Emerging Geospatial Techniques for Modelling and Simulation of Earth Dynamics and Complex Systems

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Presentation Outline

☞ **Introduction:**

- *The Concept of Geospatial*
- *Mathematics: Strength of Geodesy and Geospatial Science*
- *Why Geospatial Modelling and Simulation?*
- *Benefits of Geospatial Modelling and Simulation*
- *Objectives*

☞ **AFRIGIST R&D Activities and the Workshop Theme**

☞ **Emerging Geospatial Technologies & Techniques**

☞ **Notable Earth Dynamics and Complex Systems**

☞ **Some Studies on Earth System Modelling and Simulation**

☞ **Concluding Remarks**

INTRODUCTION

The 5 main layers from the lowest to highest are:

- **Troposphere:** 0-12 km
- **Stratosphere:** 12-50 km
- **Mesosphere:** 50-80 km
- **Thermosphere:** 80-700 km
- **Exosphere:** 700-10,000 km)

☞ The changes in the Earth systems due to *natural and man-made activities* impart complex time-dependent variations in the spatial and non-spatial domains of earth infrastructure.

☞ For effective management of the earth atmosphere, environments and processes for human benefits, the optimal monitoring, modelling and simulation of the spatially-varying elements are imperative.

Fig.1.1: The Earth's Atmosphere

☞ The measurements and representation of the *earth systems phenomena*, *shape, size, dimensions* and *temporal variations* are complex in nature; requiring the understanding and applications of the following, amongst others:

- *mathematical-physics,*
- *geodesy and surveying*
- *photogrammetry and remote sensing*
- *geosciences,*
- *space science and technology*
- *computer science and electronics*
- *cartography and GIS*
- *spatial data science,*
- *statistics and*
- *engineering, etc.*

The Concept of Geospatial

- ☞ ***Geospatial*** implies any location on the earth and its atmosphere (Fig. 1.2).
- ☞ Geospatial data or information is made up of *location's coordinates* on the earth and its *attribute* information (characteristics of the object, event or phenomena) with *temporal information* (time of the occurrence);
- ☞ Any phenomena (*physical, bio-chemical, socio-economic, etc*) that exist on the earth and space has geospatial components and require geospatial modelling.
- ☞ *Location data and time component* ***(x, y, z, t)*** are the global geospatial identifier which provides a common field for integrating and evaluating all global phenomena

☞ **Geospatial =**

- ***What?***
- ***Where?***
- ***How?***
- ***When?***

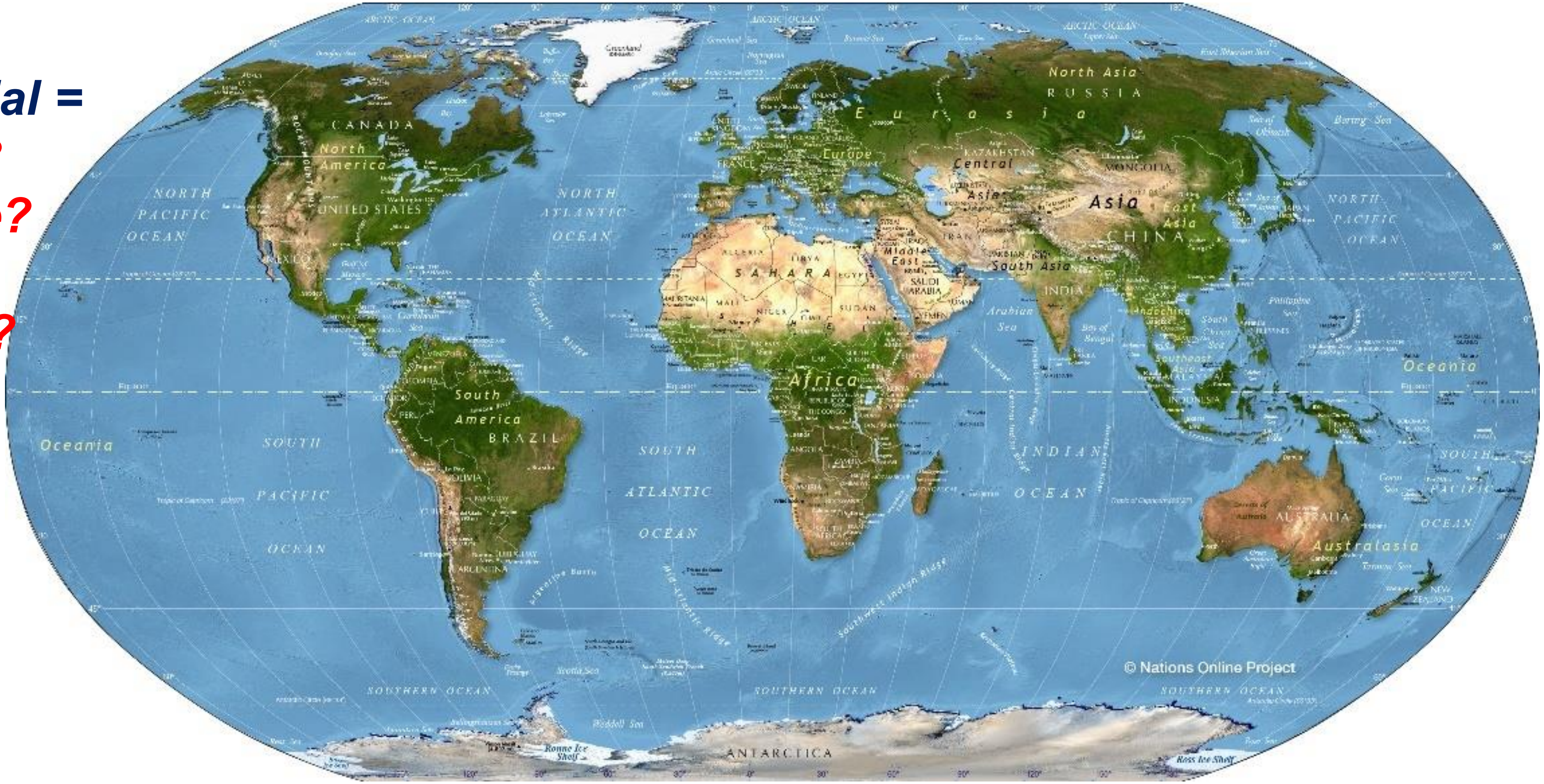


Fig.1.2: The Geospatial Physical Outlook of the Globe [Source: https://www.nationsonline.org/oneworld/map/physical_world_map.htm]

Mathematics: Strength of Geodesy and Geospatial Science

- Geodetic reference frame, maps and geospatial data must be accurate and of good quality, up-to-date and compatible both nationally and internationally, with valid location and attribute data.

- The optimal use of geospatial information demand from the user an understanding of the mathematical computations and processes by which this information are derived or produced (Martin Vermeer & Antti Rasila, 2020).

- The concept of the accurate description of positions and representation of the earth shape, size and temporal variations is only realisable with pertinent mathematical principles relating to:
  - ***Network adjustment computations,***
  - ***EMR and radio signal processing,***
  - ***Map projection and production.***

☞ Some of the pertinent mathematical principles of geodesy and geospatial science include the following, amongst others.

Mathematical Principles	**Mathematical Principles**
○ **Trigonometry (spherical and plane)** ○ **Algebra** ○ **Coordinates system and projection** ○ **Triangulation and trilateration (resection, intersections)** ○ **Linear Equations, Matrices and Tensor Analysis** ○ **Calculus (*ODE, Cal. of Several Variables, etc*),**	○ **Complex Analysis** ○ **Numerical Analysis** ○ **Approximation Theory and Spherical Harmonics** ○ **Computational and Perspective Geometry** ○ **Conformal Transformation, etc.**

$$X = (N+h)\cos\lambda\cos\varphi$$
$$Y = (N+h)\sin\lambda\cos\varphi$$
$$Z = [N(1-e^2)+h]\sin\varphi$$

$$N = \frac{a}{\sqrt{1-e^2\sin^2\varphi}}$$

.... (1.0)

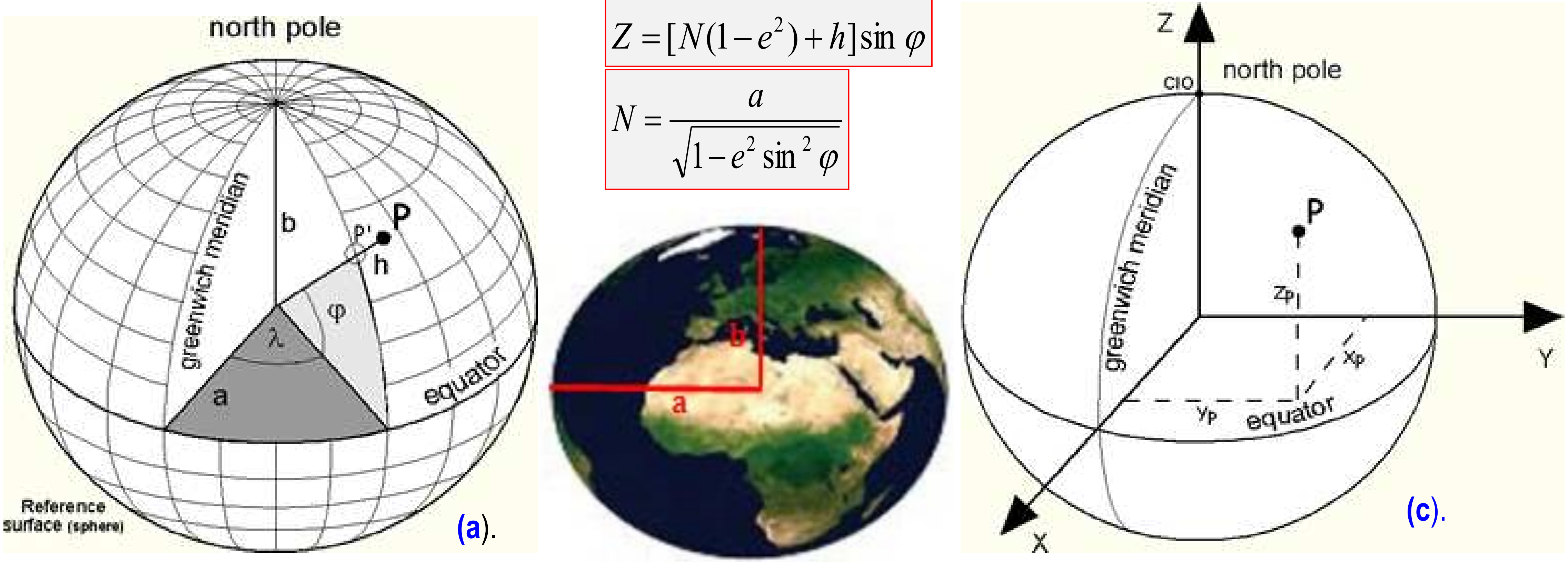


Figure1.3:(a) *Spatial Geographic Coordinates (ϕ, Λ, h);*
(b) *The Earth Ellipsoid (WGS84)*
(c) *Spatial Cartesian or Geocentric Coordinates (x, y, z)*

☞ Figure 1.4 shows NASA 3D figure/animation respectively on how gravity levels differ across the earth.

☞The EGM2008 was developed using mathematical modelling of the earth gravity field *with spherical harmonics, Legendre's functions, etc.)*

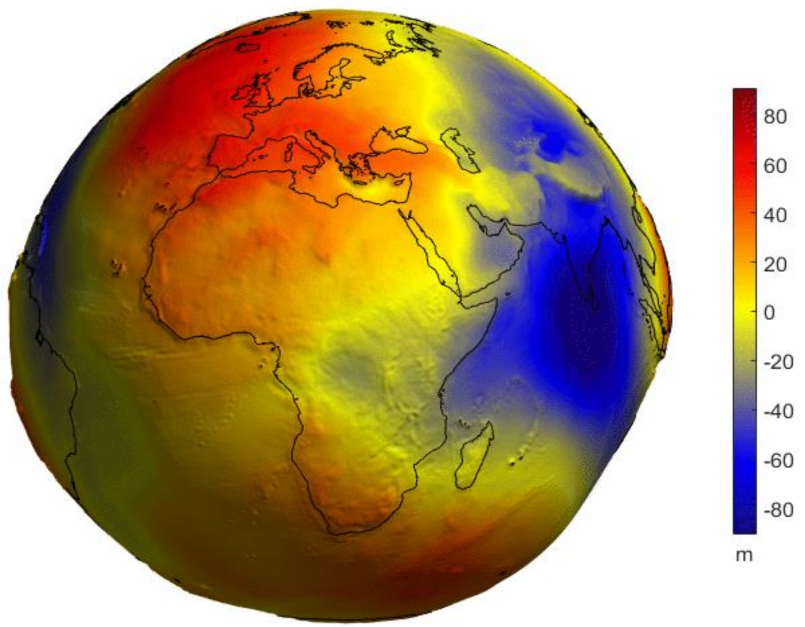


Figure 1.4: Geoid height, computed from the gravity field model EGM2008 (Pavlis et al., 2012).

☞ The global Earth's gravity field is described by *spherical harmonics*.

☞ The non-rotating part of the potential is mathematically described by (2.0) [Heiskanen and Moritz, 1967]:

$$\boldsymbol{V}(\boldsymbol{\theta},\boldsymbol{\phi}) = \frac{\boldsymbol{GM}}{\boldsymbol{r}}\left[\mathbf{1} + \sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{R}{r}\right)^{\boldsymbol{n}} \widetilde{\boldsymbol{P}}_{nm}\,(\mathbf{sin}\,\boldsymbol{\theta})(C_{nm}\boldsymbol{cosm\phi} + S_{nm}\boldsymbol{sinm\phi})\right] \quad \ldots\ldots\ (2.0)$$

where;

θ and $\boldsymbol{\phi}$ are geocentric (*spherical*) **latitude** and **longitude** respectively,

$\widetilde{\boldsymbol{P}}_{nm}$ are the fully normalized associated Legendre polynomials of degree *n* and order *m*, & $\mathbf{C_{nm}}$, $\mathbf{S_{nm}}$ are the numerical coefficients of the model.

For the Earth's gravity field model, the potential coefficient of the Earth (C_{nm}, S_{nm}) should be determined.

Note that:

- ☞ *the **gravity field of the Earth**, as well as the **centrifugal force** (due to the Earth's rotation), are two of the leading concepts that define physical geodesy (determination of the shape of the geoid and in combination with arc measurements, the earth's size and shape).*

- ☞ these concepts are defined by ***Laplace's equations in ellipsoidal spherical coordinates*** (*spherical harmonic functions*) and Legendre's functions as solutions to Legendre's differential equations.

- ☞ these are mathematical concepts that take into consideration a best *representation of the actual shape of the Earth and an assumption of the Earth's rotation about its axis.*

Why Geospatial Modelling of Earth Features & Systems ?

- ☞During or after earth surveys and observations, we often attempt to simplify the inherent complexity of the earth system by abstracting key features to create a *scalable model or representation* of a portion or phenomenon of interest.

- ☞ In this simplification, the *real earth features and phenomena* are often reduced to **data models** and **axioms** such as *entities, geometries, shapes, graphics, numerical, texts, strings*, etc.

- ☞ The big data emerging from earth system measurements call for appropriate **modelling** and **simulations** for most probable representation of each observed variable or phenomenon.

☞ In view of the **volume** and **complexity** of the earth systems, there have been progressive developments in *technology innovations and algorithms (software engineering, cloud computing, data science, AI, ML & DL, etc.)* to effectively manage and utilize geospatial data for sustainable development.

☞ This paper therefore discusses the ***emerging geospatial techniques for modelling and simulation of Earth dynamics and complex systems,*** *with a view to stimulate integrated earth science research collaborations amongst scientists and researchers in Africa.*

Benefits of Geospatial Modelling and Simulation

Geospatial modelling and simulation are beneficial in so many ways, as they're used for:

☞ *resolving and understanding many complicated and complex earth parameters and variables;*

☞ *as visualising tool for the seemingly complex earth phenomena such as climate change, marine geophysics, and atmospheric constituents, etc;*

☞ *trend monitoring of geo-hazards and geodynamic activities/threats and mitigation strategies;*

☞ *quality decision support for development and conservation of the environment;*

☞ *monitoring and predicting earth cover, anthropogenic impacts and general ecosystem's temporal variations and re-adjustment system,*

☞ *assessing, planning and integration processes of natural resource management, etc.*

Objectives of the Paper

The objectives of this paper are to:

- ☞ relate the theme of the workshop to the geospatial capacity building activities and research at AFRIGIST.

- ☞ identify key geospatial dynamic phenomena within **space/atmosphere, ocean/marine and land surface domains** that require modelling and simulations for applications;

- ☞ identify key emerging geospatial *techniques and algorithms for modelling and Simulation of Earth or geospatial Dynamics and Complex Systems;*

- ☞ *present the perspectives of some selected earth system phenomena modelling, simulations and applications*

2.0 AFRIGIST R&D ACTIVITIES & THE WORKSHOP THEME

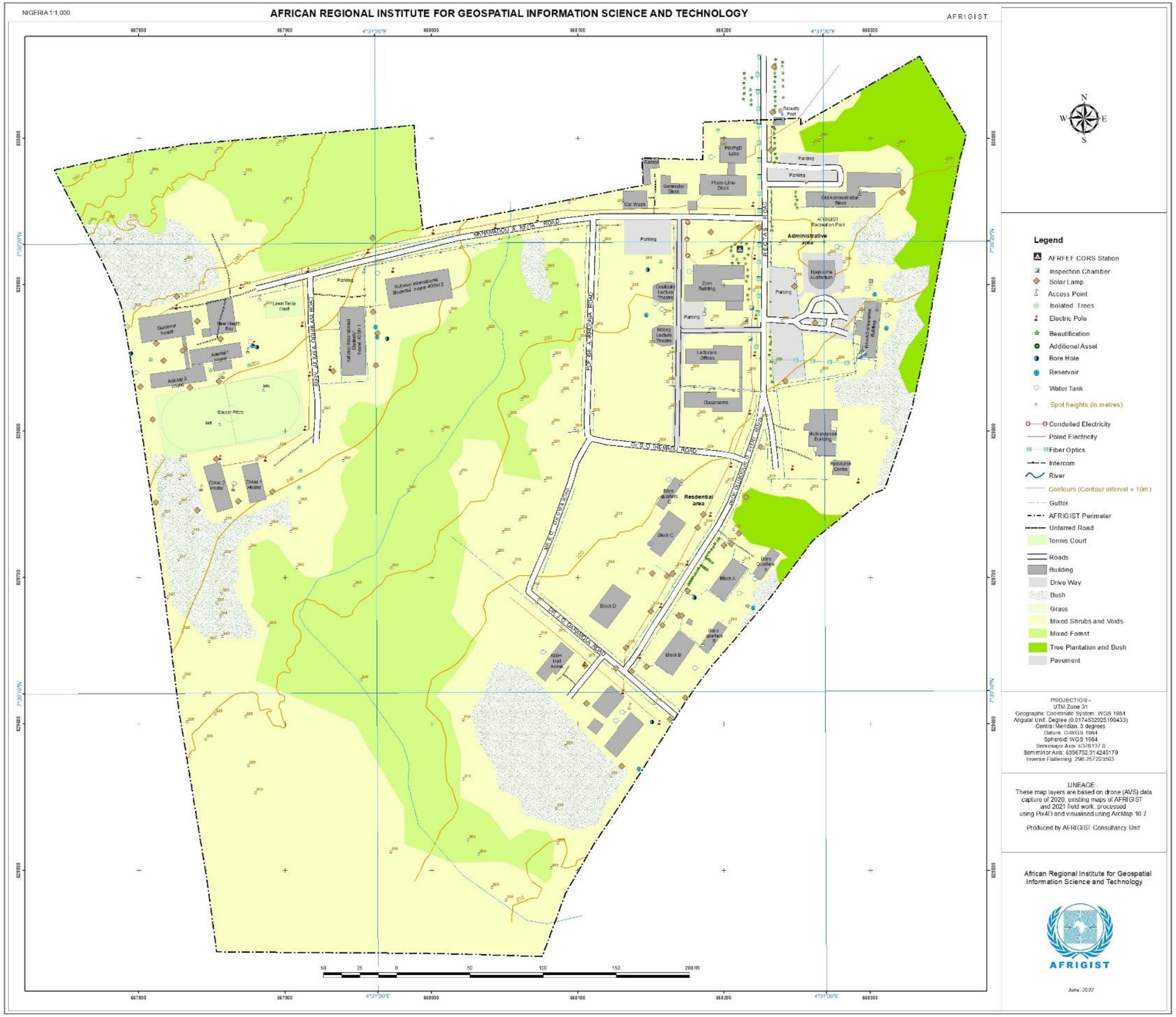
- AFRIGIST (formerly known as: *Regional Centre for Training in Aerospace Surveys - RECTAS*);
- a bilingual (English & French) intergovernmental organisation established in 1972 under the auspices of the United Nations Economic Commission for Africa (UNECA);
- with full diplomatic status in the Federal Republic of Nigeria, the host country.
- *A*n African project for the **building of critical capacity of African professionals in *geospatial information science and technology and the applications in different areas of endeavour*.**

Fig. 2.0: (i) AFRIGIST Administrative Building

Fig 2.0: (ii) MGIT Laboratory

Figure 2.1a: AFRIGIST Site Image and Boundary

Venue: AFRIGIST, OAU, Ile-Ife, Nigeria. Date: 27th -31st May, 2024.



7°30'20" N

4°31'25" E

Figure 2.1b: Physiographic Map of AFRIGIST

The Objectives of AFRIGSIT are to:

- provide theoretical and practical training in the fields of geoinformatics: integrating photogrammetry and remote sensing, geographic information system, cartography, computer science and statistics, surveying, geodetic science, hydrography and marine science, and their applications;

- conduct seminars, workshop and short-term courses with a view to providing an opportunity for disseminating of information in the field of geoinformatics;

- promote studies, research and development in the field of geoinformatics, *including developing advanced computation facilities, data science (DS), artificial intelligence (AI)-machine learning (ML) and deep learning (DL), with geospatial applications;*

- provide advisory and consultancy services on geoinformatics matters, including instrument maintenance, to Governments of the Member States of Economic Commission for Africa (ECA) and to other survey and mapping organisations in the African region.

☞ There are currently five (5) academic departments in AFRIGIST, namely:

- **Geographic Information Science,**
- **Cartography and Geovisualisation,**
- **Photogrammetry and Remote Sensing,**
- **Geodetic Science,**
- **Hydrography and Marine Science**.

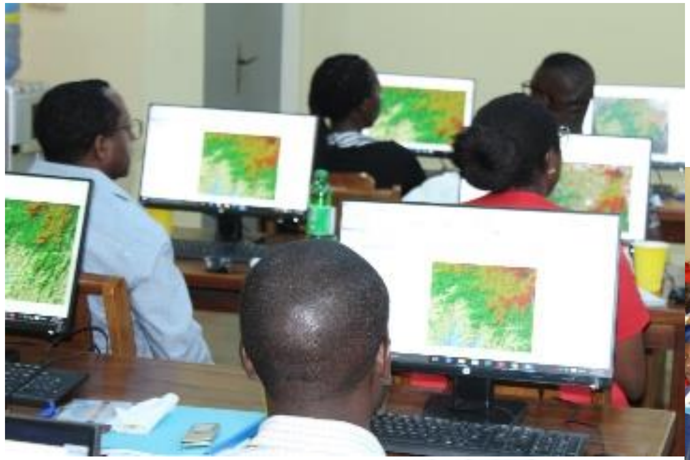
☞ There are currently ten (10) categories of post graduate programmes (PGD, M.Sc. & PhD) in three of the five academic departments.

☞ The existing academic programmes are collaboration with:

- **Federal University of Technology Akure, Nigeria,**
- **Obafemi Awolowo University (OAU), Ile-Ife, Nigeria, and**
- **University of Abomey Calavi, Benin Republic**

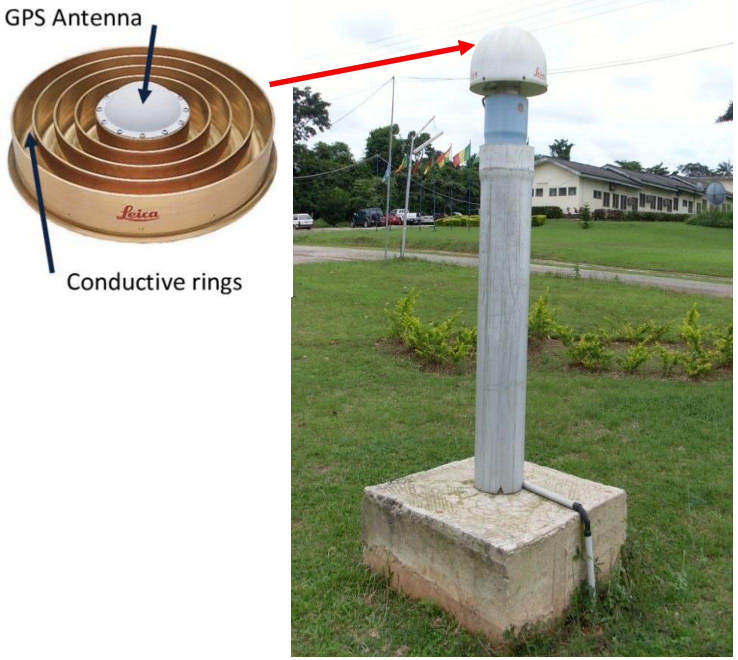
☞ There are short-term training programmes for key geospatial themes that involving big data processing, modelling and simulations, and management.

☞ The 2024 International Conference/Workshop *on Modelling and Simulation of Complex Systems, held at OAU, Ile-Ife, Nigeria,* directly aligns with the contexts of capacity building mandates and objectives of AFRIGIST



Target:

Seek to be 'Advanced Geospatial Centre of Excellence in Africa'



Training Facilities and MGIT Graduands

GR50 GNSS Receiver

AFREF GNSS CORS

3.0 EMERGING GEOSPATIAL TECHNOLOGIES AND TECHNIQUES

- *the* key ***disruptive technologies*** driving geospatial research and development. include the following, amongst others.
- *space-based & terrestrial technologies are primary*

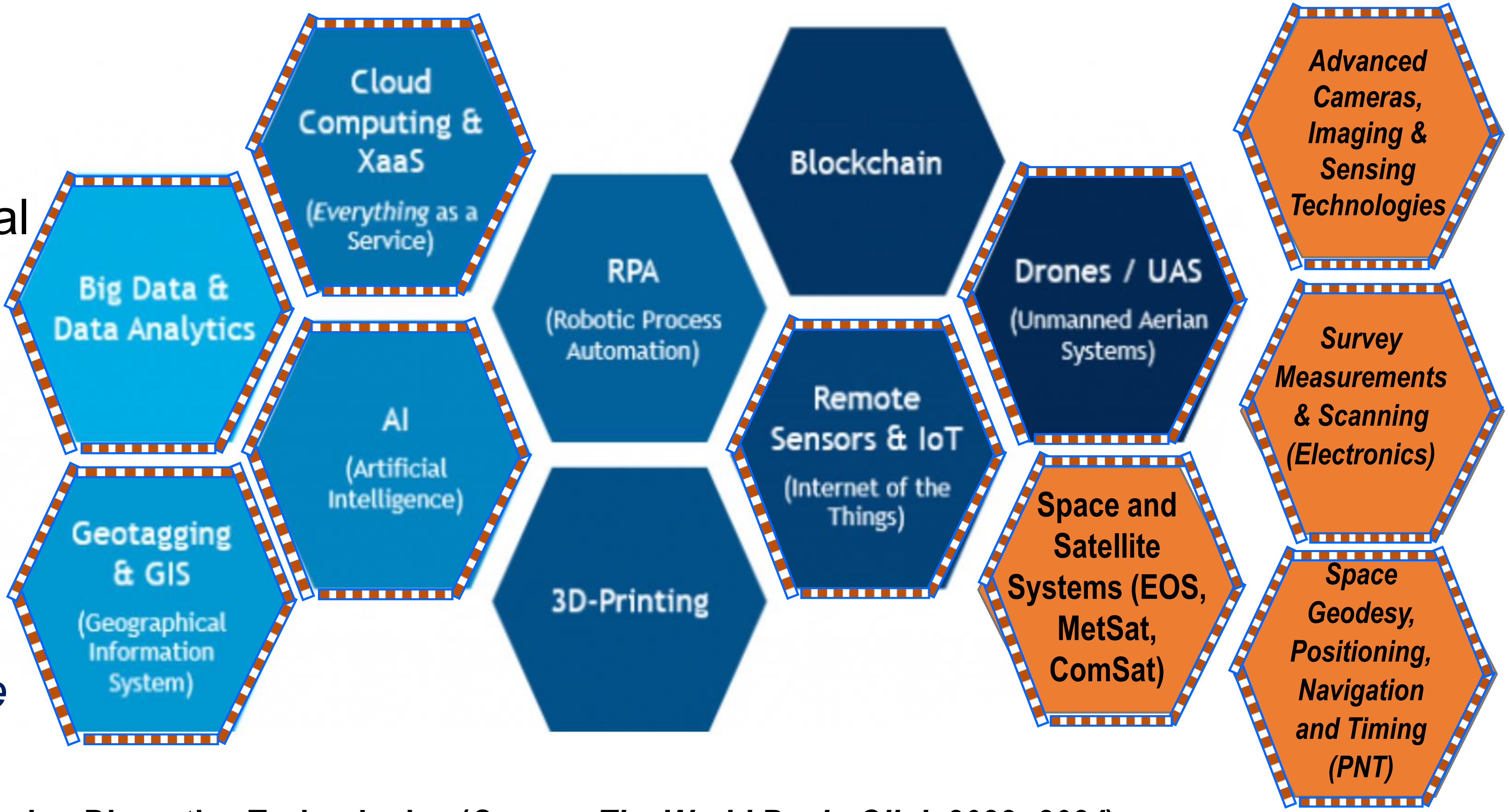


Figure 3.1: Emerging Disruptive Technologies (*Source: The World Bank; Ojigi, 2022; 2024*)

Table 3.1: Some of the key ***space and terrestrial observation*** *technologies* for geospatial modelling and simulation of complex systems are listed

Space-based Observation Techniques	Terrestrial Observation Techniques
• Earth Observation Satellite Imaging, • Satellite Surveying & Space Geodetic System (VLBI, DORIS, SLR, LLR) • Global Navigation Satellite System (GNSS) • Scientific/Special Satellites • CubeSat/Nano-Satellites, • Meteorological and Weather Satellites, • Environmental Monitoring Satellites, • Satellite Gravimetry • Satellite/Airborne RADAR, • Aerial Surveys/Photogrammetry • Airborne LiDAR/Laser, and • Unmanned Aerial System (UAS).	• Electronic Surveying (total station & theodolites and electromagnetic distance meter, etc.,) • Geodetic Levelling and Control Surveying • GNSS Reflectometry, • Automatic Weather Station, • ground-based mobile/static laser scanning, • geotechnical and soil condition surveys, • structural deformation monitoring meter (tiltmeter, inclinometer, extensometer/strain meter), • terrestrial infra-red cameras and sensors, • tide gauge meter and flood height meter, • *Other sensors*:- gravimeter, magnetometer, thermometer, barometer, gyroscope, anemometer, accelerometer, pyranometer, seismometer, etc.

Space-based Measurement Systems

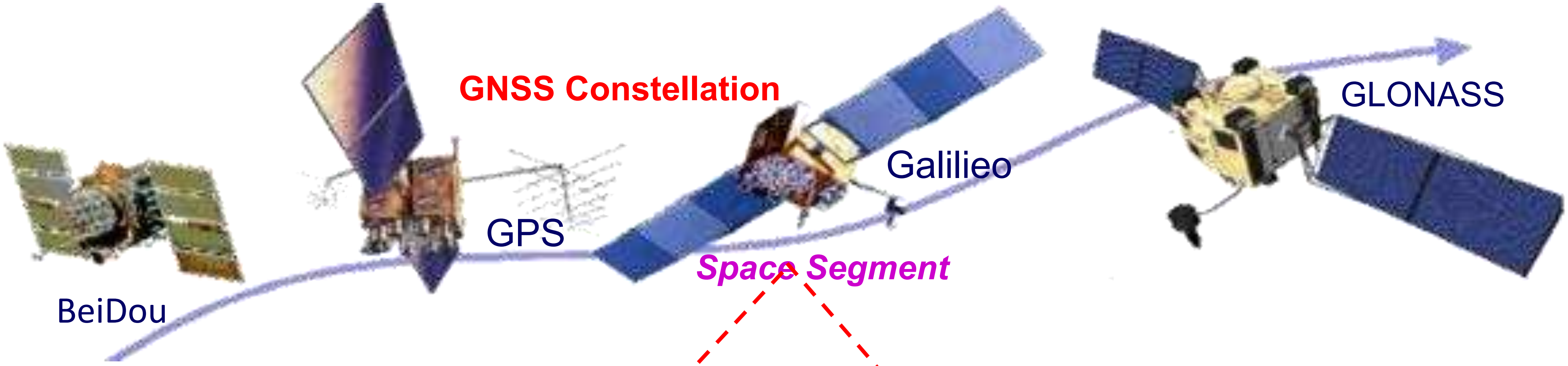
GEO Satellite
(Weather & Com. Satellites)

MEO Satellite
(GNSS, Search & Rescue, Geodetic, etc)

LEO Satellite
(Scientific, Military, Special, etc)

Figure 3.2a: Advanced space-based technologies for geospatial surveys and data modelling

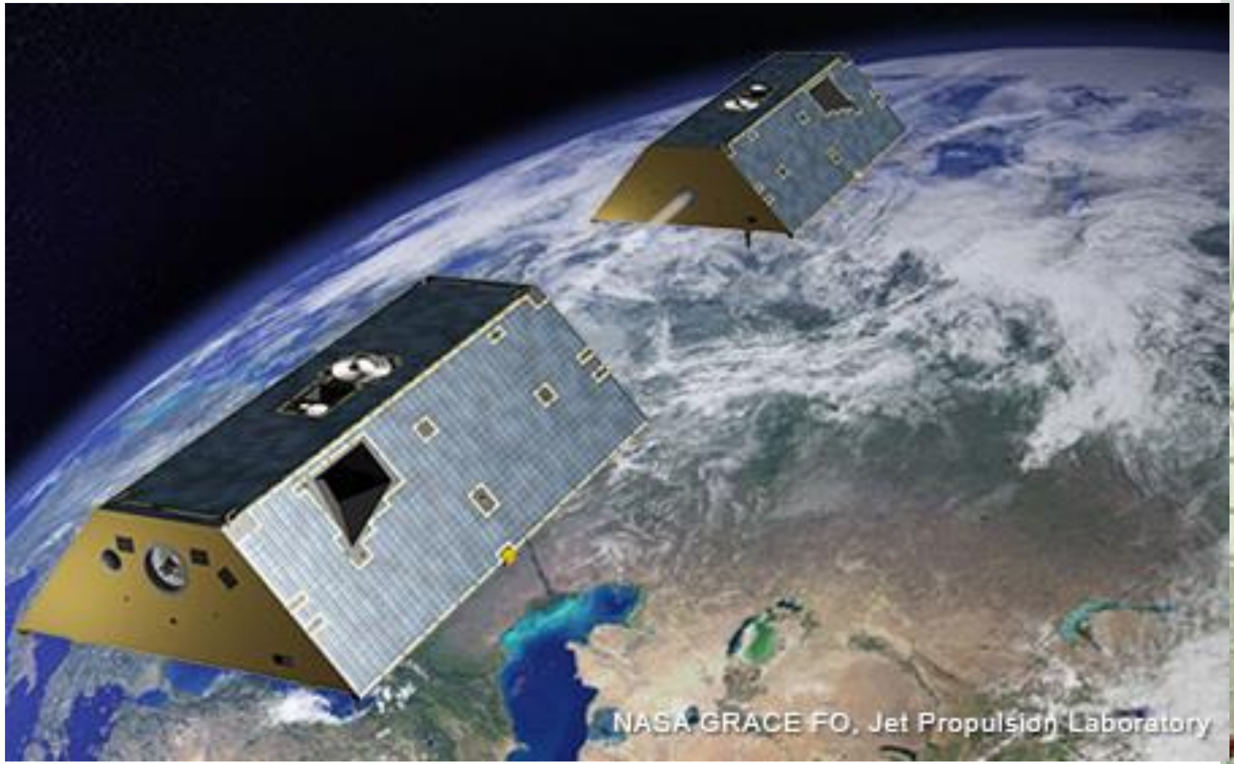
Space-based Technologies *(cont..)*



- The performance of GNSS is assessed using four (4) criteria:
  - ***accuracy***
  - ***integrity***
  - ***continuity***
  - ***availability***

Figure 3.2b: GNSS Constellation

Space-based Technologies *(cont..)*



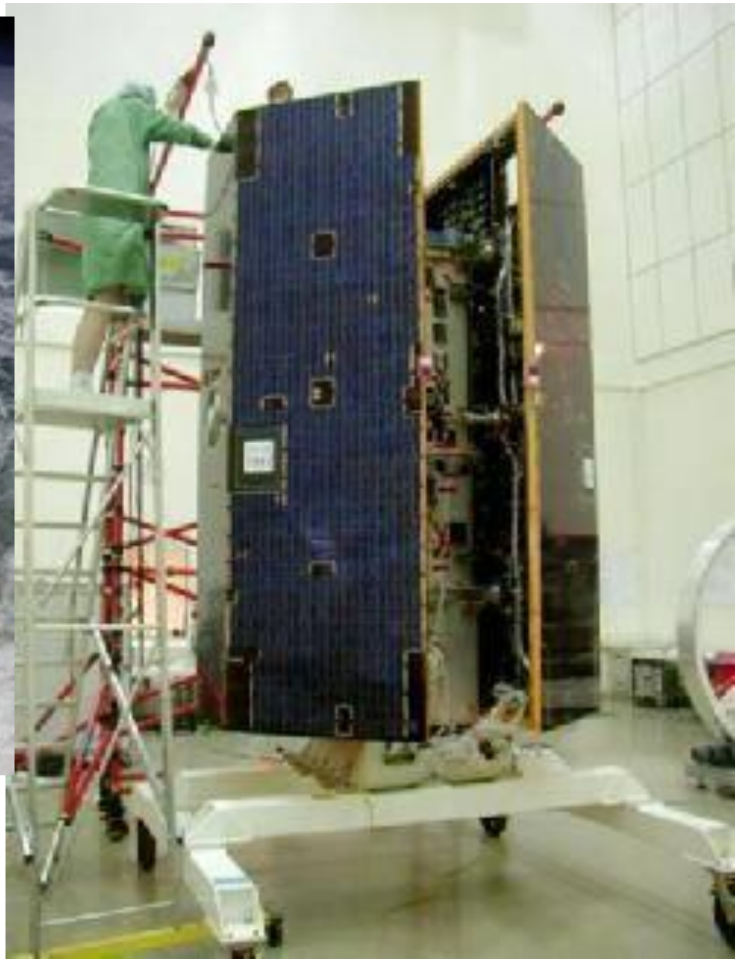


Figure 3.2c: Gravity Satellites (GRACE I/II, FO)
(Source: NASA/Jet Propulsion Lab)

AERIAL/UAS Technologies

(Airborne Photogrammetry & Unmanned Aerial System)

Photogrammetric Mapping Aircraft

Figure 3.2d: *Aerial/UAS Technologies*

Matrice DJI 350 RTK Drone

Terrestrial Measurement Technologies/Tools

GNSS CORS Choke Ring Antenna

Infrared HD Camera

DGPS Receiver

Indoor Position Sensor

Laser Distance Sensor

- **WINDCRANE**, equipped with additional sensors to measure:
  - *wind direction/speed, temperature,*
  - *solar radiation, relative humidity, &*
  - *precipitation*

Magnetometer

ScanStation C10

Sounding & Survey Vessel

Leica MS60 Robotic Total Station

WorkStation

Figure 3.2e: ***Terrestrial Survey Technologies***

☞ *The disruptive technologies have resulted in new and emerging integrated approaches and techniques for modelling* earth systems and complex phenomena/variables for effective and sustainable management.

☞*The use of* ***software engineering, cloud computing, big data science, AI, ML & DL algorithms*** *have now proved to be the most convenient, accurate and cost effective means for modelling and simulation of earth systems and dynamics such as:*

- ◊ *Earth geoid and shape*
- ◊ *Earth magnetic field*
- ◊ *Earth gravity field*
- ◊ *Wind speed modulus*
- ◊ *Sea wave height*
- ◊ *Ocean geostrophic velocities*
- ◊ *Atmospheric water vapour,*
- ◊ *Tectonic plate motions,*
- ◊ *Atmospheric constituents,*
- ◊ *Climate change variabilities, etc.*

Integrated Geospatial Approach of DS, AI, ML & DL for Modelling & Simulation

AI = Enable the machine to think

ML is a subset of AI, which provide statistical tools to explore data.

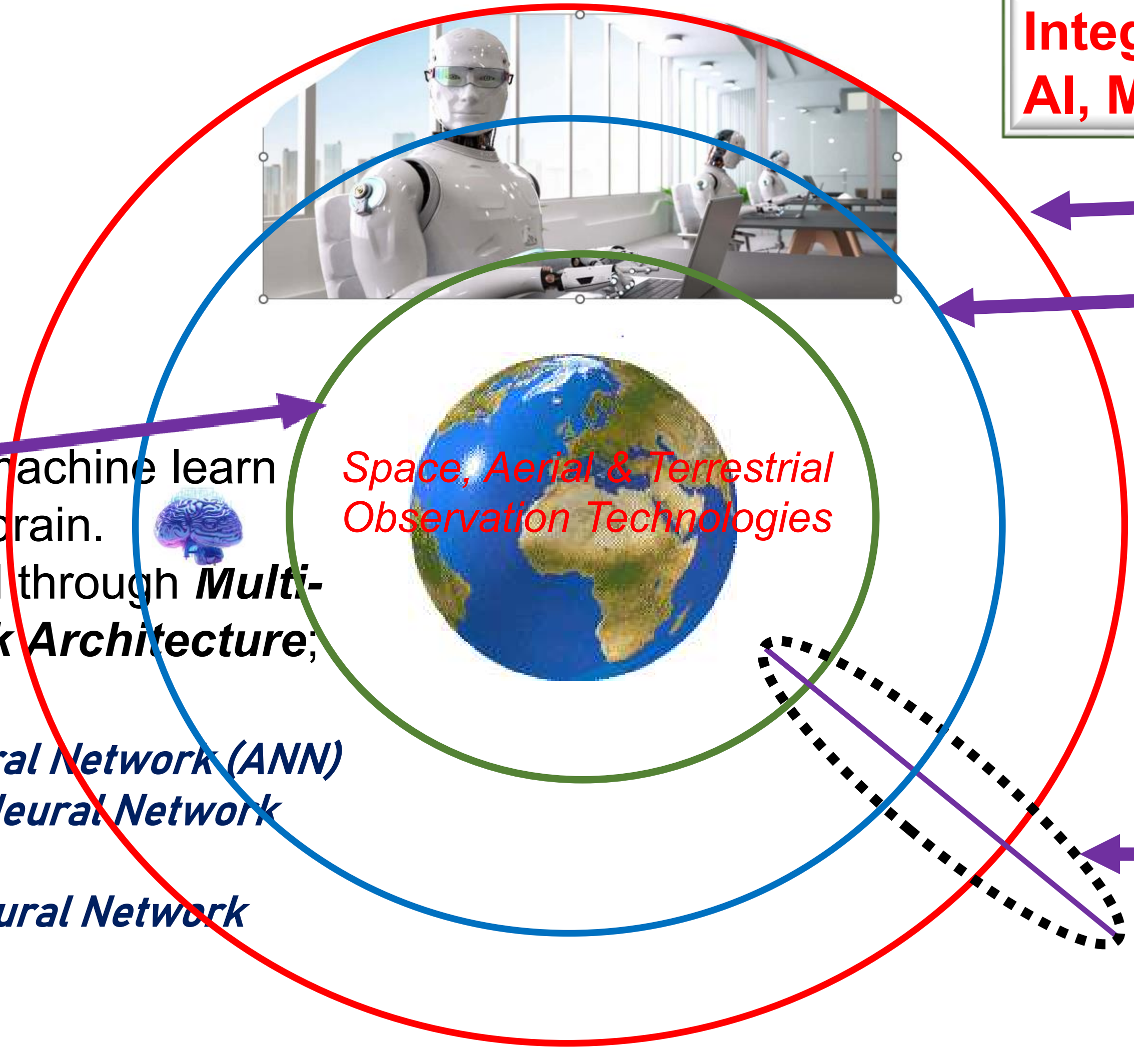
ML is categorised into three:

- ***Supervised ML***
- ***Unsupervised ML***
- ***Reinforced ML (semi-supervised ML)***

DL= Make the machine learn like the human brain.

This is achieved through ***Multi-Neural Network Architecture***; namely:

- ***Artificial Neural Network (ANN)***
- ***Convolution Neural Network (CNN)***
- ***Recurrent Neural Network***



Data Science (DS) = ML+DL+AI

(using mathematics, statistics, probability, linear algebra, approximation theory, spectral functions, etc.)

Figure 3.3: Integrated Geospatial Data Science Approach for Modelling & Simulation of Complex Systems

Software, AI, ML and Data Science Development Tools for Geospatial Modelling and Simulation

- Data exploration & Clustering
- Recommendation Systems
- Regression
- Decision Systems
- Forecasting Systems
- Neural Networks
- All Geomatics/GIS Software & APIs

- Matrix Laboratory (Matlab)
- Python
- R-Studio
- AI Coding Software (all types)
- OpenAI
- AI models with Unique no Code Approach

The Future of Geospatial Modelling and Simulation

☞ Presently, AI is transforming the geospatial information science and technology by enhancing the:

- speed,
- accuracy,
- efficiency,
- continuity
- reliability
- cloud computing
- access/availability,
- data security and compliance
- convenience/ease of data handling,
- interoperability,
- data communication, *amongst others*.

Fig.3.4: Geospatial Cloud Warehouse Security and Compliance Network & Open Datasets

4.0 EARTH DYNAMICS AND COMPLEX SYSTEMS

☞ The Earth and its environment in its three basic domains, namely:

- *Space/Atmosphere,*
- *Ocean/Marine, &*
- *Land Surface/Solid Earth*

are the fields where all dynamic phenomena and features are located.

☞ These features and phenomena (static or dynamic) can all be defined and modelled in Euclidean space as entities with coordinates and attributes (*in celestial or terrestrial coordinate systems*).

Table 4.1a: Key geospatial features & dynamic phenomena within the geospatial data domains (GDD) ***[space/atmosphere & ocean/marine Domains]***

GDD	Data Name	(GDD)	Data Name
Space/Atmospheric Domain	Temperature	Ocean/Marine Domain	Salinity
	Pressure		Sea surface temperature (SST)
	Precipitable water vapour		Ocean water density (OWD)
	Relative humidity		Mean sea level pressure (MSLP)
	Air density		Geostrophic velocities of wind (U, V)
	Albedo		Mean sea level (MSL)
	Wind speed		Significant wave height (SWH)
	Wind vorticity		Ocean current/wave
	Cloud Thickness/base height		Bathymetry
	Duct base height		Ice thickness/height
	Surface solar radiation downwards		Sea level anomaly (SLA)
	Total Electron Content (TEC)		Sea level rise (SLR)
	Aerosol		

Table 4.1b: Key geospatial features & dynamic phenomena within the geospatial data domains (GDD) [***Land Surface/Solid Earth Domain***]

GDD	Data Name
Land Surface/Solid Earth Domain	Soil moisture contents (SMC)
	Surface runoff and velocity of flow
	Land Surface Temperature/ urban heat,
	Land Use and Land Cover
	Normalised differenced vegetation index (NDVI)
	Normalised differenced water index (NDWI)
	Wind speed
	Geoidal undulation (N)
	Gravity
	Terrain height/elevation
	Surface slope/aspect
	subsidence (horizontal & vertical. deformations)

GDD	Data Name
Land Surface/Solid Earth Domain	Stress and strain rate
	Erosion depth
	Landslide magnitude/width
	Actual rainfall
	Human population
	Geology and soil types
	Seismic waves
	Aridity and land dryness
	Volume of flow
	Flood height/depth
	Magnetic field

5.0 EXAMPLES OF STUDIES ON EARTH SYSTEM MODELLING & SIMULATION

☞ Some examples of earth system modelling and use cases for references in this presentation include the following, amongst others.

- ◊ *Earth Magnetic Field Modelling*
- ◊ *Earth gravity field modelling*
- ◊ *Sea Wave Height Modelling*
- ◊ *Ocean Geostrophic Velocities*
- ◊ *Atmospheric Water Vapour Modelling*
- ◊ *Wind Speed Modulus Modelling*

(a) Earth Magnetic Field Modelling

☞At the Earth's surface the total intensity varies from 22,000 nanotesla (nT) to 67,000 nT.

☞Earth Magnetic Field (EMF) help the earth system in the following ways:

- ◊ *Protection against foreign solar objects penetrating our atmosphere.*
- ◊ *Protection against solar winds (shields the earth all from the constant bombardment by charged particles emitted from the sun)*
- ◊ *Giving Earth a magnetic pull which in turn allows for navigation with the use of a compass.*

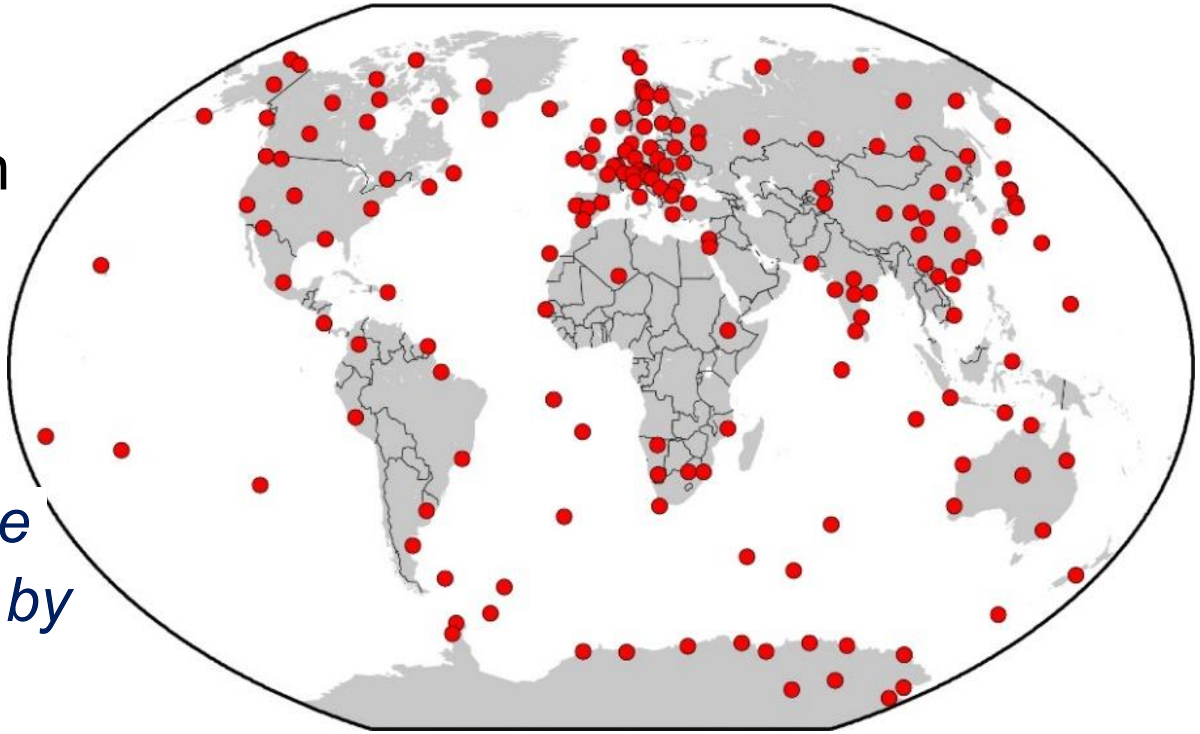


Figure 5.1a: Locations of currently operating geomagnetic observatories (https://geomag.bgs.ac.uk/education/earthmag.html)

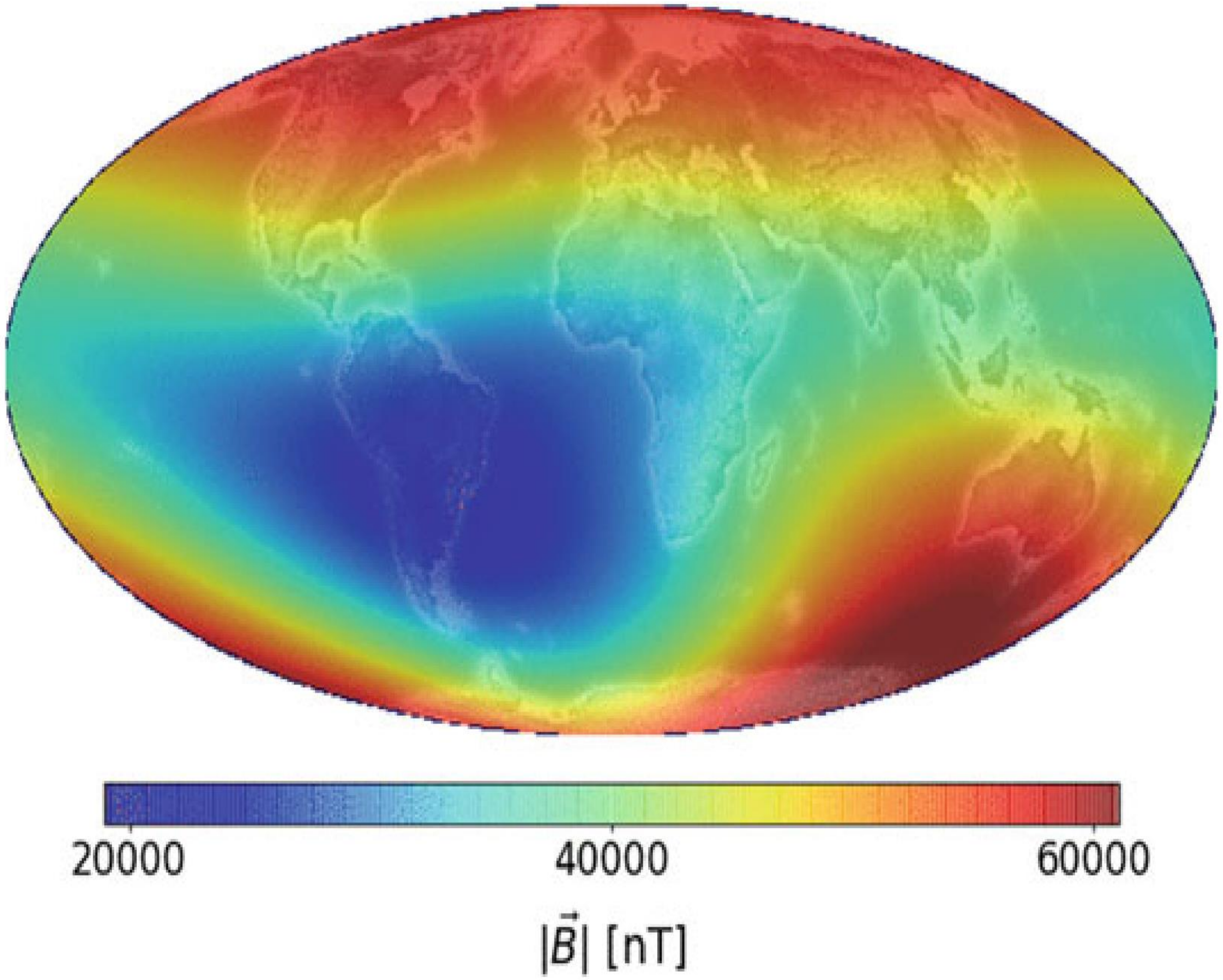
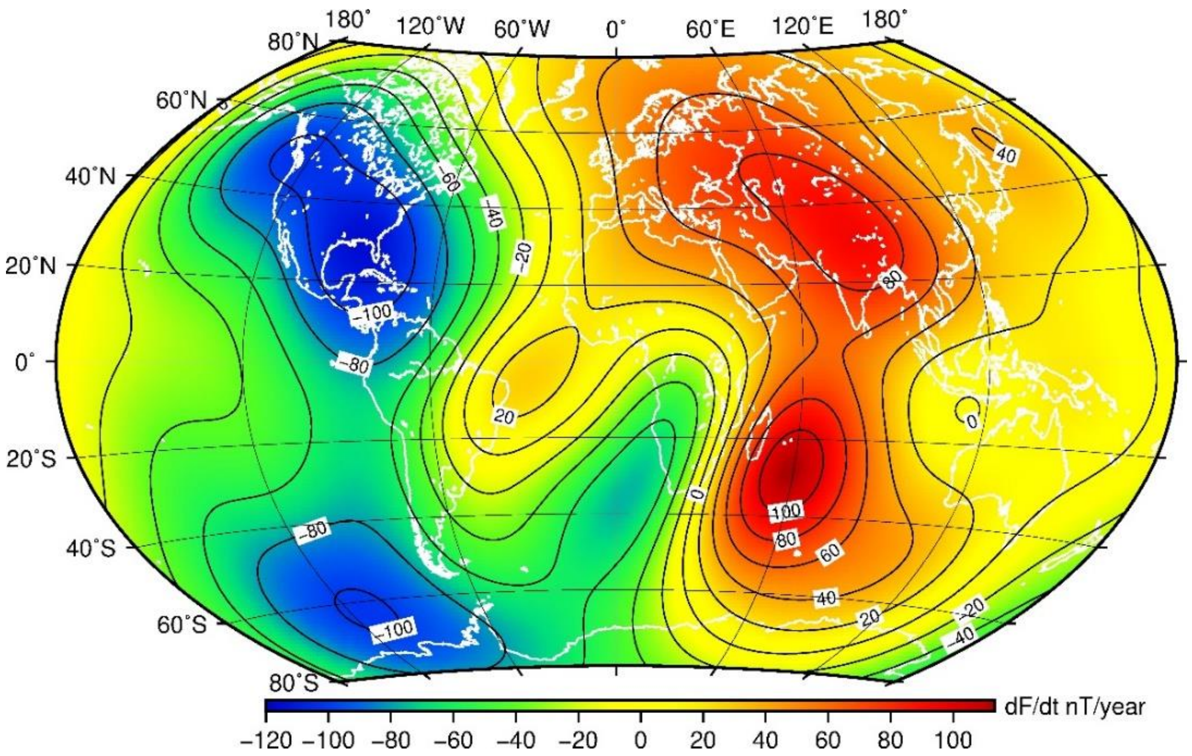


Figure 5.1: (b) Magnetic field strength at Earth's surface (Source: Ignacio Chechile, 2023)



(c) Map of predicted annual rate of change of total magnetic intensity for 2020.0-2025.0
https://geomag.bgs.ac.uk/education/earthmag.html

(b) Earth gravity field modelling

The anomalies highlight variations in the strength of the gravitational force over the surface of the Earth. ***Gravity anomalies are often due to unusual concentrations of mass in a region***.

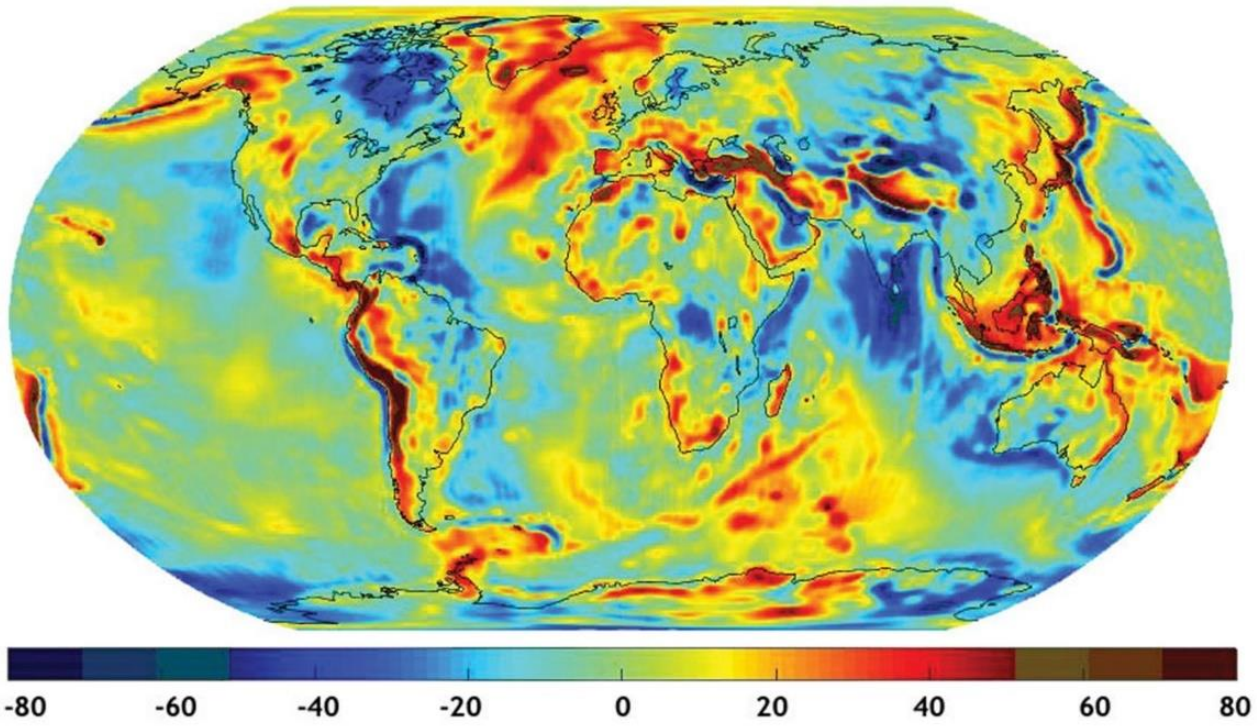


Figure 5.2a: Gravity Variation across the Globe (Source: NASA GRACE / University of Texas, Austin)

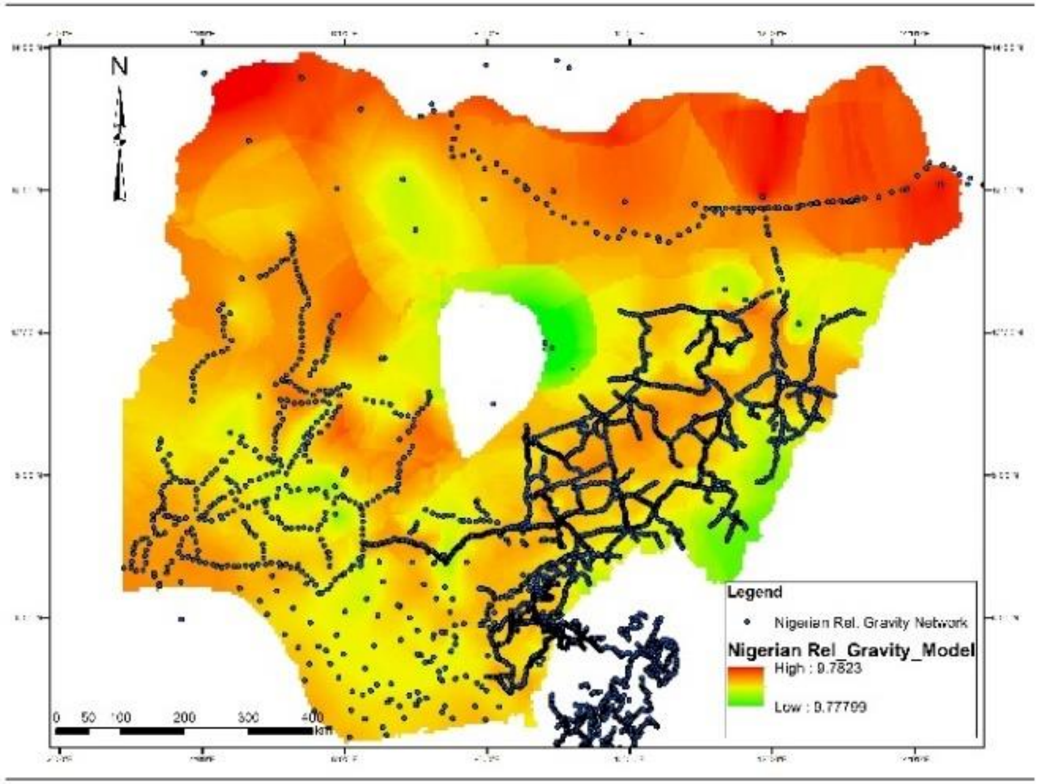


Figure 5.2b: Gravity Map of Nigeria (Ojigi, 2014; 2024)

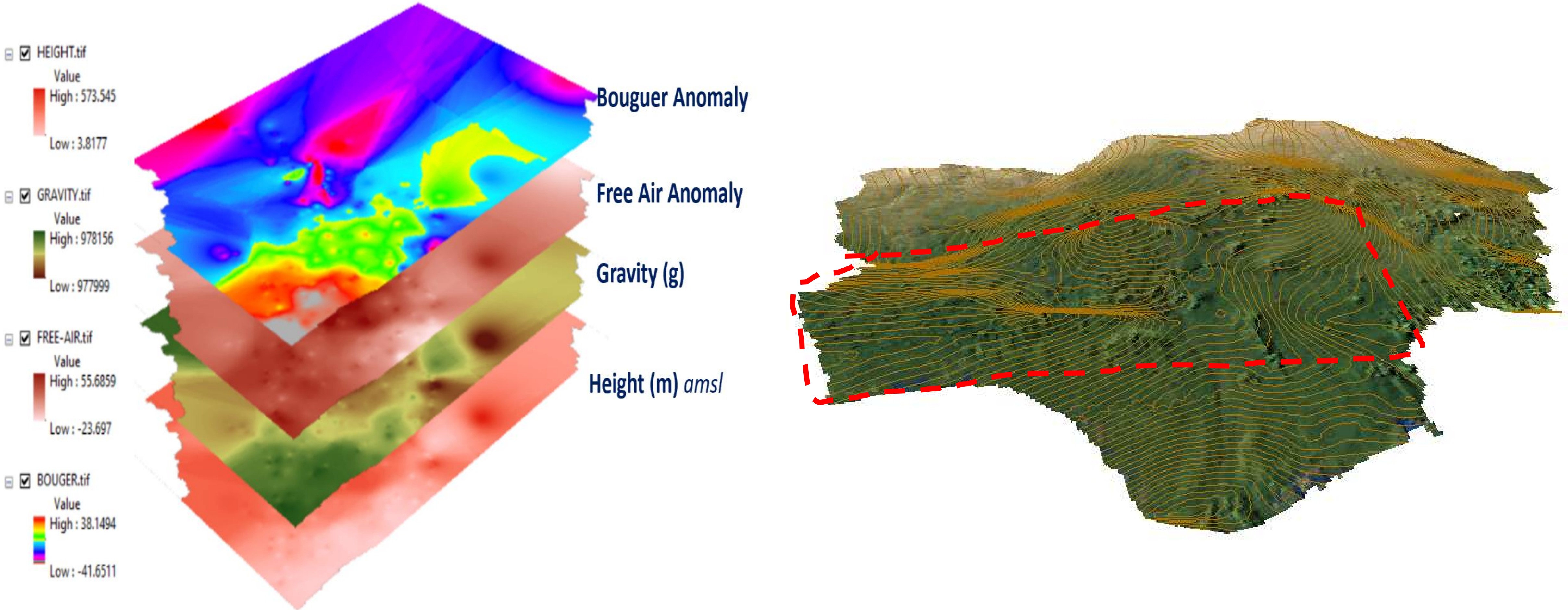
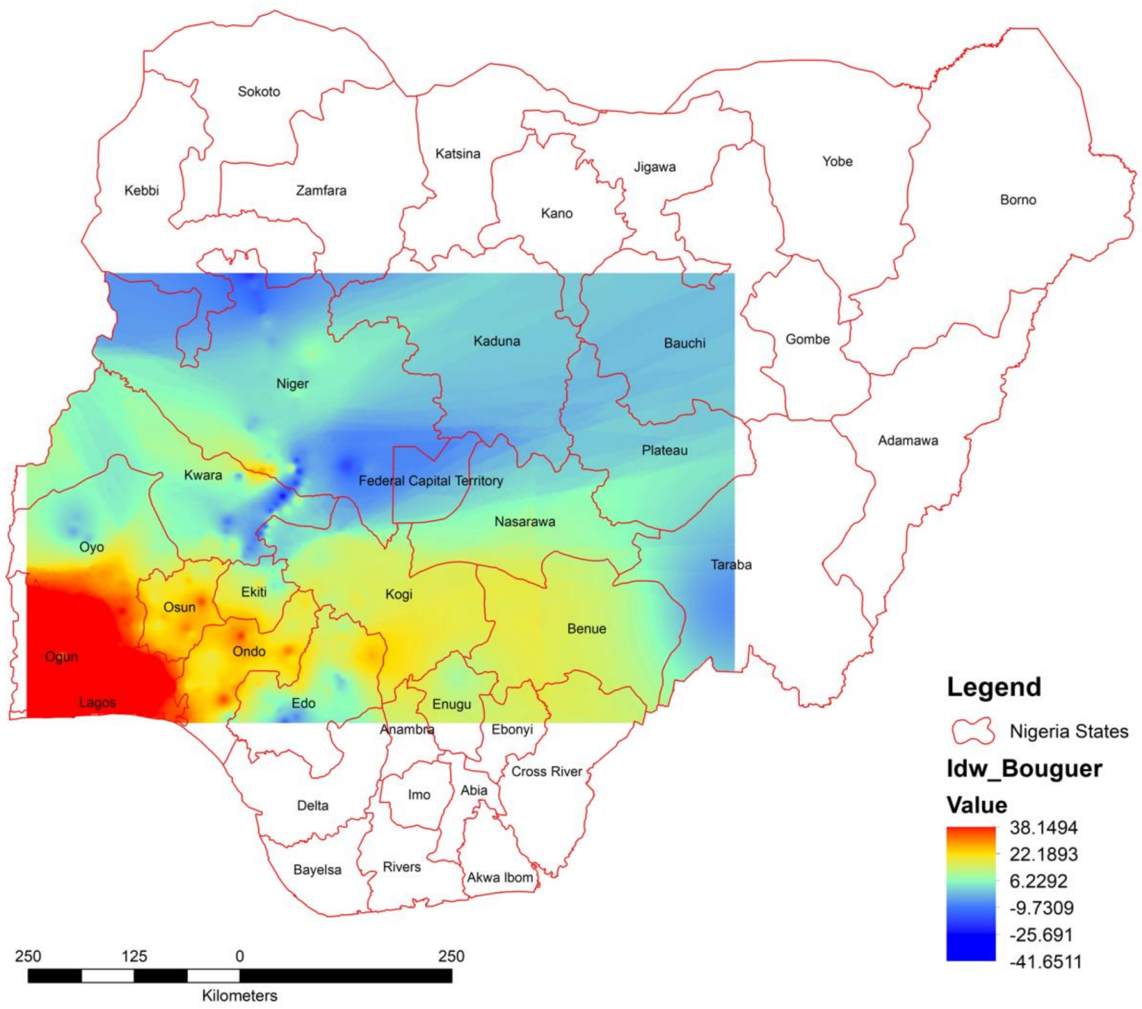


Fig. 5.2: (c) Bouguer, FA, Gravity & Topographic Elevation Overlay Modelling over parts of the SW and NC Regions of Nigeria; (d) Geoidal Undulation (1' arc grid) Over Nigeria developed from EGM2008 (Ojigi, 2014)



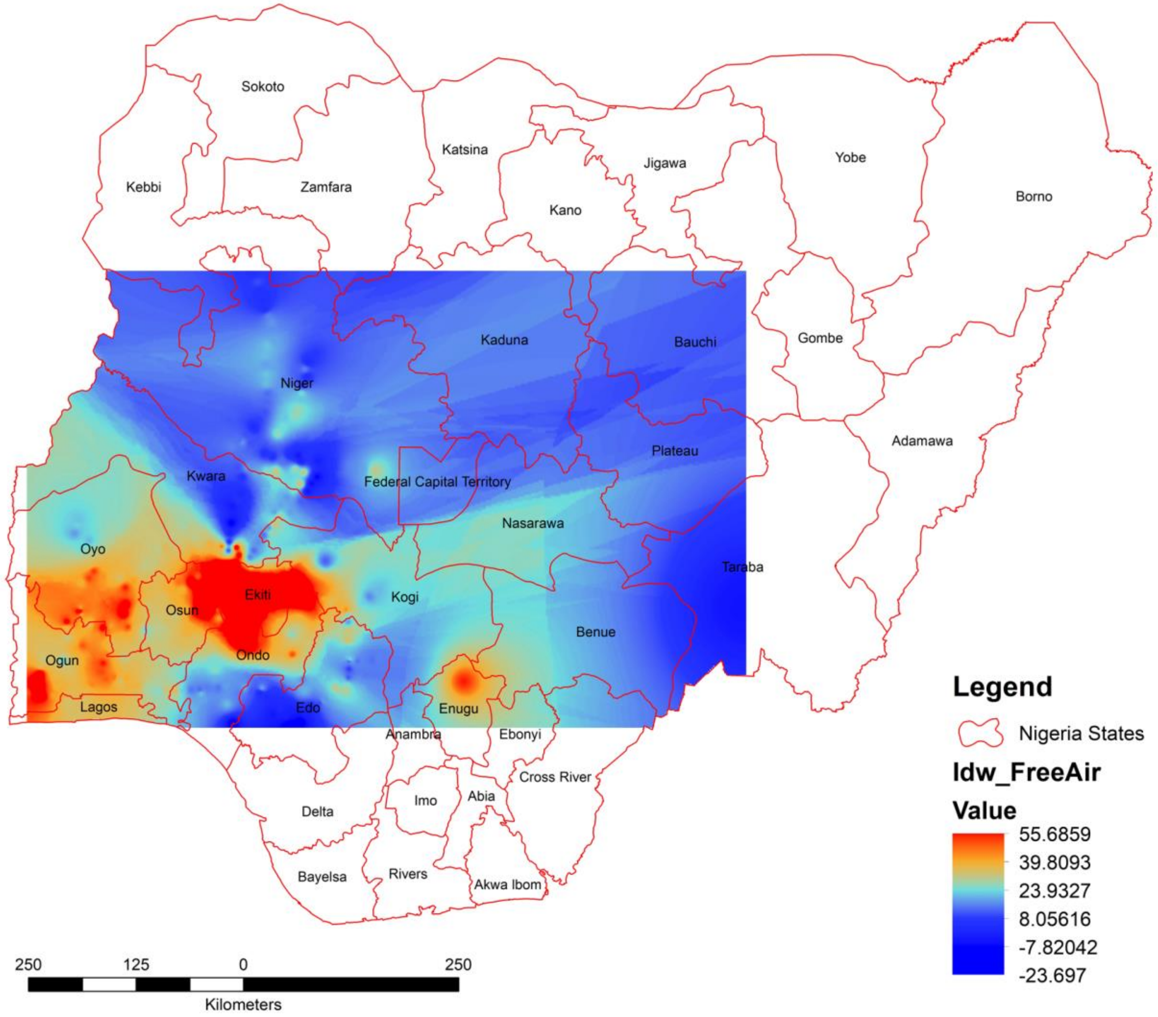


Fig. 5.2:

(e) Bouguer Gravity Anomaly Over Parts of SW and NC Nigeria

(f) FA Gravity Anomaly Over Parts of SW and NC Nigeria

(c) Modelling Sea Wave height

- The measuring and mapping of the ocean wave heights, SWH and velocity using wave echoes determined from satellite radar altimetry have become possible and convenient globally

- The key challenges and complexities facing SWH detection from satellite altimetry are *coastal data* and *low sea states*. Therefore; data in the coastal zone are flagged as bad or unreliable and left unused due to land and calm water interference in the altimeter footprint (Passaro *et al.*, 2016).

- Secondly, SWH are characterized by an extremely sharp leading edge that is consequently poorly sampled in the digitalized waveform. However, taking a look at the slope of the leading edge of the return pulse, the wave height can be measured (figure 4.3a).

Figure 5.3a: (i) Coastal Region of Nigeria; (ii) Ocean Wave height Measurement Wave form

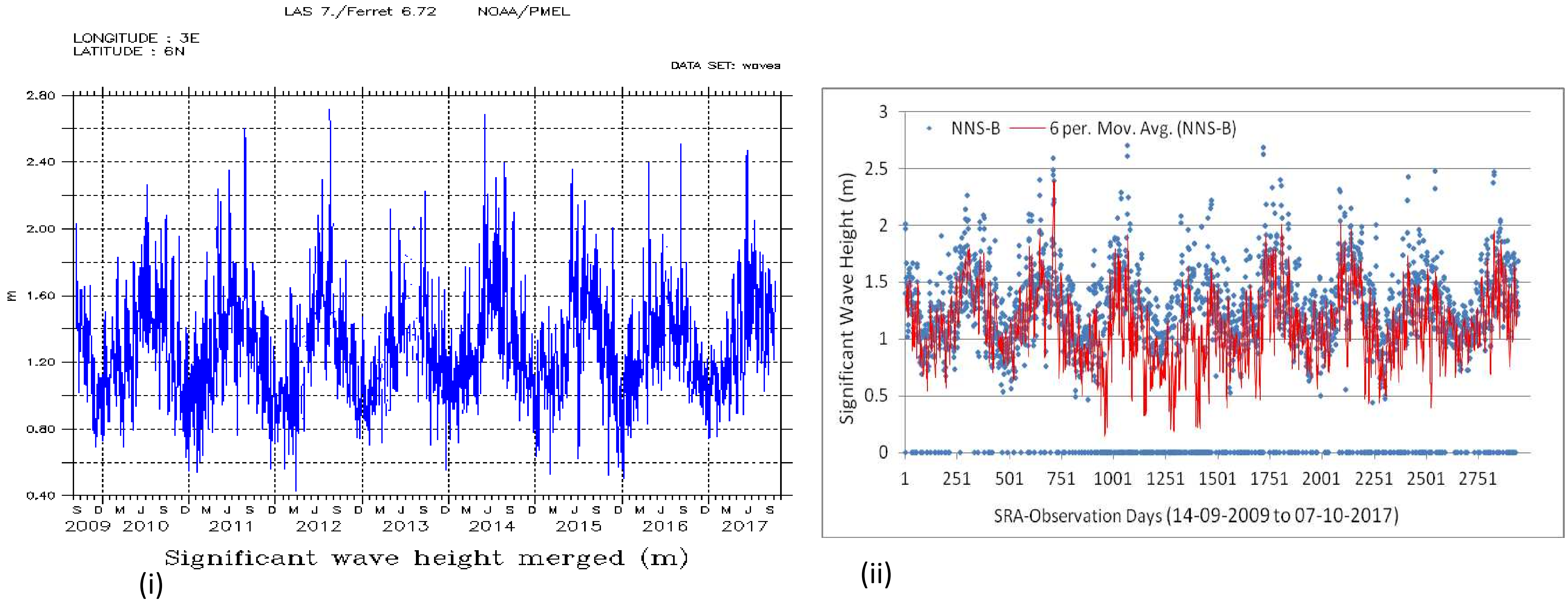


Fig. 5.3b: (i) SWH of NNS-B (2009-2017); (ii) SWH Trend Fitting for NNS-B, Apapa Lagos (2009-2017) (Ojigi, 2019)

(d) Ocean Geostrophic Velocities

- Geostrophic velocity is the component of a wind or current that arises from a balance between pressure gradients and Coriolis forces (rotation force), and on a small scale and meso-scale, it is considered as a geodynamics process arising from the rotation of the earth (AMS, 2006; Stewart, 2008; Fu, 2014).

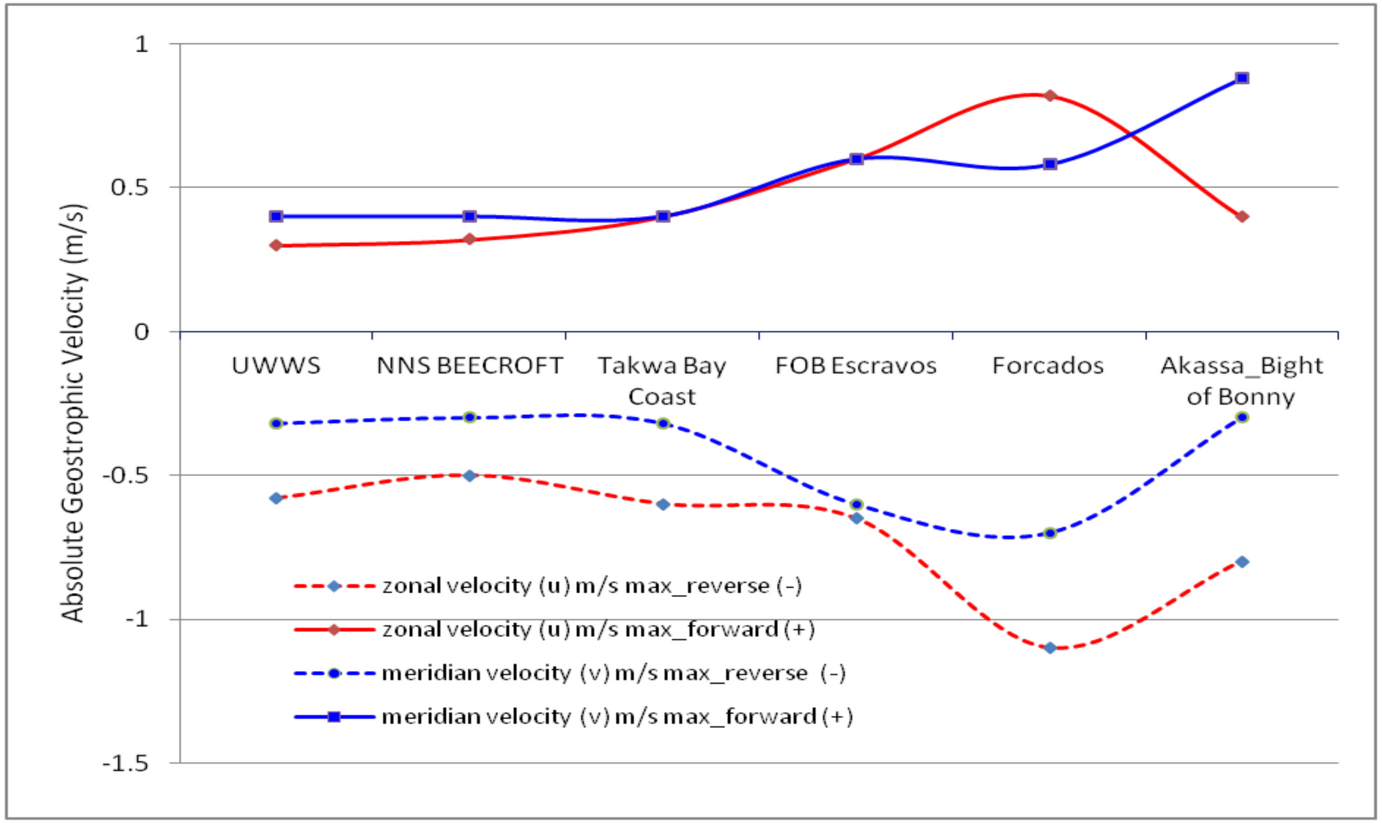
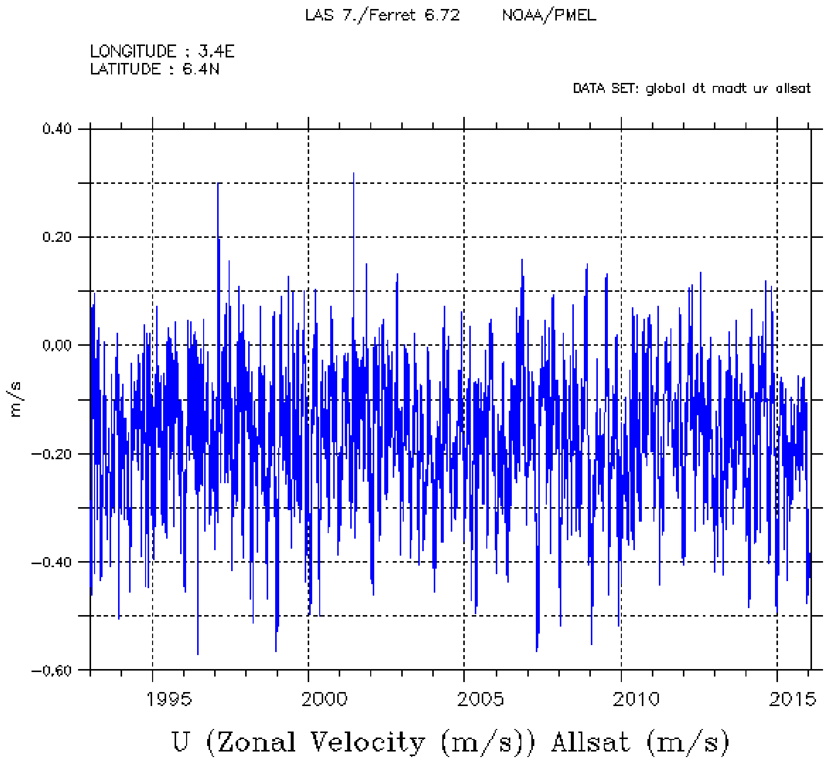
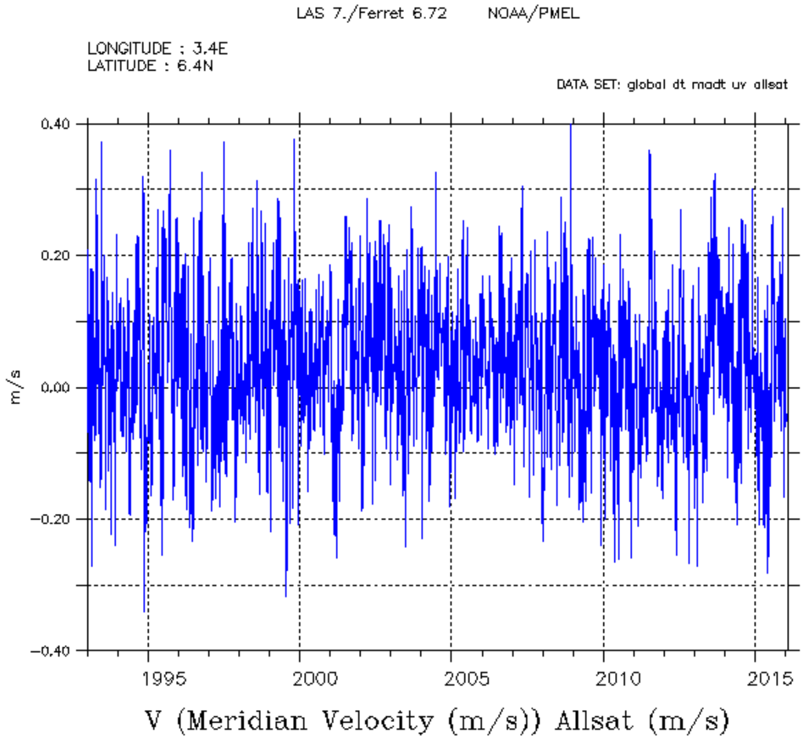


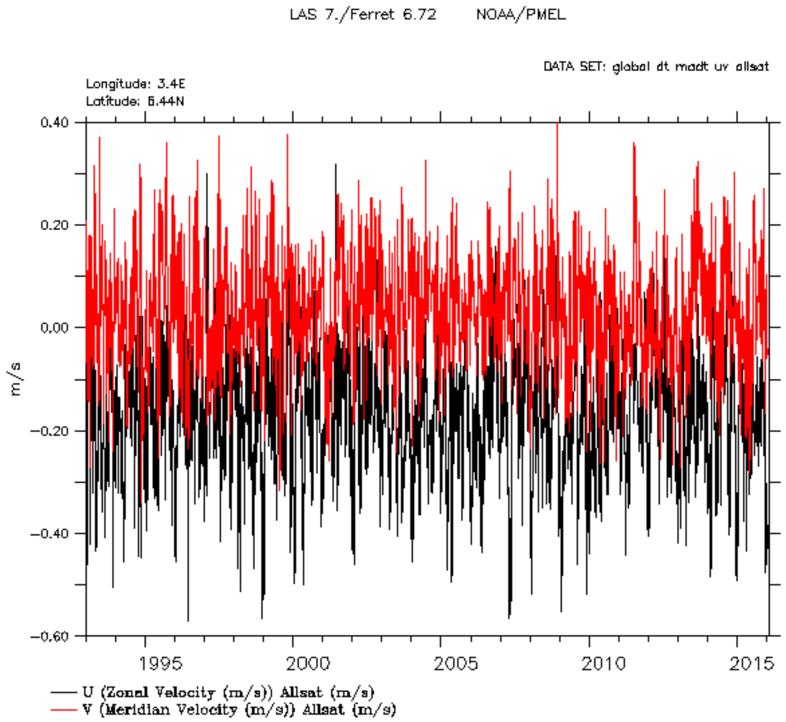
Figure 5.3c: Average Absolute Geostrophic Velocities (m/s) of Proposed Jetty Locations in Parts of the Coastal Region of Nigeria (1993-2016). (Ojigi *et al.*, 2016)



(i) NNS-BEECROFT *u-velocity*



(ii) NNS-BEECROFT *v-velocity*



(iii) NNS-BEECROFT *uv-velocity*

Figure 5.3d: Time Series Absolute Geostrophic Velocities (m/s) at the NNS-BEECROFT Jetty in Lagos Coastal Waters of Nigeria (1993-2016) (Ojigi *et al.*, 2016)

(e) Atmospheric Water Vapour Modelling

- ☞ Spatial variability of water vapour in the atmosphere influences the earth weather, climate system, quality of spatial positioning, and radio waves propagation of communications signals amongst others.

- ☞ *Water vapour is the most important natural greenhouse gas and the dominant source of infrared opacity in the clear sky atmosphere, and key parameter for earth energy budget and climate change analysis.*

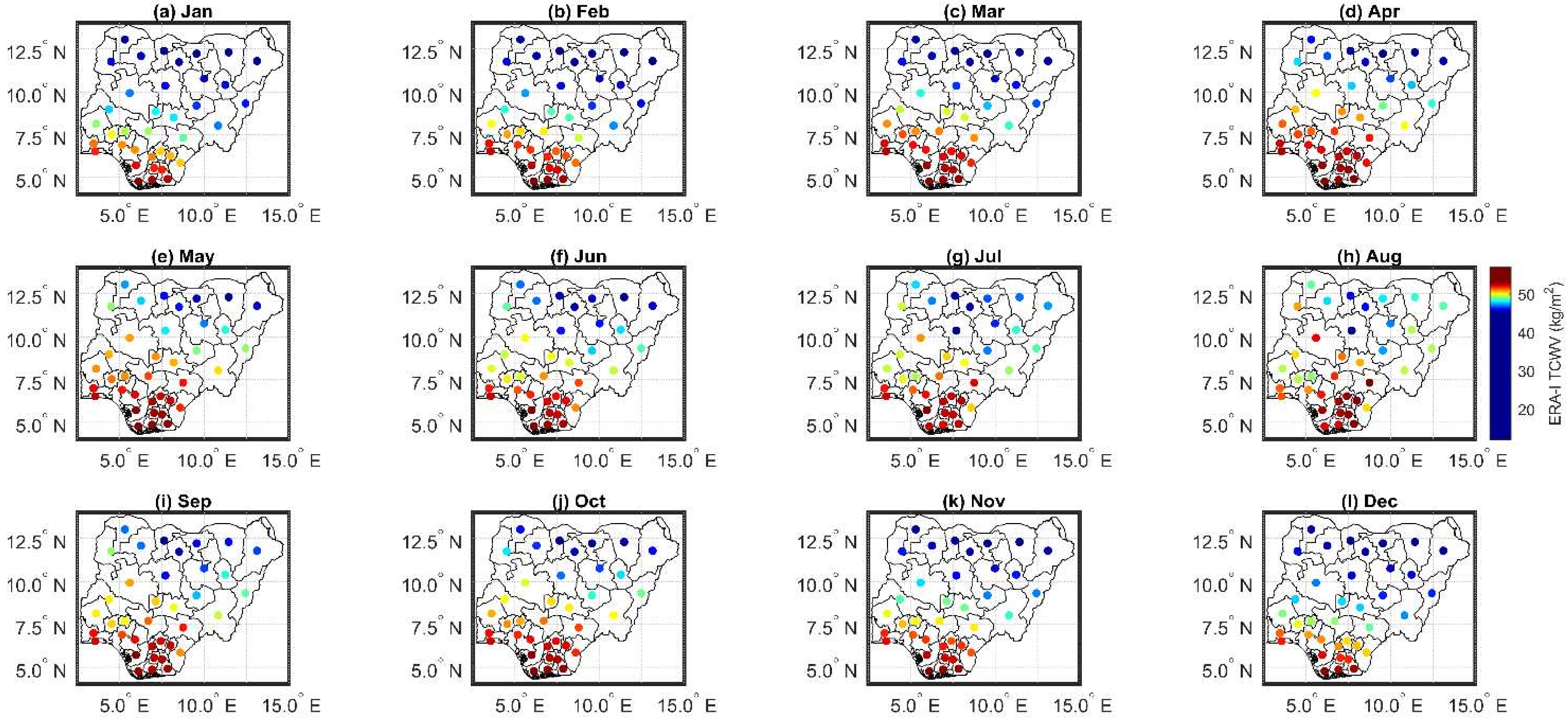


Figure 5.4: Monthly Mean of ERA-Interim Atmospheric Water Vapour (kg/m^2) over 37 City Locations in Nigeria for year 2007-2017 (Ojigi and Opaluwa, 2019)

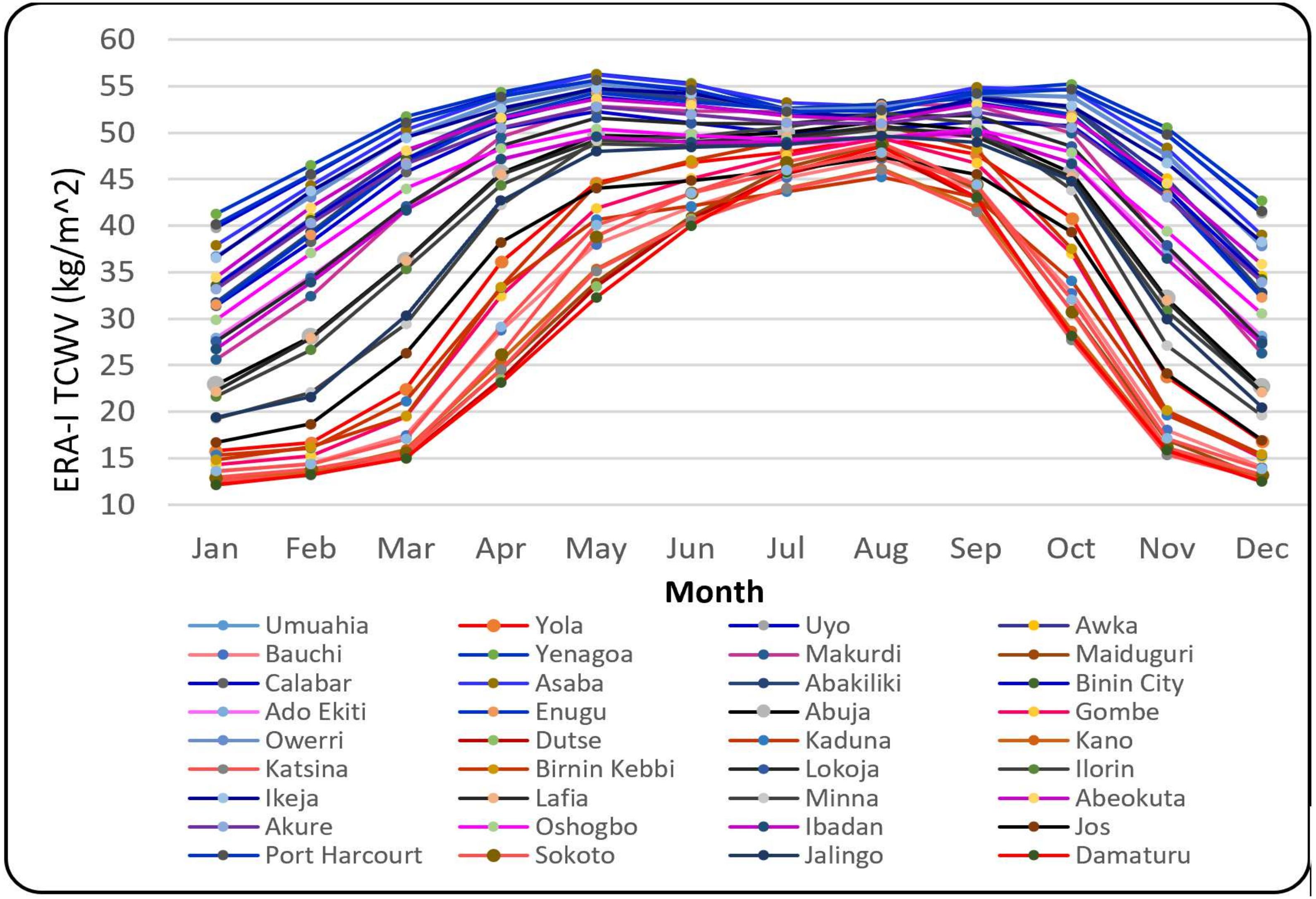
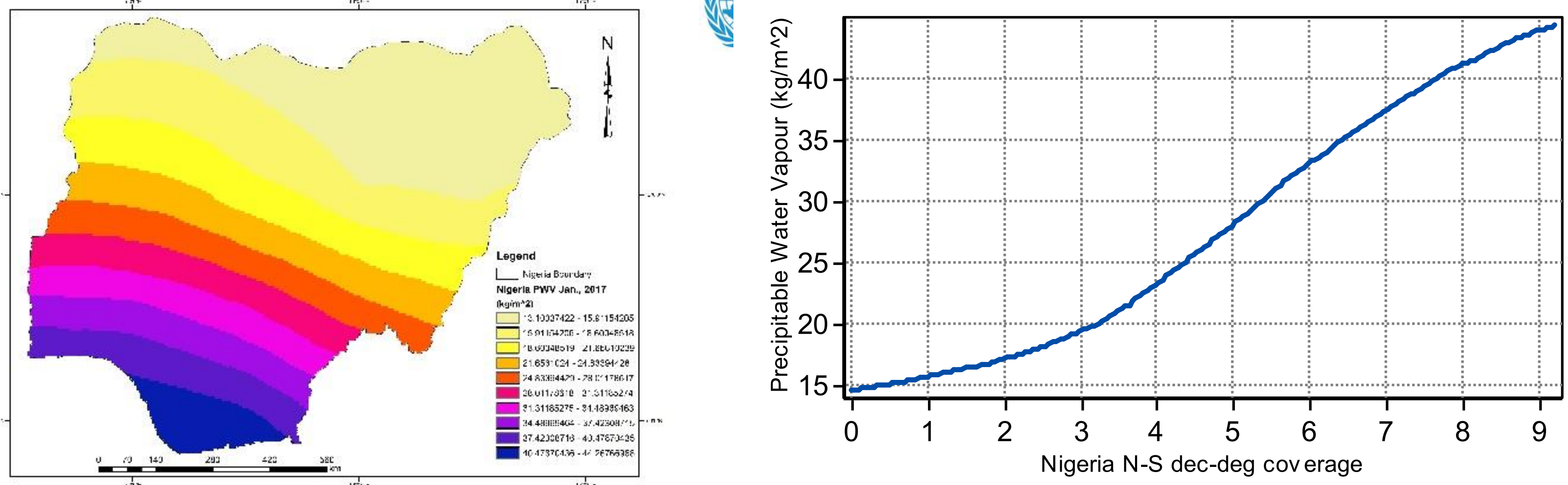


Figure 5.5: ERA-I Monthly average atmospheric water vapour (kg/m^2) for 37-selected cities in Nigeria (Ojigi and Opaluwa, 2019)

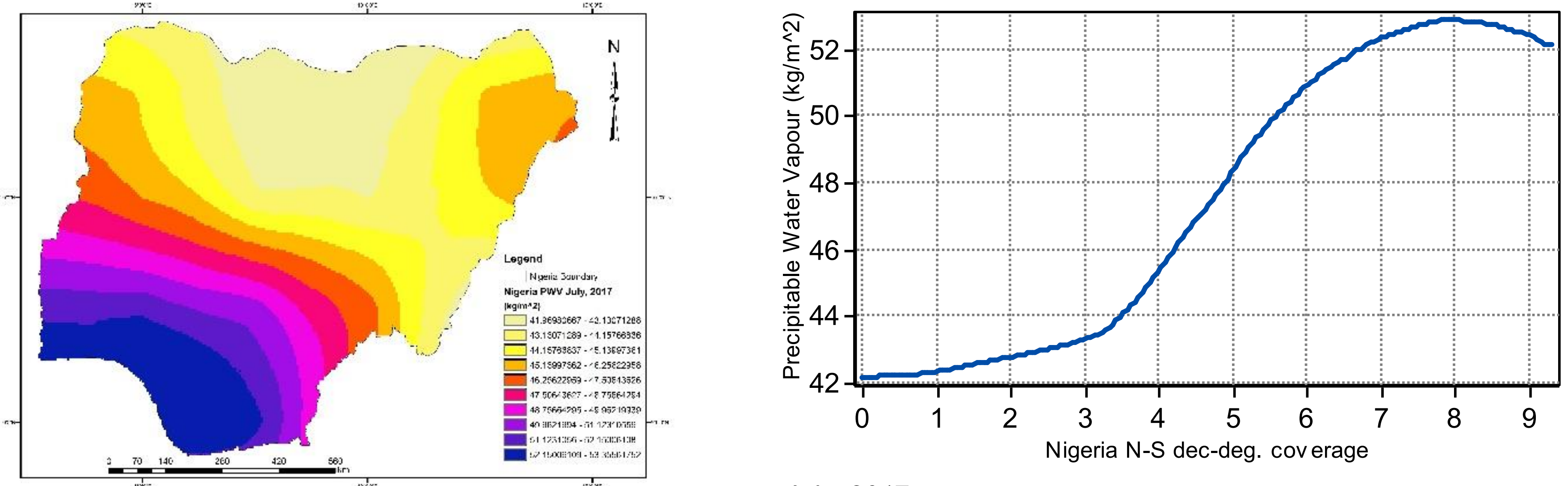
Table: 5.1: Polynomial trend fitting models for some cities in the geopolitical zones of Nigeria (Ojigi and Opaluwa, 2019)

City/Zone	Model ERA-I	R^2
Damaturu (NE)	$y = -1.0852x^2 + 15.064x - 11.67$	0.7836
Oshogbo (SW)	$y = -0.6763x^2 + 9.0096x + 21.937$	0.9445
Lafia (NC)	$y = -0.9856x^2 + 13.248x + 7.2087$	0.9575
Birnin Kebbi (NW)	$y = -1.2211x^2 + 16.794x - 9.9597$	0.8695
Enugu (SE)	$y = -0.7354x^2 + 9.8735x + 22.592$	0.9359
P/H (SS)	$y = -0.6763x^2 + 9.0096x + 21.937$	0.9445

Note: *y* (kg/m^2) represents the vapour value and *x* represents the period of month



Jan., 2017



July, 2017

Figure 5.6: (iii) Spatial Map of Precipitable Water Vapour Content Over Nigeria (Jan/July, 2017)

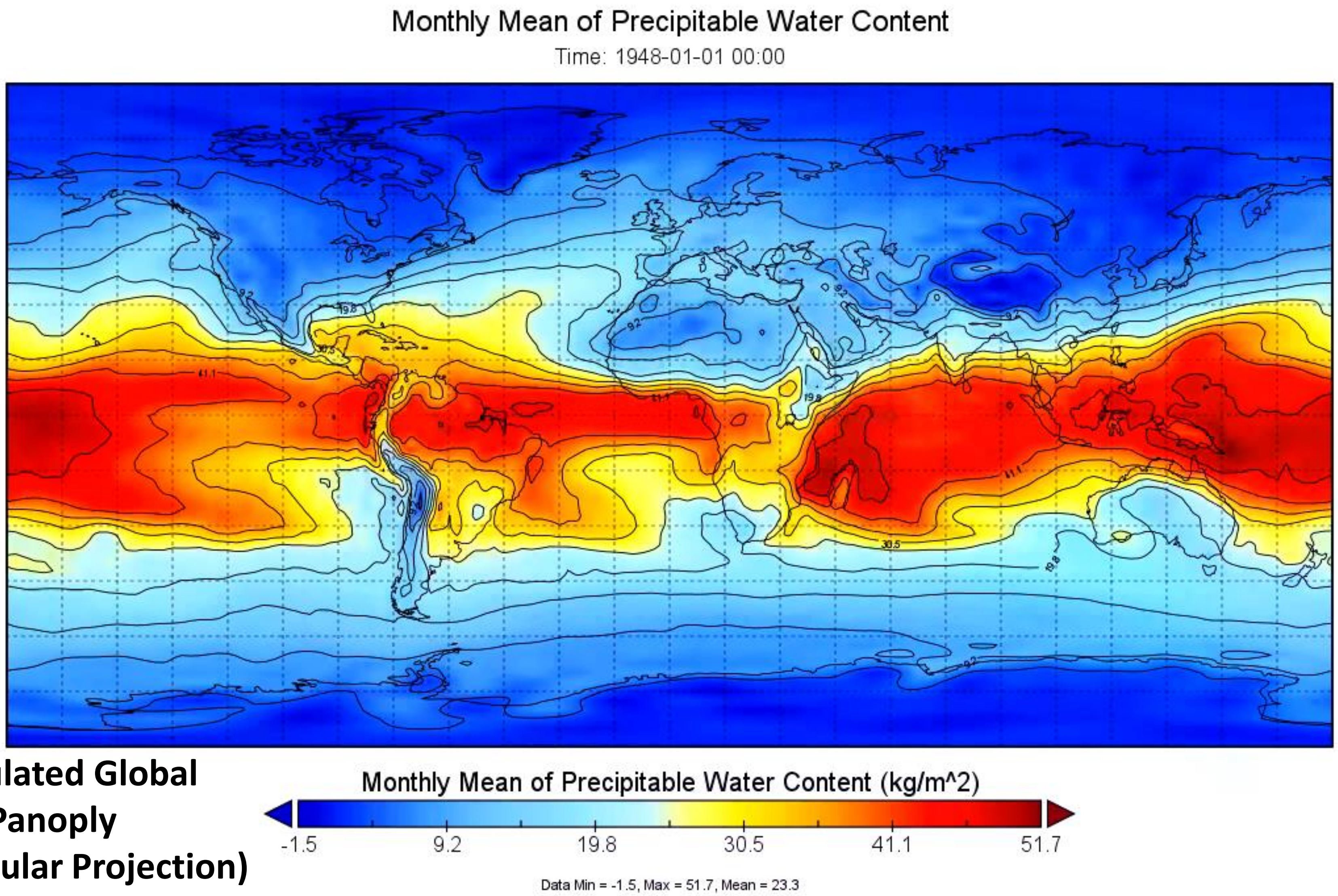


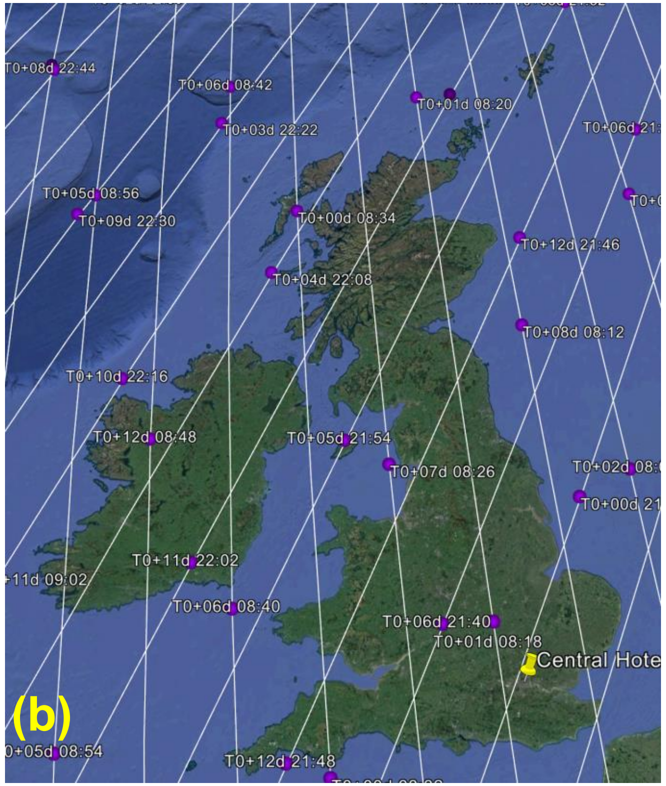
Fig.5.7: Simulated Global PWVC with Panoply (Equirectangular Projection)

(f) Wind Speed Modulus Modelling

☞ Wind speed phenomena is one of the climate change variables with the following effects, amongst others:

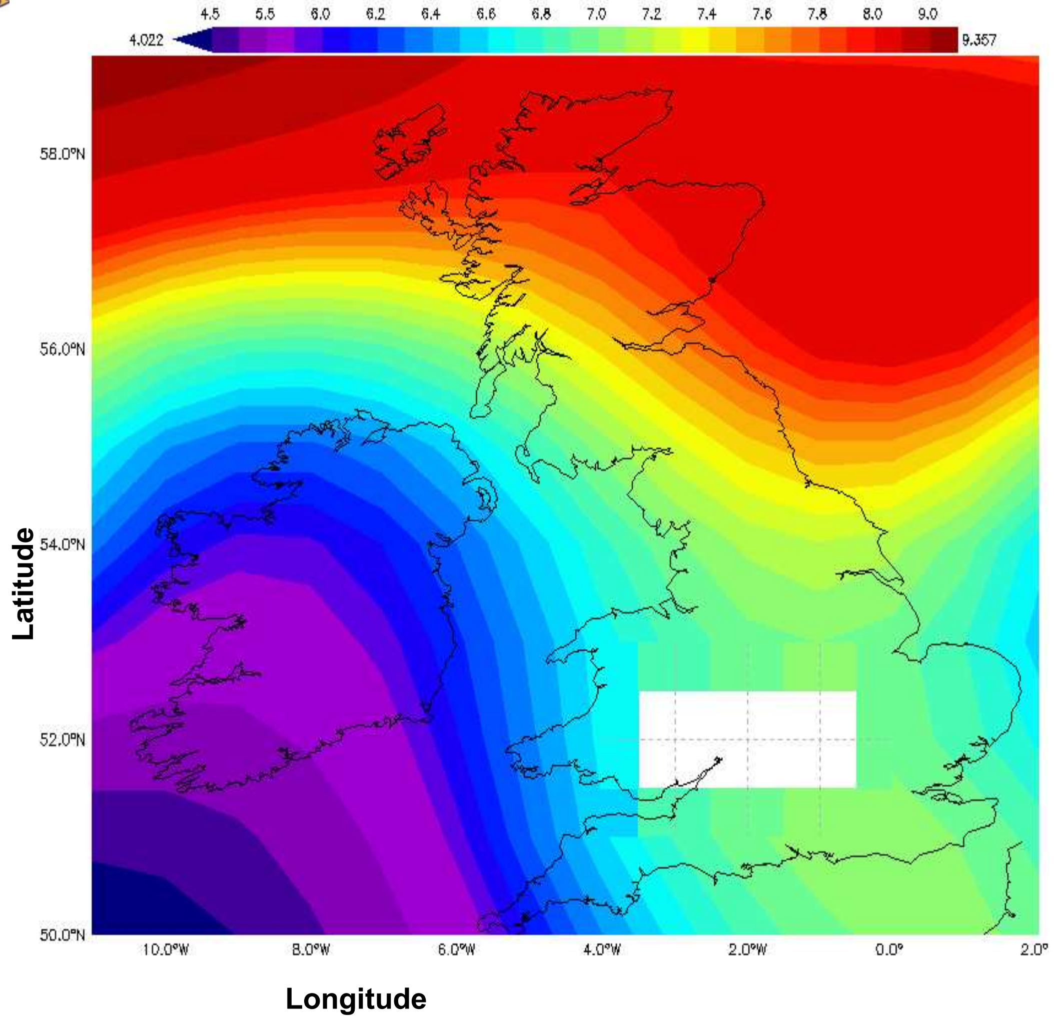
- ◊ Protection against foreign solar objects penetrating our atmosphere.
- ◊ a massive source of renewable energy
- ◊ has damaging and disruptive impacts on earth/engineering infrastructure
- ◊ *regulate or modify air quality over a region.*
- ◊ *a critical factor in the spread of pathogens* across an area
- ◊ cause motions (u, v, w) and circulations to marine-atmospheric variables such as; vapour/precipitation, temperature, pressure, radiation, etc.

Wind Speed Modulus Modelling

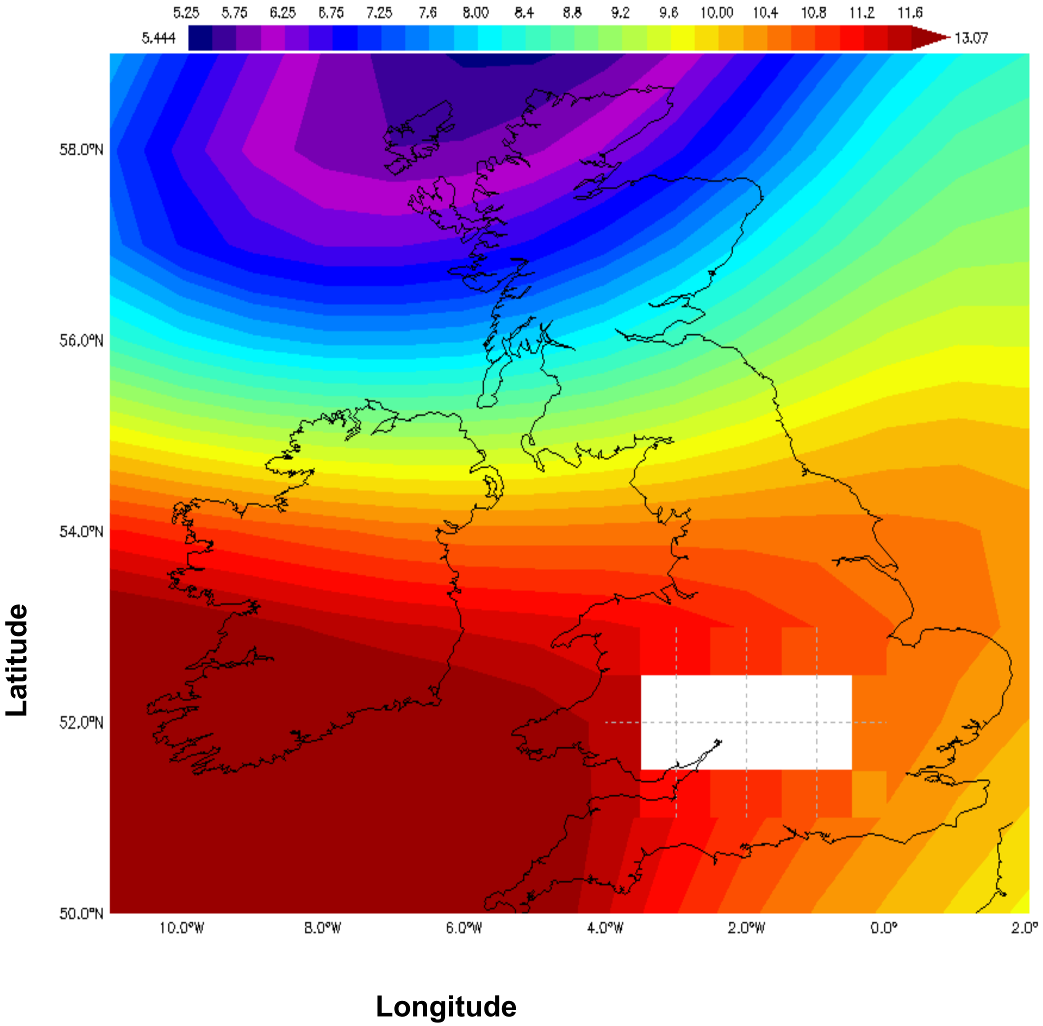


S/no	Location	Longitude (λ)	Latitude (ϕ)
1	London	0.13W	51.50N
2	Manchester	2.24W	53.48N
3	Nottingham	1.14W	52.95N
4	New Castle Upon Tyne	1.60W	54.98N
5	Glasgow	4.24W	55.89N
6	Bristol	2.59W	51.45N
7	Cardiff	3.18W	51.48N
8	Norwich	1.29E	52.62N
9	Canterbury	1.08E	51.28N
10	Edinburgh	3.20W	55.95N

Figure 5.8: (a) Map of the United Kingdom [ESRI]; (b) Satellite Altimetry Ground Track Over the UK

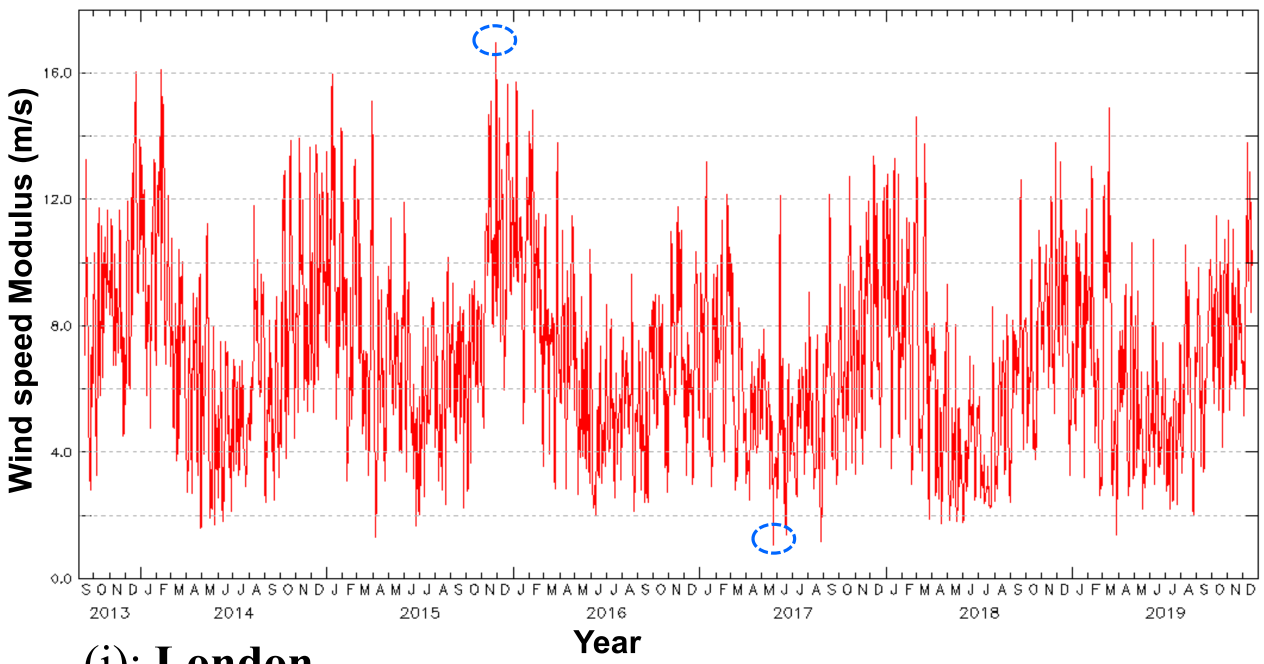


(i) 14-SEP-2013 (start date)



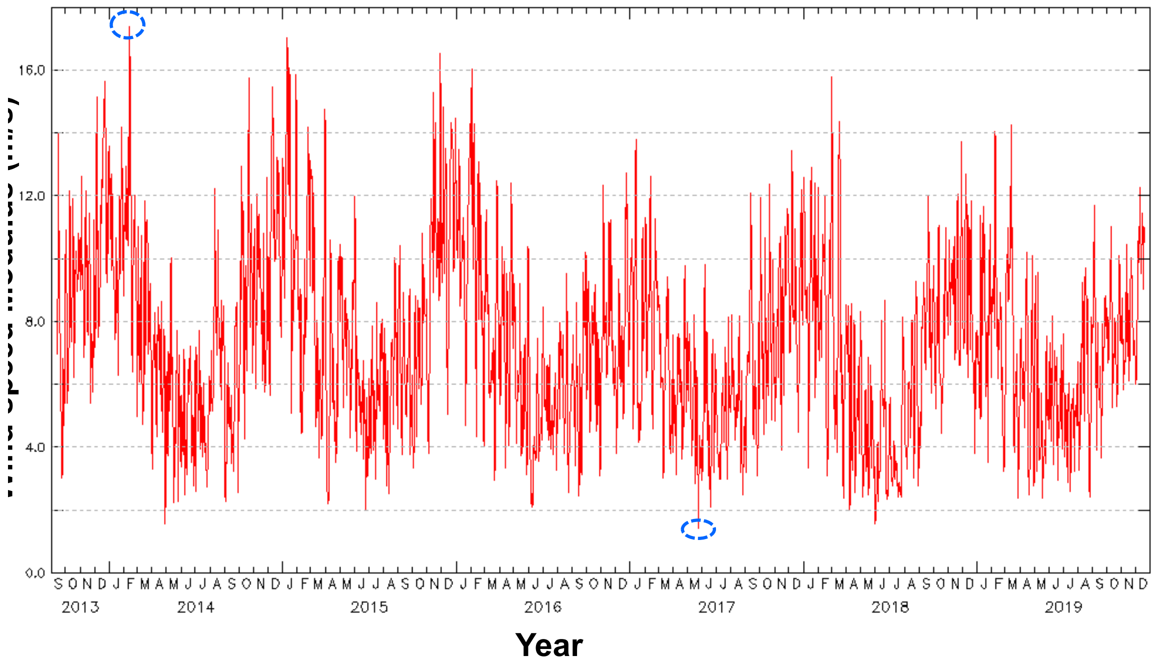
(ii) 19-DEC-2019 (end date)

Figure 5.8b: Spatial map of wind speed modulus merged (m/s) over UK (Ojigi, 2023)



(i): **London**

Min. speed/Date (m/s)	Avg. Speed (m/s)	Max. speed (m/s)
1.08 (25/05/17)	6.94	16.94 (29/11/15)



(ii): **Manchester**

Min. speed/Date (m/s)	Avg. Speed (m/s)	Max. speed (m/s)
1.42 (25/05/17)	7.29	17.38 (13/02/14)

Figure 5.8c: The times series (2013-2019) wind speed modulus over London & Manchester, UK derived from Satellite Radar Altimetry (Ojigi, 2023).

Table 5.2: The estimated wind speed and corresponding wind load force on a vertical surface area of $10m^2$ in selected locations in the United Kingdom (Source: Ojigi, 2023)

Location	Wind Speed (m/s)			Force of Wind Load (N) ($F_w = \frac{1}{2} \rho v^2 A$]; [1Pa = $1N/m^2$]		
	Min.	Avg.	Max.	Min (F_w)	Avg (F_w)	Max (F_w)
London	1.08	6.94	16.94	6.982947	288.95	1722.42
Manchester	1.42	7.29	17.38	12.13256	319.1871	1812.343
Nottingham	1.29	7.27	17.46	9.972328	317.3302	1829.749
New Castle Upon Tyne	1.30	7.62	18.58	10.16288	347.9516	2070.712
Glasgow	1.43	7.87	18.84	12.33549	371.9706	**2130.675**
Bristol	1.43	7.09	16.62	12.31151	301.5073	1656.547
Cardiff	1.43	7.09	16.62	12.31151	301.5073	1656.547
Norwich	1.16	7.27	17.42	8.092877	317.3406	1821.386
Canterbury	1.01	6.93	16.74	6.126577	288.2667	1681.864
Edinburgh	1.41	7.83	18.92	11.94935	367.5595	**2148.641**

CONCLUDING REMARKS

- ☞ *Software scripts and languages, AI, ML and DL algorithms* are being used to effectively analyse/model complex environmental data, detect, map and simulate changes in environment over time; allowing for the geospatial scientists to easily predict environmental condition index and provide accurate data for development strategies.

- ☞ The emerging geospatial technologies and techniques are parts of the global **disruptive technologies *(software evolutions, AI, ML and space science and technology, etc.),***

☞ *All aspects of* ***geospatial science and engineering*** are evolving, fast growing, and causing revolutions in industries, lifestyles and various applications, methods and integrations strategies for decision support in earth systems governance.

☞ Mathematical-physics is the driver of effective monitoring, modelling and simulation of complex and spatially-varying elements of the earth atmosphere, environments and processes for human benefits.

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‘technology innovation capital is the driver of sustainable global development’ ….’ ***Lazarus Mustapha Ojigi***

THANK YOU