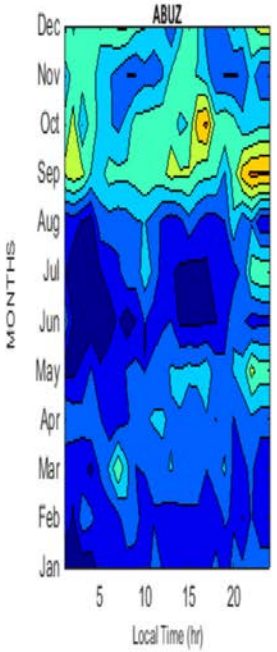


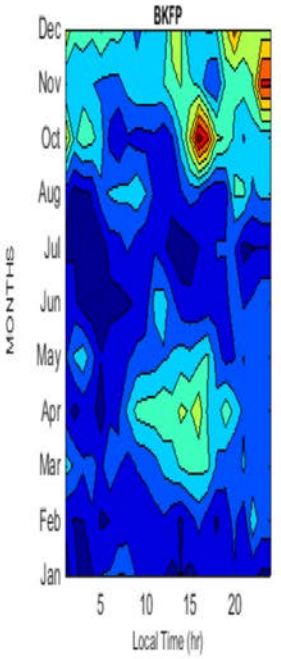
Tariku, 2015

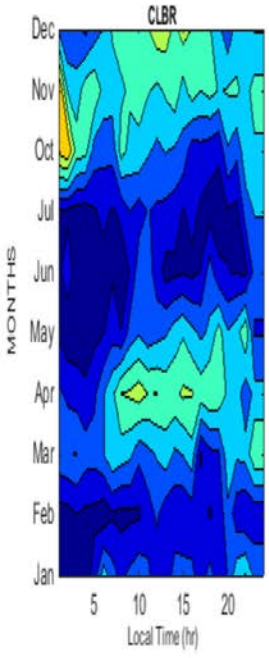
LSA: 2009

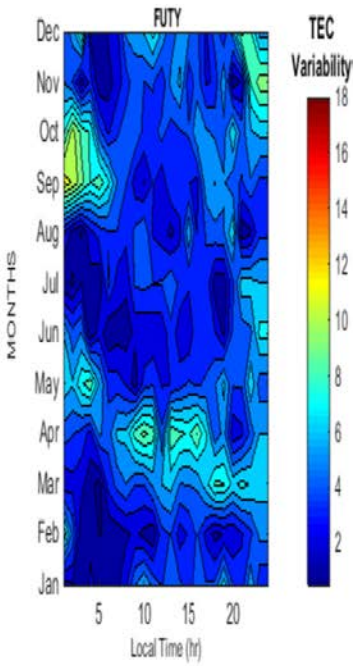
HSA: 2012

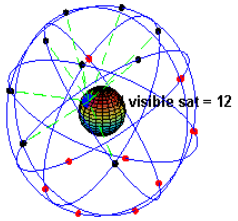
The top panels (a, b) show the monthly and seasonal variation of the VTEC over Nazret during the low solar activity (2009), and the bottom panels (c, d) show the monthly and seasonal variation of the VTEC over Arba Minch during the high solar activity (2012) phase.

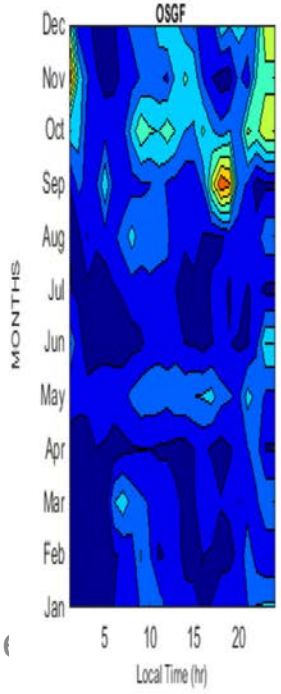


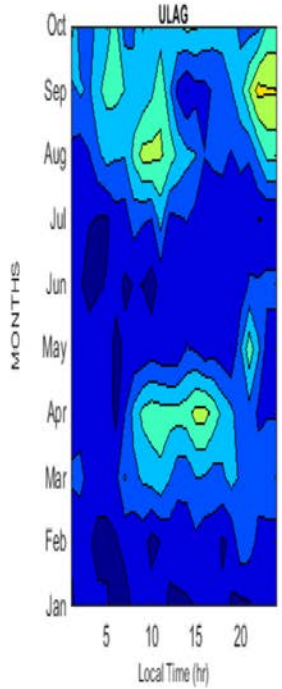


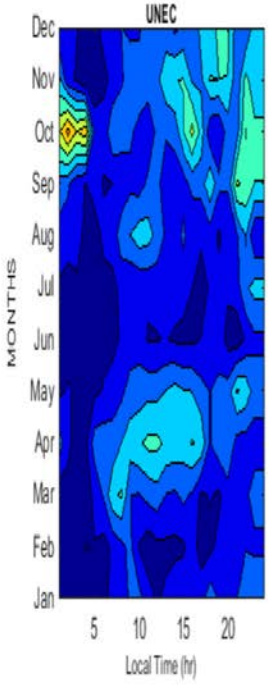








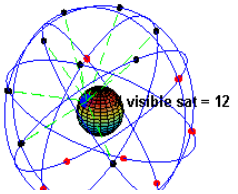




Inter Hour variability of TEC Over Nigeria

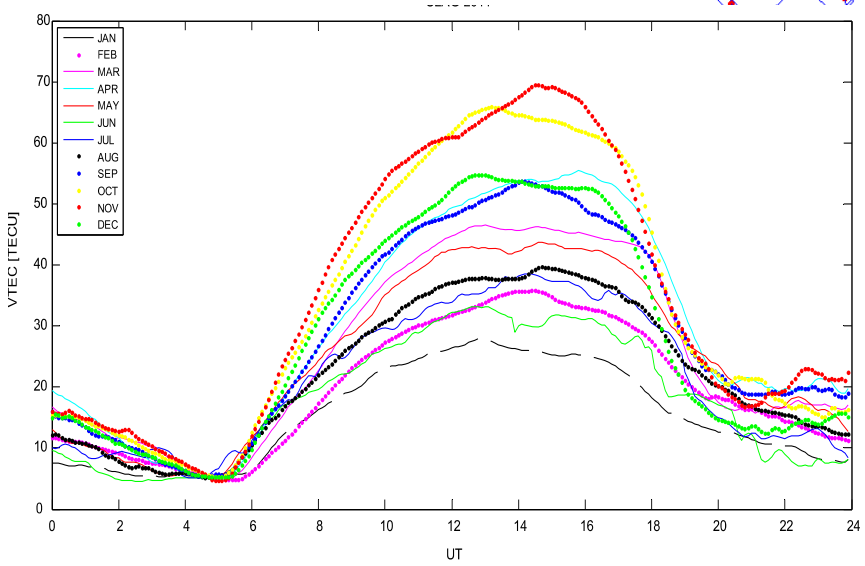
Ayorinde et al, 2016

GPS Derived TEC & Models

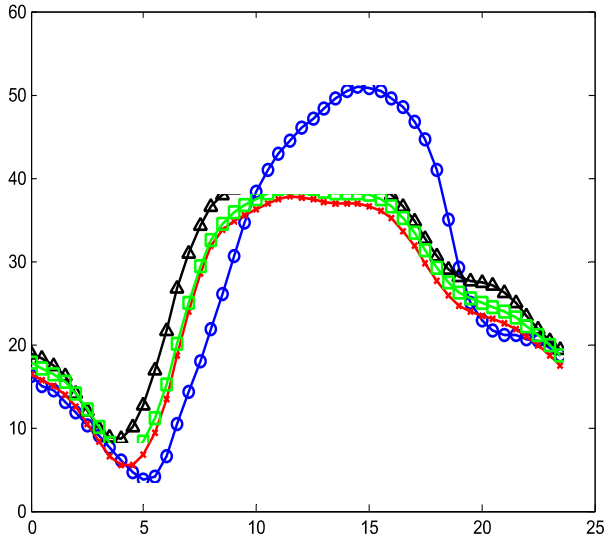


- The TEC exhibits daytime maximum

- IRI & NeQuick modelled values follow the diurnal and seasonal variation patterns of the observed values of VTEC



Rabiu, et al., 2014



Mean quarterly GPS-vTEC versus IRI-vTEC diurnal profiles for the Ilorin station.

(a) First quarter

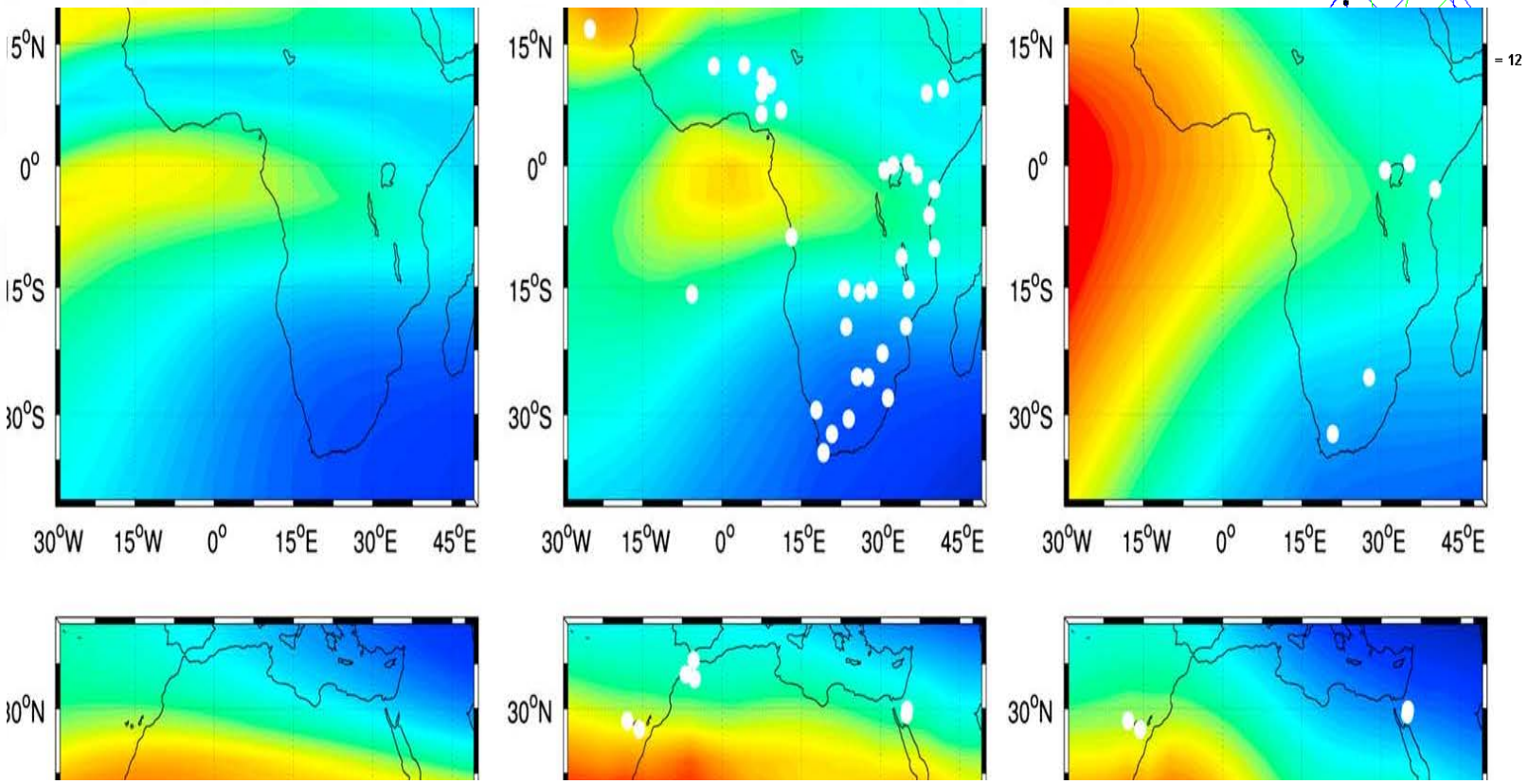
(b) second quarter

(c) third quarter

(d) fourth quarter.

Okoh et al, 2015

TEC studies



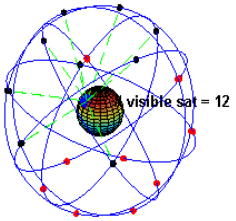
IRI simulations

Using all available GPS stations

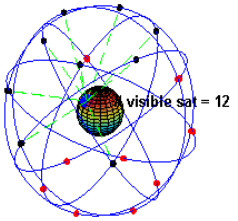
On IGS stations only

Chartier et al., (2014)

Summary



- Intensified complimentary efforts at densifying the GNSS ground infrastructures
- International GNSS programs has impact in Africa
- GNSS is being used for ionospheric and space weather research in Africa
- TEC derived from GPS installed in Africa gives good signature of the ionosphere and are good for SW services
- Existing Ionospheric models need to be improved using ground observed data



Acknowledgements

- ICTP
- BC
- UNOOSA
- NASA
- US Air Force


Thank
You

Thank You