

Historical Perspective of Geodesy in Africa

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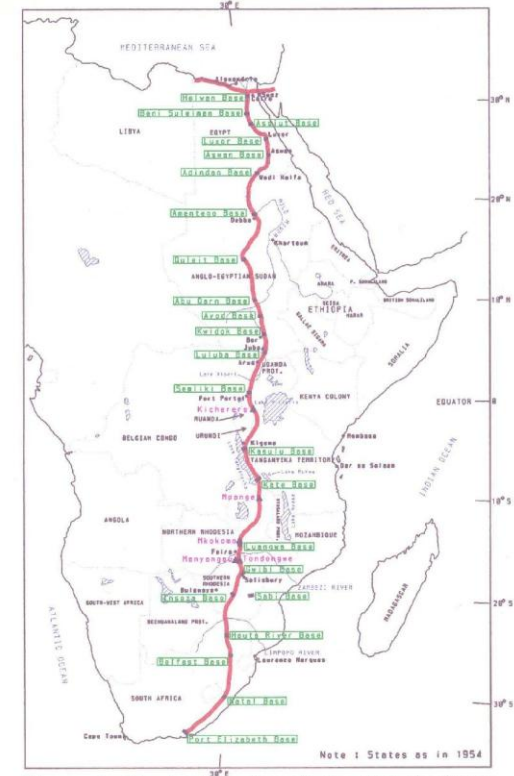


Figure 3. The African Arc of the 30th Meridian
(1883 - 1954)

Approx. Scale 1:35 000 000
1cm = 350km

Part 1: Foundations of Geodesy

Understanding the earth's geometry, gravitational field, and historical arc measurements across the African continent.

What is Geodesy?

Core Definition

Geodesy is the scientific discipline dealing with the precise measurement and representation of the Earth's three-dimensional geometric shape, orientation in space, and gravitational field over time.

Primary Pillars

Modern geodesy integrates three interrelated pillars: **Geometry** (positioning and motion), **Earth Rotation and Polar Motion** (precession and nutation), and **Gravity Field** (geoid modelling and mass transport).

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Core Geodetic Objectives

Earth Geometry

Determining the precise dimensions, oblateness, and ellipsoidal figures that best fit the physical Earth surface.

Reference Frames

Establishing consistent coordinate reference systems essential for national mapping, navigation, and cadastral boundary surveys.

Geodynamics

Monitoring crustal deformation, sea-level rise, tectonic plate movements, and global mass redistribution.

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Historical Evolution

~230 BC

BC: Eratosthenes

Calculated Earth's circumference using solar elevation at Syene and Alexandria.

1751 - 1753

Lacaille's Arc

Measured the first southern hemisphere arc of meridian at the Cape of Good Hope.

1838 - 1848

Maclear's Arc

Verified Lacaille's findings and expanded the primary triangulation network.

1879 - 1907

Sir David Gill

Pioneered the Arc of the 30th Meridian project spanning Cape Town to Cairo.

Part 2: Early Arc Determinations

From ancient Alexandrian shadow ratios to 18th-century meridian arc surveys in Southern Africa.

Eratosthenes' Measurement

The First Geodetic Measurement

Around 230 BC, Eratosthenes of Cyrene compared the sun's zenith angle at noon on the summer solstice in Syene (Aswan) and Alexandria, Egypt.

By establishing an angular difference of $1/50$ th of a circle (7.2°) and an estimated distance of 5,000 stadia, he calculated Earth's circumference with remarkable precision for antiquity.



Part 2: Early Arc Determinations

From ancient Alexandrian shadow ratios to 18th-century meridian arc surveys in Southern Africa.

Meridian Arc Principles

Astro-Geodetic Alignment

A meridian arc combines terrestrial triangulation distance measurements with astronomical latitude observations at both endpoints.

Curvature Determination

Comparing physical linear distance per degree of latitude across different latitudes reveals Earth's true oblateness.

Newtonian Verification

Vital in testing Sir Isaac Newton's theoretical prediction that the Earth is an oblate spheroid flattened at the poles.

Fundamental Baseline Standard

Triangulation chains require precisely measured physical baselines using standardized rods or invar wires.

Part 2: Early Arc Determinations

From ancient Alexandrian shadow ratios to 18th-century meridian arc surveys in Southern Africa.

Quest for Earth's Figure

Oblate Spheroid (Newton)

Newton's gravitational and centrifugal theory posited that Earth's rotation forces fluid material outward at the equator, producing a flattened shape at the poles.

Prolate Spheroid (Cassini)

Early measurements by Cassini in France suggested the Earth was elongated at the poles (prolate/lemon-shaped), sparking intense international debate across Europe.

Resolved by **French Academy of Sciences** expeditions, confirming oblate shape as proposed by **Newton**.

Part 3: The Abbé de Lacaille Arc

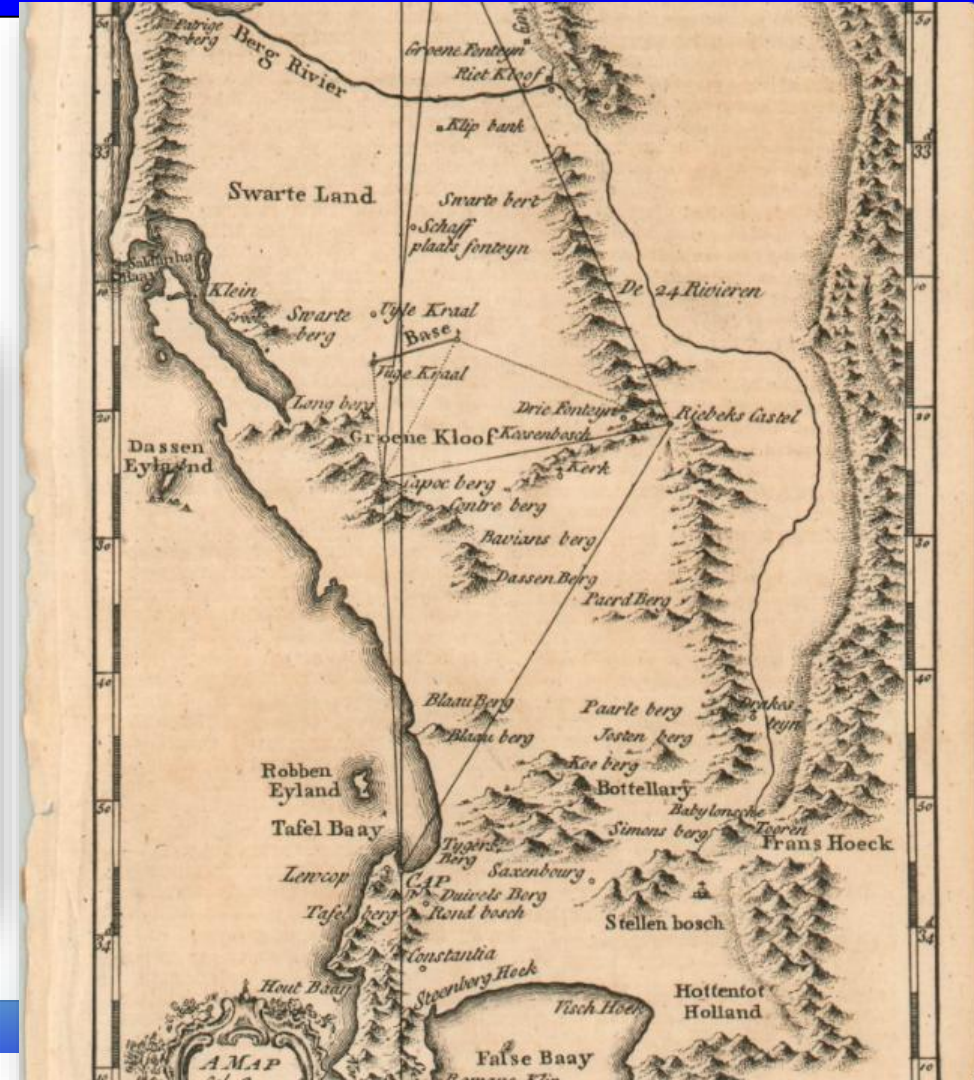
The 1751–1753 astronomical expedition to the Cape of Good Hope and the mysterious southern hemisphere anomaly.

Lacaille's Cape Mission

Pioneering Southern Astronomy

Sent by the French Academy of Sciences in 1751, Abbé Nicolas-Louis de Lacaille established an observatory in Strand Street, Cape Town.

Besides cataloguing nearly 10,000 southern stars, he measured a 1.25° meridian arc running north to Klipfontein in the Piquetberg mountains to test Earth's southern curvature.



Part 3: The Abbé de Lacaille Arc

The 1751–1753 astronomical expedition to the Cape of Good Hope and the mysterious southern hemisphere anomaly.

The Northern Anomaly

Unexpected Curvature Result

Lacaille's 1752 arc calculation indicated that a degree of latitude in the southern hemisphere was longer than in corresponding northern latitudes.

"Pear-Shaped" Earth Theory

His findings suggested the Southern Hemisphere was fatter/prolate compared to the Northern Hemisphere, alarming the global scientific community.

Scientific Dilemma

For nearly 90 years, geodetic scientists questioned whether gravity operated differently in the South or if measurement errors had occurred.

Part 3: The Abbé de Lacaille Arc

The 1751–1753 astronomical expedition to the Cape of Good Hope and the mysterious southern hemisphere anomaly.

Resolving Mountain Effect

Sir George Everest's Hypothesis

Visiting the Cape in 1821, Sir George Everest suggested that adjacent high mountain masses (Table Mountain in the South, Klipfontein in the North) attracted Lacaille's plumb-lines.

Sir Thomas Maclear, HM Astronomer at the Cape, undertook the verification from 1838 to 1848, accounting for gravitational attraction and vindicating Lacaille's operational accuracy.



Part 3: The Abbé de Lacaille Arc

The 1751–1753 astronomical expedition to the Cape of Good Hope and the mysterious southern hemisphere anomaly.

Lacaille's Baseline Error

Parameter	Lacaille's 1752 Survey	Modern Verified Value	Source of Discrepancy
Baseline Location	Darling Flats (Groenkloof)	Darling Flats Baseline	Measured with wooden rods
Latitude Amplitude	1° 13' 17.5"	1° 13' 25.0"	Plumb-line deflection at terminals
1° Arc Length	111.17 km	111.30 km	Mass effect of Table Mountain & Klipfontein
Geodetic Conclusion	Prolate / Pear-shaped Earth	Oblate Spheroid (Symmetric)	Uncorrected gravitational deflection

Part 4: Maclear's Verification Arc

Sir Thomas Maclear's exhaustive re-measurement (1838–1848) and the resolution of the plumb-line anomaly.

Primary Triangulation

Meridian Arc Extension

Maclear expanded Lacaille's 1.25° arc to an amplitude of $4^\circ 37'$, stretching from Cape Agulhas to Kamieskroon in Namaqualand.

Maclear's Beacon

Established primary geodetic stations across rugged mountain peaks, including the famous Maclear's Beacon on top of Table Mountain (1,087m).

Standardization

Employed Bradley's zenith sector and Colby's compensation bars (Cape Bars A & B) for high-precision baseline control.

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Maclear's Geodetic Standard

Foundational Backbone

Maclear's primary chain of triangles provided the first rigorous geodetic framework for Southern Africa.

His verification conclusively proved that the Earth's southern hemisphere exhibits the same oblate curvature as the northern hemisphere, resolving a century-old mystery in mathematical geodesy.

4.6°

Latitude Amplitude Extended

Part 5: Arc of the 30th Meridian

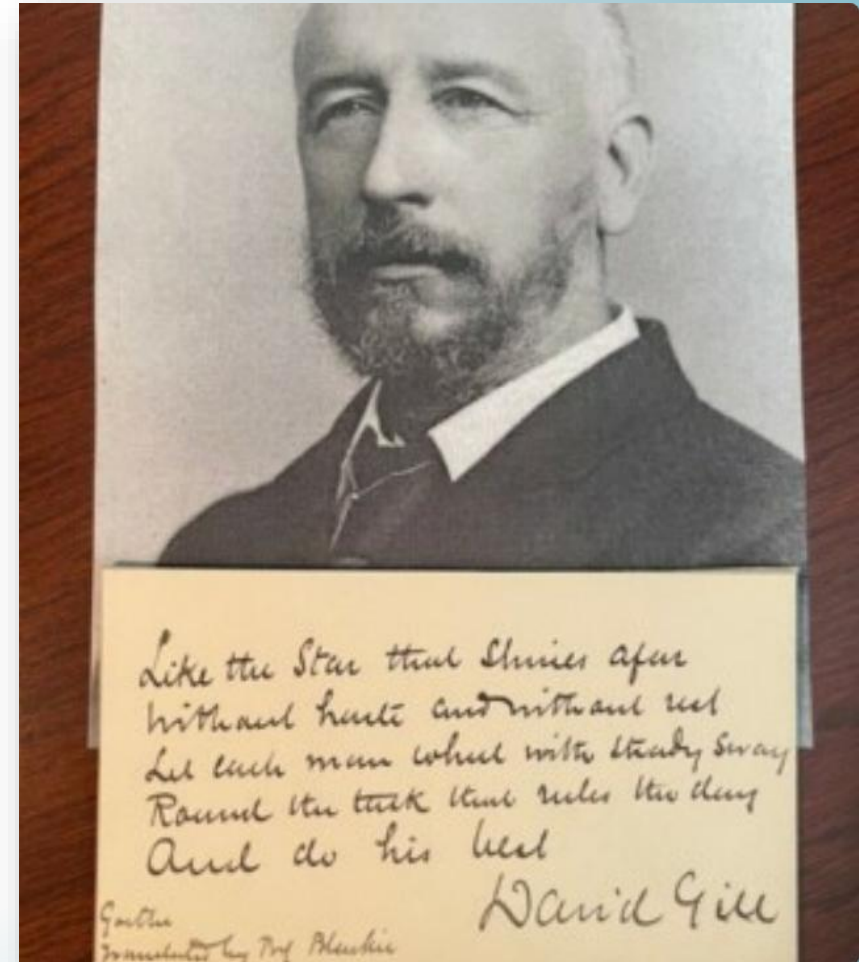
Sir David Gill's monumental grand design to measure a continuous geodetic arc from Port Elizabeth to Cairo and Europe.

The 30th Meridian Arc

A Grand Vision for Africa

Appointed HM Astronomer at the Cape in 1879, Sir David Gill proposed measuring the Arc of the 30th Meridian, which would span 64° in latitude (~7,100 km) from Port Elizabeth to Cairo, consisting of 608 primary triangulation stations, 23 precision baseline measurements, and 42 astronomical stations.

Connected across the Mediterranean to the Struve Geodetic Arc in Europe, it would span 105° in latitude (~11,650 km), to be the longest continuous terrestrial arc in human history.



Part 5: Arc of the 30th Meridian

Sir David Gill's monumental grand design to measure a continuous geodetic arc from Port Elizabeth to Cairo and Europe.

Scale of the African Arc

Trans-Continental Engineering

The Arc spanned 11 African countries: South Africa, Botswana, Zimbabwe, Mozambique, Zambia, Tanzania, Burundi, Rwanda, Uganda, Sudan, and Egypt.

It served as the primary geodetic reference frame for mapping the entire African continent throughout the 20th century.

~7,100
Kilometres Total Arc Distance

Part 5: Arc of the 30th Meridian

Sir David Gill's monumental grand design to measure a continuous geodetic arc from Port Elizabeth to Cairo and Europe.

Inter-Continental Arc

1883 - 1897

Initiation

Geodetic Survey of South Africa & Natal begins under Gill.

1897 - 1906

Rhodesian Arc

Triangulation advances through Zimbabwe & Zambia.

1906 - 1952

East Africa

Central African gap surveyed across East African Rift.

1952 - 1954

Completion

Final connection made in Sudan linking to Cairo & Europe.

Part 5: Arc of the 30th Meridian

Sir David Gill's monumental grand design to measure a continuous geodetic arc from Port Elizabeth to Cairo and Europe.

UNESCO World Heritage

"The Arc of the 30th Meridian represents an extraordinary human achievement in scientific collaboration, bridging continents to define the exact shape of our planet."

International Federation of Surveyors (FIG) Preservation Proposal

Part 6: South African Infrastructure

Establishment of the Trigonometrical Survey Office and national geodetic datums.

Primary Triangulation

Institutional Setup

Establishment of the Trigonometrical Survey Office in 1919 (now CD:NGI) under Dr. WC van der Sterr.

Primary Triangulation

Systematic breakdown into 1st, 2nd and 3rd order triangulation chains covering the entire landmass.

Town Survey Schemes

Dense network of urban reference markers supporting legal cadastral title registration.

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Evolution of Datums

Datum / Projection CRS	Reference Ellipsoid	Origin Point / Type	Operational Era
Cape Datum	Clarke 1880 (modified)	Buffelsfontein (Astro)	1900 – 1998
Gauss Conform Projection CRS	Clarke 1880 (modified)	2° 2-Degree Strips (West South)	1920 – 1998 (Cadastral)
Hartebeesthoek94 Datum	WGS84 Ellipsoid	Geocentric / ITRF Alignment	1 January 1999 – Present
Gauss Conform Projection CRS	WGS84 Ellipsoid	2° 2-Degree Strips (West South)	1999 – Present (Cadastral)

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Trigonometrical Beacons

Iconic Physical Monuments

South Africa features over 29,000 physical trigonometrical beacons built on elevated peaks and prominent landmarks.

These white painted concrete pillars with black metal quadripod vanes serve as visible passive monuments for passive geodetic control and local engineering positioning.



Part 7: Space Geodesy & GNSS

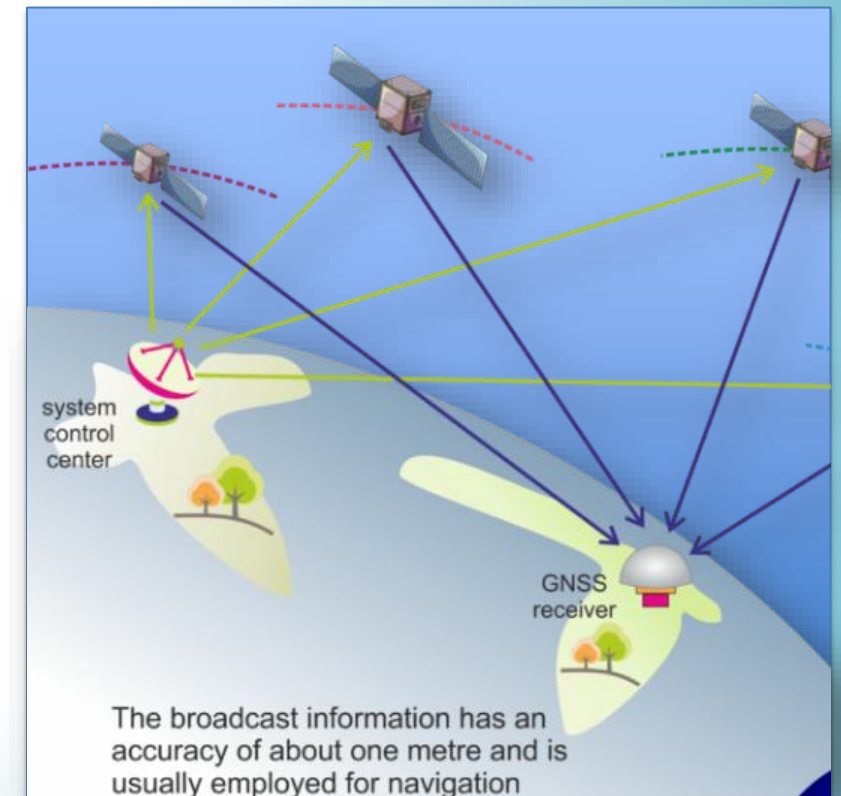
Transitioning from ground triangulation to satellite constellations and multi-technique observatories.

Satellite Positioning Era

Revolution in Spatial Measurement

The advent of Transit Doppler in the 1970s and GPS/GNSS in the 1990s rendered traditional line-of-sight triangulation obsolete.

Continuous satellite tracking enabled millimetre-level 3D positioning and real-time dynamic earth monitoring.



Part 7: Space Geodesy & GNSS

Transitioning from ground triangulation to satellite constellations and multi-technique observatories.

TrigNet GNSS CORS Network

TrigNet CORS Stations

70+ Stations

Data Stream Rate

1Hz / Real-Time RTK

Reference Datum

Latest ITRF TrigNet computation (ITRF 2020?)

TrigNet continuously streams dual-frequency GNSS observations managed by CD:NGI, providing active positioning services across South Africa.

Part 7: Space Geodesy & GNSS

Transitioning from ground triangulation to satellite constellations and multi-technique observatories.

Multi-Technique Geodesy

VLBI (Very Long Baseline Interferometry)

Measures time arrival differences of radio signals from distant quasars to determine Earth orientation parameters and deep space celestial reference frames.

SLR (Satellite Laser Ranging)

Fires ultra-short laser pulses at retroreflector-equipped satellites to determine accurate geocentric motion and absolute orbit scale.

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Transitioning from ground triangulation to satellite constellations and multi-technique observatories.

HartRAO Space Observatory

Africa's Premier Geodetic Station

Located in Gauteng, the Hartebeesthoek Radio Astronomy Observatory (HartRAO) is the only co-located fundamental space geodetic station in Africa.

It operates VLBI, SLR, GNSS, and DORIS systems, providing critical observations to international scientific services (IERS, IGS, IVAS, ILRS).



Part 8: Gravity & Geoid Determination

Physical geodesy, gravimetry networks, precise levelling, and regional geoid modelling.

Regional Gravimetry Network

Absolute Gravity

High-precision FG5 absolute gravimeter measurements at key primary base stations across South Africa.

Relative Gravimetry

Regional land gravity surveys along levelling lines for orthometric height corrections.

Airborne Gravimetry

Airborne gravity fill-in data across un-surveyed mountainous and coastal marine zones.

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South African Gravimetric Milestones

1818

First Gravity Data

Pendulum observations conducted at Cape of Good Hope, which would then become the Southern Hemisphere gravimetric calibration reference station.

1950s

National Surveys

First systematic land gravity campaigns across South Africa where relative gravimeters were used. Regional gravity anomaly (Bouguer) maps produced.

1960s

30°S Profile

Geoidal profile constructed from astro-geodetic observations to calculate deflections of the vertical and establish geoid-ellipsoid separation trends.

1985

First Geoid Model

Developed at UCT by Drs. Merry and van Gysen, combining terrestrial gravity, early satellite geodesy and global geopotential models to produce 1st geoid surface.

2006

EGM96 Model

Refined regional geoid framework for Southern Africa, providing direct transformation of GPS ellipsoidal heights to local vertical datums.

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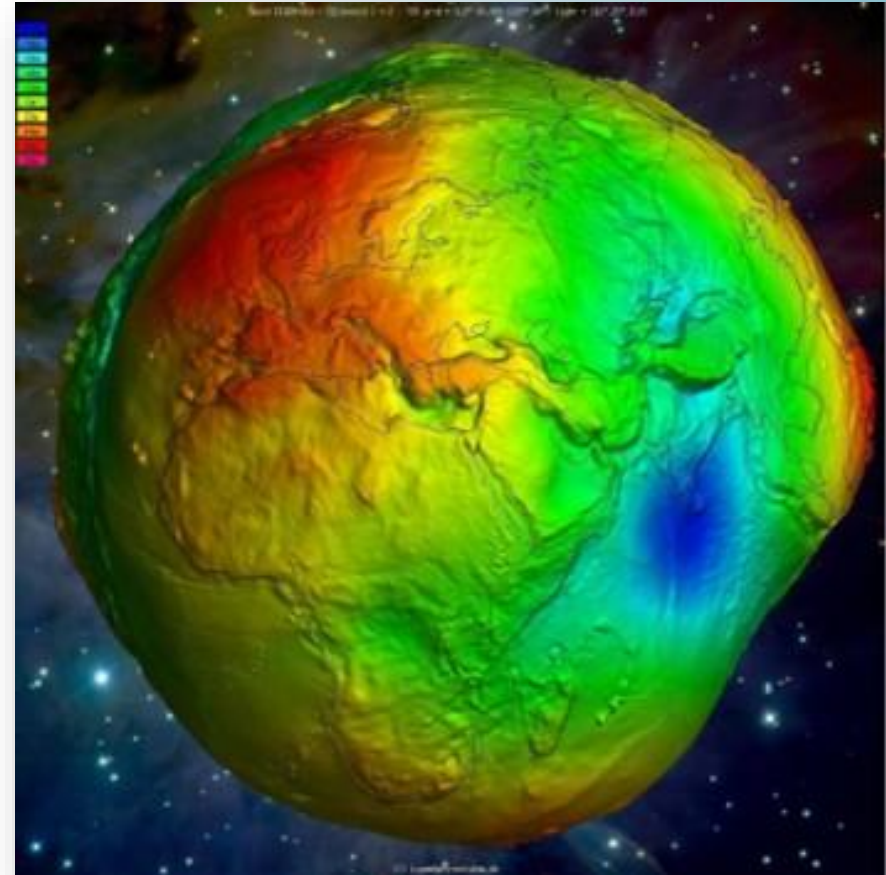
Regional Geoid Modelling

SAGeoid2010 (South African Geoid)

Development of high-resolution regional gravimetric geoid models enabling direct GNSS-derived orthometric height determination.

Combines satellite gravity models (GRACE/GOCE), terrestrial gravimetry, and high-resolution Digital Elevation Models (DEMs).

SAGeoid2010 is the **Official South African Hybrid Quasi-Geoid** and provides a geoid height grid at 2.5' x 2.5' (4.5km x 4.5km) intervals.



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Modern Height Systems

Ellipsoidal Height (h)

Geometric (GNSS)

Geoid Undulation (N)

Hybrid Gravity Model (SAGeoid2010)

Orthometric Height (H)

Physical Height (MSL)

Fundamental Geodetic Relationship: $h = H + N$. Connecting GNSS heights to mean sea level tide gauges.

Part 8: Gravity & Geoid Determination

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International Height Reference System (IHR)

Airborne & Satellite Gravity

Fill terrestrial data gaps across mountainous and coastal regions.

IHR Unification

Harmonizing local tide gauge offsets with global geopotential standards.

Part 9: Capacity Development

Human capital development, research infrastructure, and pan-African geodetic integration.

Geodetic Skills & Training

Academic Degrees

Geodesy specialized courses in Geomatics degree programs at UCT, UKZN, DUT, CPUT and TUT.

Analysis Capacity

Training young researchers in GAMIT/GLOBK, Bernese and GipsyX high-precision GNSS analysis software.

Professional Registration

Professional accreditation via the South African Geomatics Council (SAGC) framework.

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Analysis & GGOS Integration

Global Geodetic Observing System

South Africa plays a critical role in the Global Geodetic Observing System (GGOS), providing primary tracking data in the Southern Hemisphere.

Active processing nodes contribute to global frame stability (ITRF) and regional plate velocity models.



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Human capital development, research infrastructure, and pan-African geodetic integration.

AFREF Regional Integration

Unified Continental Reference Frame

AFREF aims to establish a single, unified geodetic reference frame across all African nations based on ITRF.

CORS Network Expansion

Harmonizing national GNSS networks to eliminate border discrepancies in infrastructure projects.

South African Leadership

CD:NGI and HartRAO provide technical analysis, data hosting, and workshop capacity building for neighboring African states.

Acknowledgements & References

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Thank you for your attention!!!!

QUESTIONS?