

Modern Geodesy and Imperatives for Integrated Capacity Development in Africa

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Presentation Outline

- ◇ Introduction
- ◇ An Overview of Modern Geodesy
- ◇ Imperatives for Geodesy Capacity Development Programmes in Africa
- ◇ Framework for Integrated Geodesy Capacity Development In Africa
- ◇ Challenges of Geodesy Capacity Building in Africa
- ◇ Conclusion

Introduction

- ❑ Technological advancements and globalisation have:
 - i. nearly moved all measurement systems in geodesy from terrestrial/ground to space/airborne platforms; resulting in complex and big data system across board;
 - ii. made geodetic science to increasingly become relevant to a wider range of other disciplines, industries and organisations;
 - iii. through *advanced satellite technologies, big data science, artificial intelligence and machine learning* approaches democratise geodetic data access, processing and management systems;
 - iv. created a paradigm shift in the knowledge and capacity requirements for geodesists and scientists to remain relevant across the globe.
- ❑ The understanding of the full demands and implications of these advancements in the fields of geodesy is key in developing strategies for investing in its **broad-based capacity development (human, institutional and infrastructure) in Africa.**

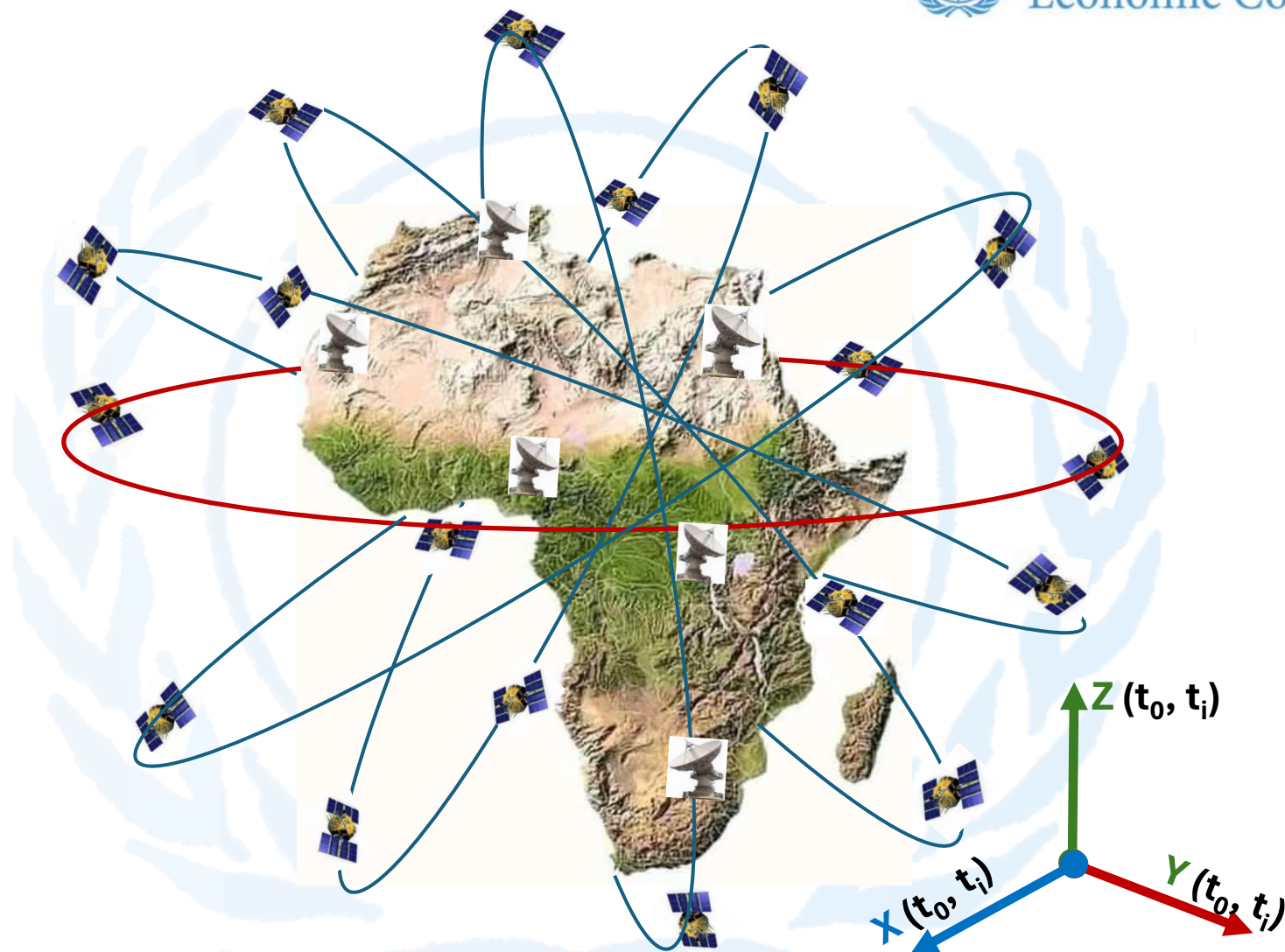


Figure 1: Prototype of a Well-Connected and Georeferenced Africa (after: Ojigi, 2025)

- Space geodetic techniques (GNSS, VLBI, DORIS, SLR, and LLR) and EOS (Optical and Microwave Remote Sensing/InSAR, Satellite Radar Altimetry, Satellite Gravimetry, LiDAR/Laser Systems, etc.) are largely responsible for the shift in the fortunes of modern geodesy.
- However, despite these developments, African scientists and policy makers could still only access and efficiently use these technologies, depending on affordability of the tools and techniques of the technology ecosystem.
- This has become the fate of Geodesy in Africa, where it is largely being look at from the perspective of Global Navigation Satellite System (GNSS), rather than the entire Geodetic Science Ecosystem as envisioned by IAG through the GGOS initiative (see Figure 1.1).
- **Lu *et al.* (2014) observed that a modern geodetic technology system centered on space geodesy has not only expanded the application area of geodesy in socio economic development but also improved its status as a basic discipline in geoscience.**

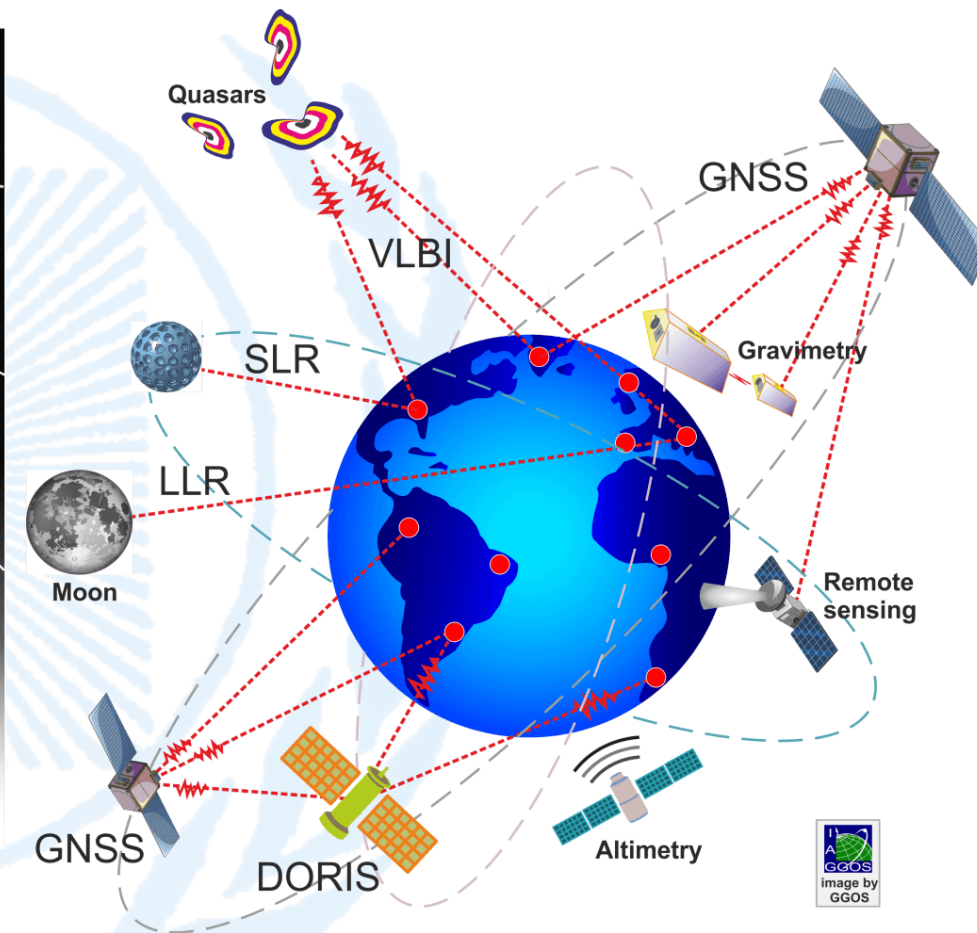
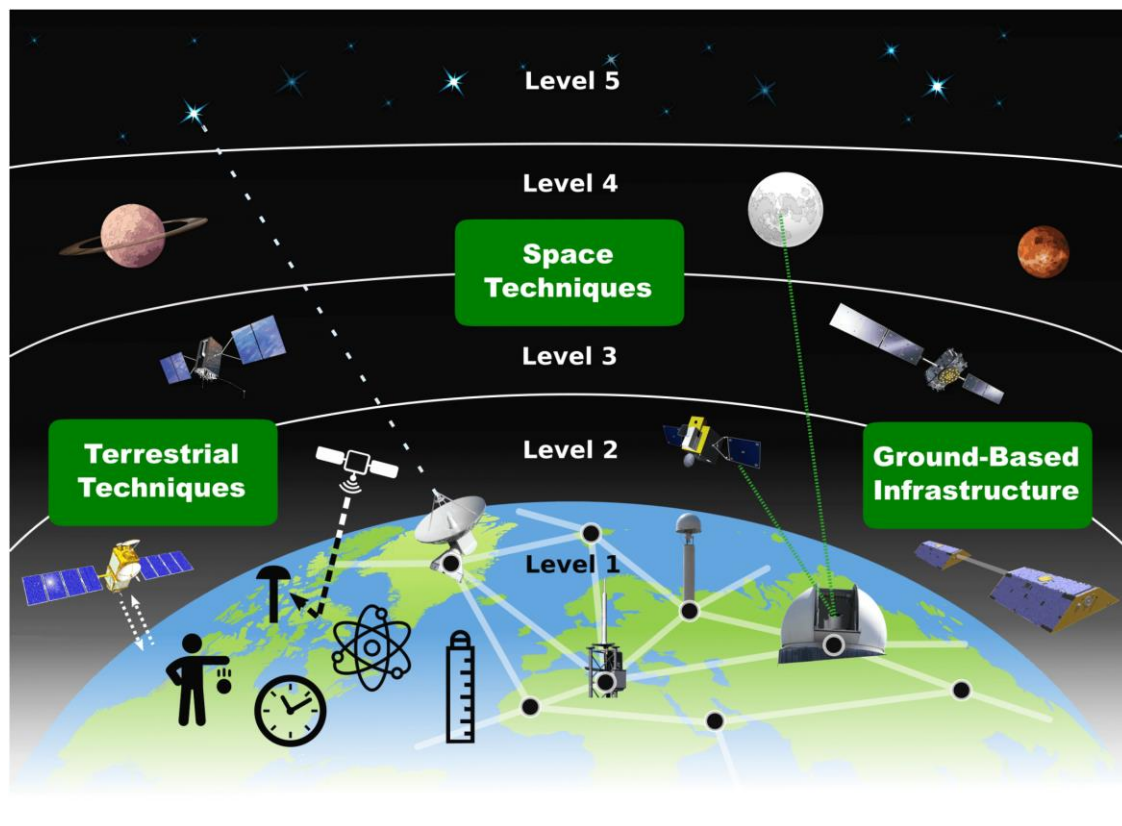


Figure 1.1: GGOS Architecture
(Source: <https://ggos.org/obs/>)

Objectives of the Paper

- i. Highlight the fundamental objectives of geodesy as a core science that underpins global sustainable development.
- ii. Briefly do overview of the areas and aspects of modern geodesy and reclassify based on widening relevance and applications due to emerging technologies.
- iii. provide perspectives on modern geodesy and the imperative for specialised geodetic capacity development programmes in Africa.
- iv. propose a framework for inclusive and integrated geodesy education and capacity building for sustainable development in Africa.

AN OVERVIEW OF MODERN GEODESY

- Geodesy is part of the geosciences and engineering science (including surveying, mapping and navigation), and is concerned with the monitoring and determination of the state and temporal variations of the **following** (IAG, 2012):
 - i. **Earth gravity field:** gravitational potential, centrifugal potential, total gravity potential, normal field, and anomalous field (*gravity anomaly, geoid undulation, and deflection of the vertical*);
 - ii. **atmosphere with satellite geodetic techniques:** ionosphere and troposphere composition and physical state/space weather;
 - iii. **spatial positioning, and their temporal variations:** precise positioning of points on or above the surface of the Earth;
 - iv. **solid Earth:** displacement, subsidence or deformation of the ground and structures, due to tectonic, volcanic and other natural phenomena, as well as human activity;
 - v. **liquid Earth:** sea level rise, ice sheets, mesoscale surface topography features, mass transport;
 - vi. **Earth's rotation and dynamics:** polar motion, the length of the day;
 - vii. **satellite orbits**, including earth observation, navigation and communication satellites.

- Modern perspectives of geodesy show, it has wide range of coverage and applications across fields of *human endeavour* , *assisted by advanced space geodetic techniques and data science, AI/ML*
- Therefore, modern geodesy is critical to the solutions of countless human existential challenges and global sustainable development strategies
- **Lu et al. (2014)**, classified geodesy based on the three thematic areas, namely:
 - i. scope of geospace: *ellipsoidal geodesy, geodetic control survey, marine geodesy, and engineering geodesy*),
 - ii. spatial-temporal attributes of the Earth: *geometric geodesy, physical geodesy, dynamic geodesy, and integrated geodesy*), and
 - iii. the technical means of carrying out the fundamental tasks of geodesy: *terrestrial geodesy, space geodesy, and inertial geodesy*

Areas of Modern Geodesy

- Geodesy provides the active nerve for surveying and mapping and the fundamental geospatial framework (*terrestrial and celestial reference frames, computational and geometric principles, coordinate systems, and gravitational models, etc.*) that enables all satellites and earth observation data to be accurately located, compared, processed, modelled, and analysed over time/space.
- In addition to the foundational training contents of geodesy, the current cross-cutting and multidisciplinary applications of geodesy due to emerging technologies justifies a streamlined reclassification of aspects of modern geodesy into its core subject areas for effective capacity development strategy and specialisation.

Areas of Modern Geodesy (cont..)

Modern geodesy could be categorised slightly different from the thematic perspectives by Lu *et al.* (2014) into the following nine areas.

Aspect of Geodesy	Aspect of Geodesy
▪ Geometric Geodesy & Reference Systems ▪ Physical Geodesy ▪ Space and Satellite Geodesy ▪ Mathematical Geodesy ▪ Marine Geodesy	▪ Geodetic Astronomy and Astrometry ▪ Environmental Geodesy & Geodynamics ▪ Engineering Geodesy ▪ Earth Observation Systems (EOS)

Areas of Modern Geodesy (cont..)

- This categorisation of aspects of geodesy in paper considers both the principles and applications, which in some cases are interwoven with other aspects of geosciences and engineering.
- For instance, remote sensing systems, which use EOS tools like InSAR, Satellite Gravimetry, Satellite Altimetry and LiDAR, etc. to map elevation, sea level changes, and surface deformation fall perfectly within the scope geodesy (space and satellite geodesy and EOS respectively).
- Also, Cartography and GIS forms parts of map projections and production, datums definitions, etc in geometric geodesy, and spatial data analysis, which fuses with the entire landscape of geodetic solutions and representations.
- Therefore, looking at modern geodesy from these stand points will encourage inclusiveness and avoid losing strategic grounds in emerging multi-disciplinary application fields

Modern Geodesy and Capacity Needs

- Africa has **capacity gap in geodesy**, and need to implement a deliberate training and capacity development across selected regional institutions, universities and research centres offering surveying and geomatics/geoinformatics, navigation and space science courses.
- The need for capacity building is to avoid losing grip of key scientific areas of engagements inherent in modern geodetic science.



Fig 3: Capacity gap

- Enhanced capacity scheme for geodesy in Africa, will strengthen the future role of the geodesist in the ***following areas of human endeavour, amongst others.***
 - i. Space science and rocketry
 - ii. Satellite mission planning and data management
 - iii. Tunnelling and underground construction
 - iv. Signal processing
 - v. Highway engineering
 - vi. Dam and large engineering structure monitoring
 - vii. Earthquake and landslide studies
 - viii. Geo-safety and plate tectonic motions
 - ix. Geophysical investigations
 - x. Navigation, timing and logistics management
 - xi. Satellite search and rescue & disaster management
 - xii. Oceanography and marine geodynamics
 - xiii. Oil and mineral prospecting,
 - xiv. Geospatial intelligence, GeoAI and security, etc.
- Technology ***funding/investments, trainings, research and development***, etc., leveraging the emerging advances in geospatial information science and technology, and artificial intelligence are the viable ways for Africa to develop and apply geodetic science.

IMPERATIVES FOR GEODETIC CAPACITY DEVELOPMENT IN AFRICA

- Capacity development is an indispensable driver of **innovation, growth and sustainability** for the realisation of goals and aspirations of any individual, institution, or country.

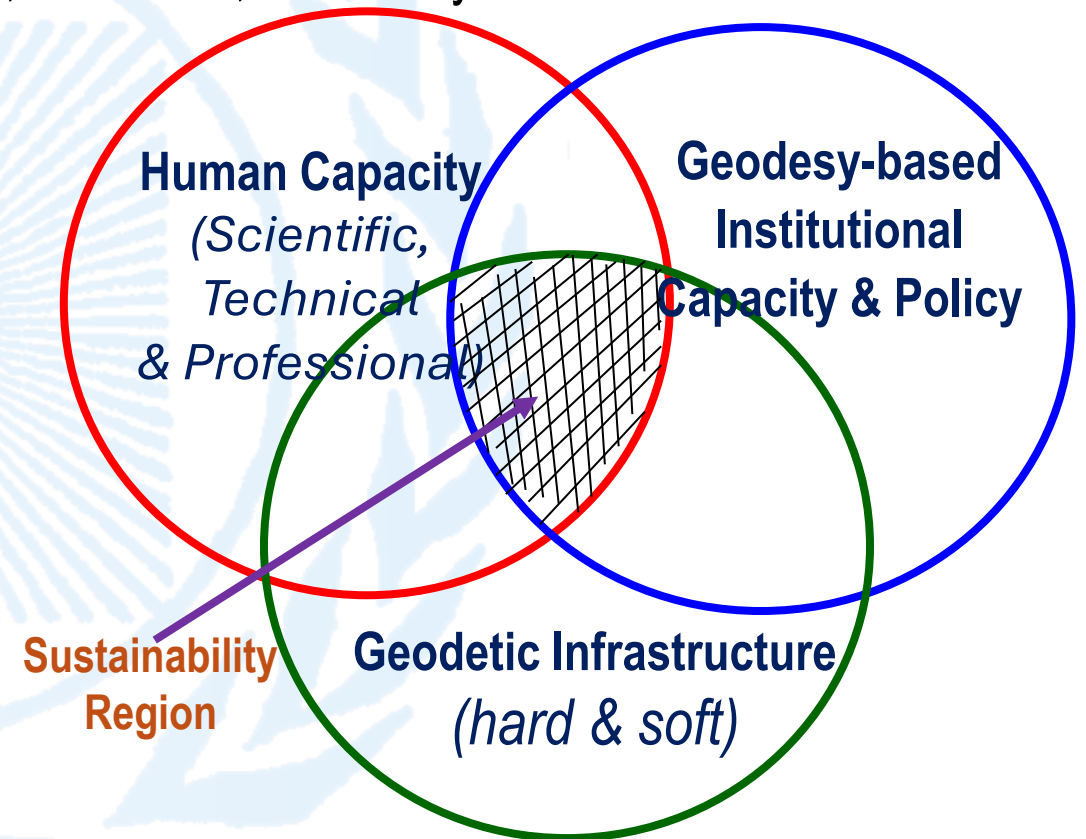
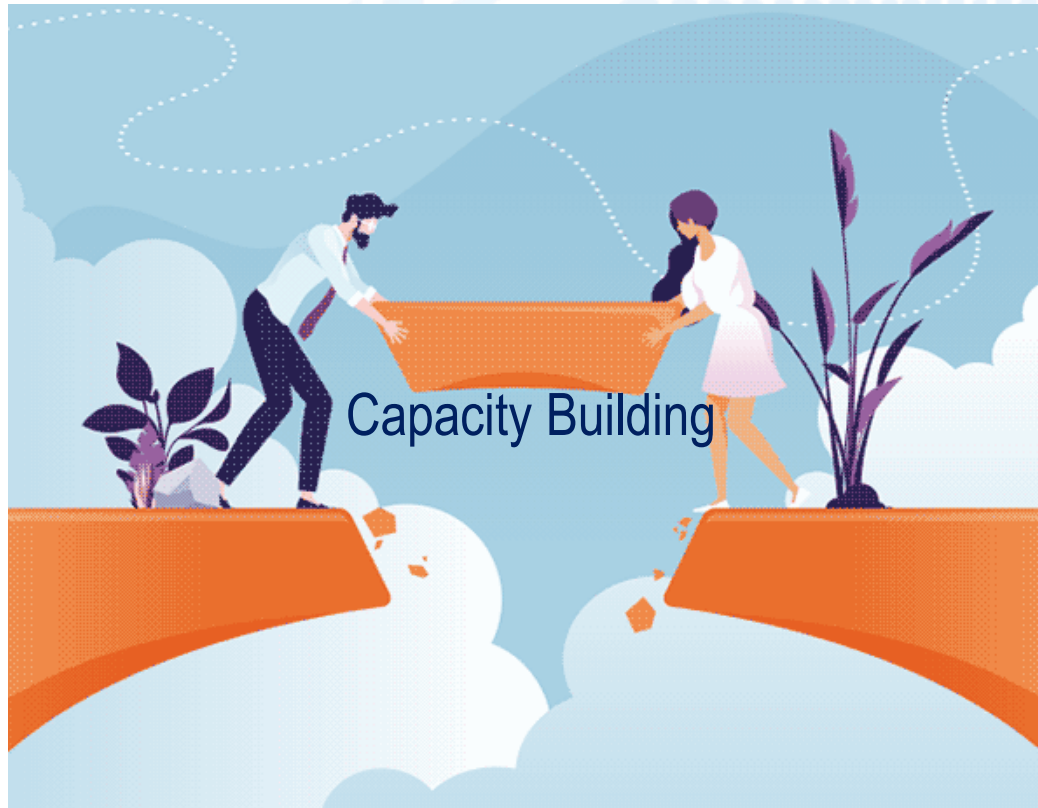


Figure 3.1: Geodesy Capacity Development Nexus (after: UNDP, 1997; Ojigi, 2017)

Table 3.1: The Tiers of Geodesy Capacity Development

Human capacity	Geodesy-based Institutional Capacity & Policy	Geodetic Infrastructure (Hard and Soft)
⇒ Human capacity building in geodesy has to do with the education and training of individuals to be aware of, access, use and develop geodetic science solutions.	◆ Focused on developing and fostering an environment for the use of geodetic techniques to enhance decision making. ◆ This includes policies, funding, programs and organisational structures in governments and institutions aimed at enhancing the understanding of the value.	◇ related to the hardware, software, geodetic equipment, GNSS CORS, VLBI, SLR, DORIS, LEOS for geodesy, etc, ◇ other systems required for accessing, using and developing <i>geodetic products for decision making and sustainable development</i>

- Modern geodesy capacity development is a strategic imperative for Africa to secure and apply emerging geodetic techniques and infrastructure reference networks needed to:
 - **observe,**
 - **measure**
 - **monitor, model**
 - **map/represent,**
 - **predict,**
 - **define reference frame, &**
 - **understand the changes, etc. on the continent's**

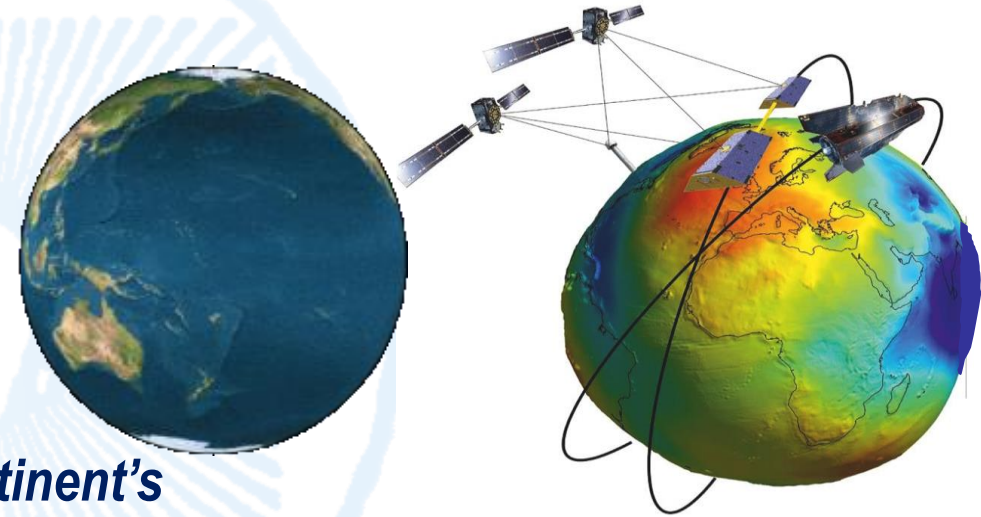


Fig.4.0: Earth Models

environment, space, lithosphere, and mass distribution, positioning, navigation and time parameters, and other relevant geospatial value chains that underpins regional and global economies, disaster management, transport and logistics management infrastructure planning and sustainable development.

Imperatives for Integrated Geodetic Capacity Development in Africa

- **Mainstreaming Geodesy into Strategic Governance:** The need to elevate geodesy from a purely technical task to a governmental priority, enhancing the status and communication of geodesy for wider patronage and support, establishing robust institutional frameworks and sustainable funding models.
- **The need for a Unified or Modern Reference Systems:** The need to transition smoothly to modern Geospatial Reference Systems (GRS) and standardised registries like the ISO Geodetic Register, and the realisation of the mission and vision of a unified geodetic reference frame for Africa (AFREF).
- **Enhancing Human and Institutional Resources/Capacity:** Train technical staff, update academic curricula, and foster international technology transfer through collaboration and partnership international geodetic organisations and centres of excellence such as United Nations Global Geodetic Centre of Excellence (UN-GGCE), Bonn, Germany, GFZ Helmholtz-Zentrum für Geoforschung, Geodesy and Remote Sensing, Potsdam, Germany, etc.

Imperatives for Integrated Geodetic Capacity Dev.... (cont.)

- **The Geodesists' Technical Competitiveness and Scientific Relevance:** Requirements for geodetic professional skills enhancement for new employment and practice opportunities with emerging technologies and tools. This will promote multi-disciplinary collaborations and efficiency; which underpins socio-economic survival, technical competitiveness and relevance.
- **System Efficiency, Cost Effectiveness and Speed with Modern Solutions:** The integration of AI and ML, robotics, software engineering, cloud computing and data analytics with geodetic techniques for earth system monitoring, modelling and management have the potential for enhancing *efficiency, speed, saving cost and time and performance (accuracy, reliability, availability and continuity) in handling geodetic tasks*

FRAMEWORK FOR INTEGRATED GEODESY CAPACITY DEVELOPMENT IN AFRICA

- The framework for integrated Geodesy capacity development in Africa provides a structured, long-term approach to advancing geodetic science skills, institutional readiness, infrastructure and operational efficiency across the continent:
- Some of the existing and emerging regional training initiatives or platforms for Geodesy education, capacity developments and applications in Africa include, the following, amongst others:
 - **Universities and Polytechnics in Africa**
 - **Regional Institutes/Centers**
 - **Short-Term and Specialised Trainings/Capacity Development Workshops:**
 - *UN-GGCE Bonn*
 - *Africa GNSS Lab & GNSS in Africa Academy by SatNav JPO, Dakar, Senegal.*
 - *Geodesy for a Resilient Africa Summer School.*
 - *UN-GGIM AFREF Working Group:*
 - *In-country National Capacity Building/Training in Geodesy and Mapping (train-the-trainer)*
 - *National Geodesy Centres/Laboratories*

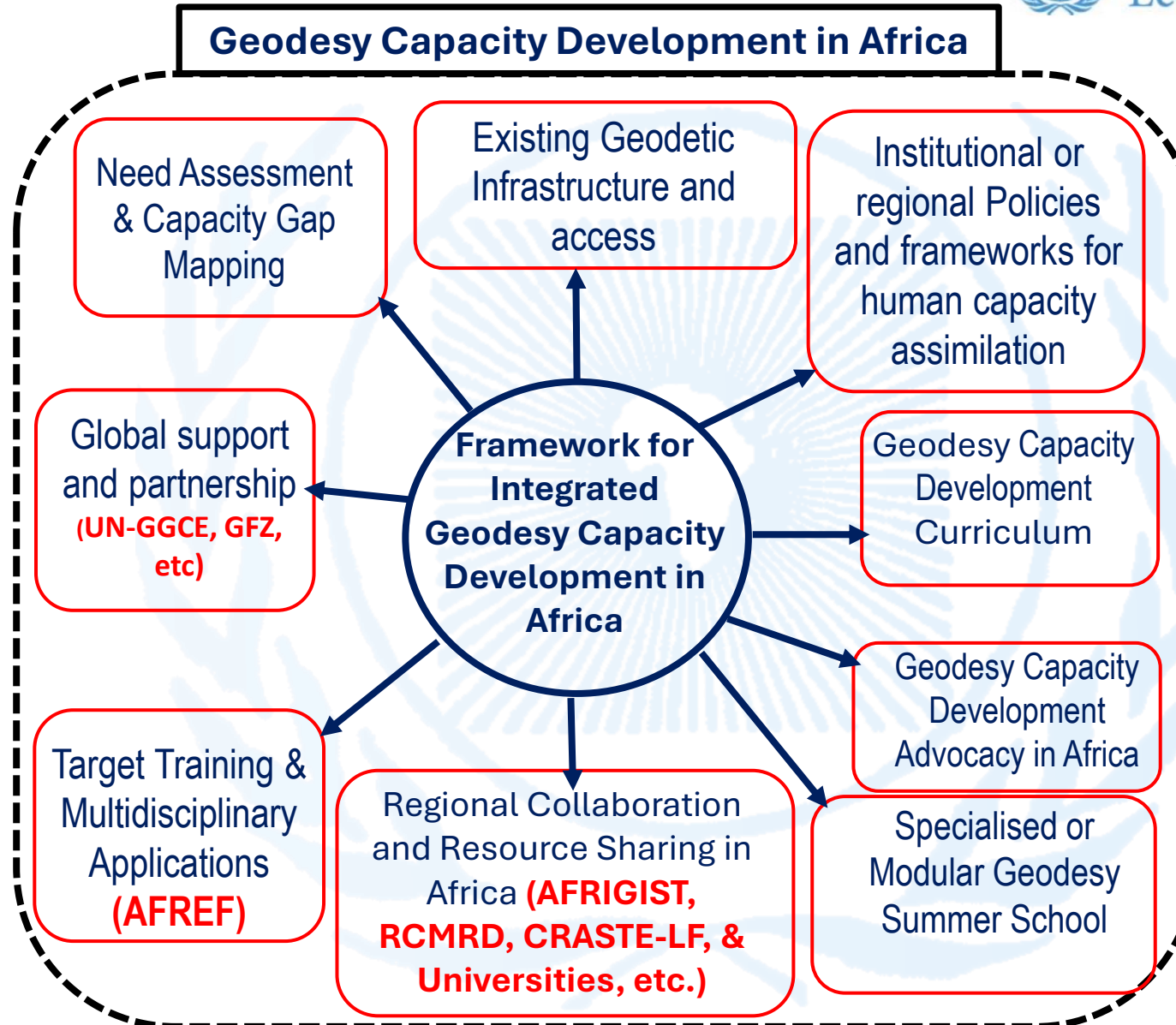


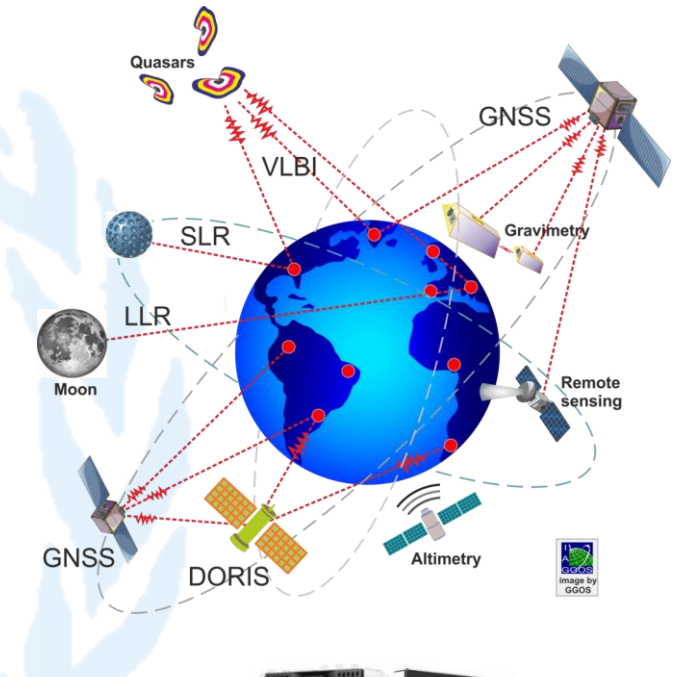
Fig. Framework for Integrated Geodesy Capacity Development in Africa *(modified after: Ojigi, 2026a)*

The eight (8) key framework pathways defined for integrated geodesy capacity development in Africa include the following, amongst others.

- ◇ **Manpower Capacity Gap Mapping**
- ◇ **Existing Infrastructure**
- ◇ **Institutional or regional policy framework for human capacity assimilation**
- ◇ **Geodesy Capacity Development Curriculum**
- ◇ **Geodesy Capacity Development Advocacy in Africa**
- ◇ **Specialised or Modular Geodesy School**
- ◇ **Collaboration and Resource Sharing**
- ◇ **Global support and partnership**

The Proposed Areas for Geodesy Capacity Development in Africa

- ◆ GNSS Positioning, Navigation and Timing
- ◆ GNSS CORS data processing, analytics and applications
- ◆ VLBI, DORIS, SLR and LLR Techniques and Applications
- ◆ Software development, databases and data analytics;
- ◆ International boundary/border management and integrated systems;
- ◆ Gravimetric analysis and geodynamics/geo-hazards
- ◆ Precision UAS and LiDAR applications
- ◆ Signal processing and data filtering
- ◆ High resolution image feature extraction and processing
- ◆ AI, ML & GeoAI applications in Geodesy
- ◆ Height systems, sea level dynamics and geoid development
- ◆ Geodetic field campaigns, data collections and hands-on skills
- ◆ Reference frame realisation and velocity modelling, etc.
- ◆ Geodetic solutions in meteorology and climate change issues



CHALLENGES OF GEODESY CAPACITY DEVELOPMENT IN AFRICA

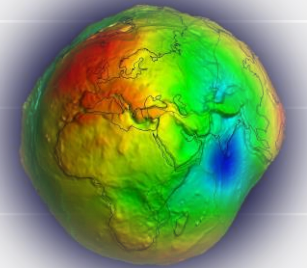
Building capacity for geodetic science in Africa has several pit-hole and challenges, namely:

- i. **Limited graduate specialisation options:** Relatively, few schools in Africa offer advanced Master's or PhD degrees focused purely on geodesy.
- ii. **Practical and industrial experience gaps:** Students and even educators often lack hands-on time with advanced national gravity and reference frame tools, GNSS CORS data processing workstations with scientific software. VLBI is out of reach because it's now only operational at The Hartebeesthoek Radio Astronomy Observatory (HartRAO), South Africa, the Kuntunse VLBI facility in Ghana: and the about to be commissioned VLBI facility at the Centre for Geodesy and Geodynamics (CGG), NASRDA, Toro Nigeria.
- iii. **Poor funding and training infrastructure:** Many obsolete training equipment are not readily replaced due to poor funding for most graduate and undergraduate programmes. Many institutions rely on donations of equipment by development partners, individual or private companies, mapping organisations, etc., to access some basic or core geodetic training equipment.

iv. Over-reliance on global data retards the drive for local big data acquisition.

- *Lack of sustainable initiatives for collection of local or in-situ big geodetic datasets in Africa is leading to over-reliance on global geodetic data, particularly Services coordinated by International Gravity Field Service (IGFS) of the IAG & other NASA and ESA spatial models and databases.*
- *The implication of this development is that it slows down the growth in local capacity for big geodetic data collection and management in Africa.*

Logo	Name of Data Centre
	International Centre for Global Earth Models (ICGEM) , GFZ Potsdam Germany ((Ince et al., 2019). https://icgem.gfz.de/home
	Bureau Gravimetrique International International Gravimetric Bureau (BGI) , Toulouse, France
	International Service for the Geoid (ISG) , Politecnico di Milano, Italy
	International DEM Service (IDEMS) , EOST Strasbourg, France
	International Geodynamics and Earth Tide Service (IGETS) , ESRI, Redlands, CA, USA



Challenges of Geodesy Capacity.....

- v. **Inadequate technical manpower:** In most countries of Africa, the number of available manpower for the teaching, training and research in geodesy programmes is abysmally low and inadequate. For instance, in Nigeria, the membership of Nigeria Association of geodesy is about 130, and less than two-third of this number are involved in geodetic teaching and research. ***The need for geodetic services across the countries of Africa are on the increase, but without corresponding response due to low capacity .***
- vi. **Low drive for sustained result-oriented geodesy capacity development and utilization in Africa.** The government institutions and organisations responsible for geodetic policies and also require geodetic databases and solutions for their day-to-day operations are reluctant in driving and motivating capacity building and utilization in Africa due to political or sentimental reasons.

CONCLUDING REMARKS

- A larger majority of graduates and professionals with geodetic science bias today in Africa have appreciable exposure with GNSS principles and techniques than they do with physical geodetic tools and techniques such as gravimetry. This is not a fault of theirs, rather the availability and affordability of the GNSS tools have made it the most popular and user-friendly geodetic data collection techniques.
- The Earth Observation Systems (EOS), have cross-cutting applications and relevance in all areas of human endeavours, but its products support the spatial visualisation and communication of geodetic phenomena. On the other hand, geodetic principles of satellite orbit mechanics, reference frame, map projection, mapping, geodetic/GNSS ground control points and georeferencing, numerical/spatial modelling, etc. form the geometric and dynamic framework or fabric for all EOS and datasets/applications.
- At the local and national levels in Africa, there is lack of primary ground-based and sit-specific in-situ geodetic data collection; *leading to over-reliance on global geodetic data, particularly Services coordinated by International Gravity Field Service (IGFS) of the IAG, and other NASA and ESA spatial (imaging and non-imaging) models and databases.*
- This critical gap must be closed by deliberate government and corporate policies, capacity development, financing and monitoring to sustainably implement a fit-for-purpose geodetic information service across Africa.

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Thank You !

