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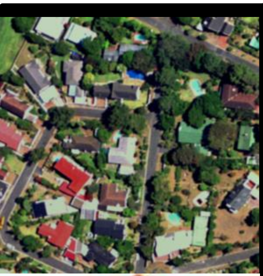
International Federation of Surveyors
Fédération Internationale des Géomètres
International Vereinigung der Vermessungsingenieure
Commission 5 – Positioning and Measurement

IAG

GGIM



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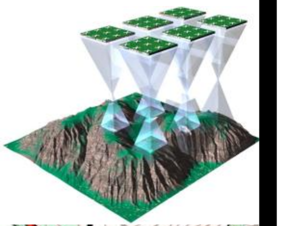

The National Control Survey System of South Africa

Aslam Parker
Chief Director: National Geospatial Information
Branch: National Geomatics Management Services
Department of Agriculture, Land Reform and Rural Development
GISSA Gauteng 23 Jan 2023

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WELCOME- UYAKWAMUKELA - WAMKELEKILE WELKOM- AMOHELA

CD: NGI – Organisational Context

- CD: NGI within the Branch: National Geomatics Management Services (NGMS), reports to Chief Surveyor General: Mr Siyabonga Mdubeki.
- One of many Branches within the Department of Agriculture, Land Reform and Rural Development.

Mandate of CD: NGI

- Mandated in terms of sec 3A of the Land Survey Act No. 8 (1997).
- The policy framework details the duties of the Chief Director in terms of the Land Survey Act (Act No. 8 of 1997), as well as other key legislation, such as the Spatial Data Infrastructure Act (Act No. 54 of 2003).
- This addresses the requirements of the Intergovernmental Relations Framework Act.

VISION & MISSION OF CD: NGI

- VISION
  - The CD: NGI aspires to be South Africa's foremost organization supplying fundamental geospatial information.
- MISSION
  - We strive for excellence through ensuring the availability and accessibility of reliable and up-to-date national geodetic survey, aerial imagery, mapping and other geo-spatial information and services to the public and private sectors, national and international communities and ourselves.

CD: NGI….Applicable Legislation:

- 1) Land Survey Act, 1997 (Act 8 of 1997)
  - Sec 2A – appointment of Chief Director : Surveys and Mapping (CD: NGI)
  - Sec 3A – duties of Chief Director
  - Secs 42, 43, 44 – beacons and marks of national control survey system

Duties of Chief Director 3A.

- (1) The Chief Director shall be in charge of such geodetic and topographical surveying and geospatial information services in the Republic as the Minister may direct and, subject to this Act, shall:
- (a) promote and control all matters connected with those surveys and services;
- (b) conduct such geodetic, topographical and other relevant survey operations as may be required;
- (c) acquire such aerial photography or other remotely sensed imagery as may be required;
- (d) establish and maintain a national control survey system;
- (e) prepare, compile and amend such maps and other cartographic representations of geospatial information as may be required; and
- (f) take charge of and preserve the records of all geodetic and topographical surveys, maps and aerial photography or other remotely sensed imagery.

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Everything is relative..who has moved?

Where on Earth is this ?

- An architect sent you a text file with the coordinates that looks like this.

1. -5 433.22 365.23
2. -5 365.22 244.236

Where on Earth is this ?

- A diagram in South Africa shows the following coordinates.

1. -239 810.22 11 928 365.23

2. - 245 365.22 11 925 244.236

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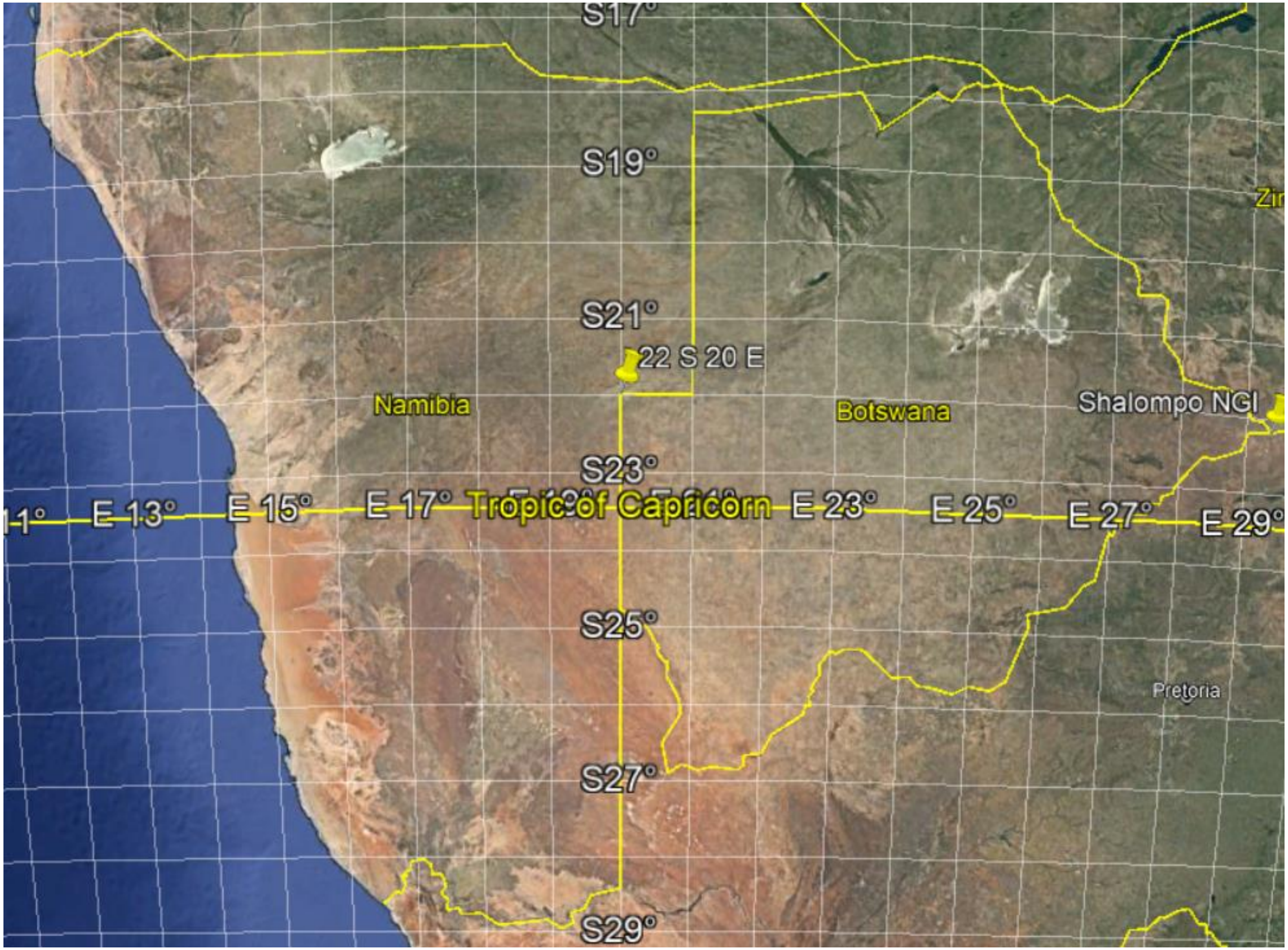
SA -Namibia Border



Where on Earth is this ?

- An architect sent you a text file with the coordinates that looks like this.

1.	-3 445 433.22	28 365.23
2.	-3 445 365.22	25 244.236

Where on Earth is this ?

- Further to our telecon earlier this morning, could you please assist in advising re the following co-ordinates in the DRC.

1. 0439810 08775478,
2. 0439264 08775344
3. 0439314 08775378

The National Control Survey System Of SA

- Provides unique Spatial Reference Framework that provides integrated, unambiguous positioning, connected locally, nationally and internationally.

- CD: NGI defines the South African Coordinate Reference System / South African Spatial Reference System

Spatial/Coordinate Reference Systems (SRS/CRS)

- **CRS = Coordinate (Spatial) Reference System**

- Set of mathematical rules for specifying how coordinates are to be assigned to points **(coordinate system)** that are related to the real world by a **datum/reference frame**.

Overview

A. Approximations of the shape of the Earth

B. Geocentric Cartezian & Geographic Coordinates

C. Projected coordinated and Map Projections

D. Geodetic Datums \Reference Frames

E. The South African Coordinate Reference System

A

APPROXIMATIONS OF THE SHAPE OF THE EARTH

A. Approximations of the shape of the Earth

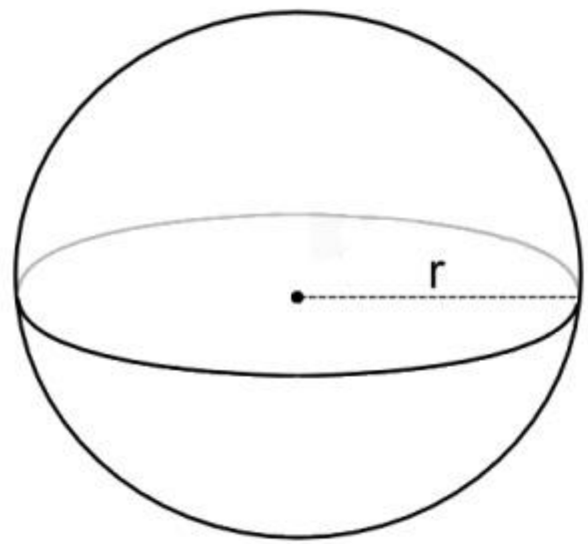
The shape of the Earth is NOT any of the below:

- Sphere
- Ellipsoid
- Spheroid
- Geoid
- Global DTM/DSM

The real shape of the earth is far too complex to be useful as a reference for measurement…. above are all approximations.

A.1. Sphere

- A sphere is symmetrical, round in shape.
- Three dimensional solid, that has all its surface points at equal distances from the centre.
- Only appropriate for explaining basic concepts. Eg. “Earth is not flat”.
- **Sphere ≠ Spheroid



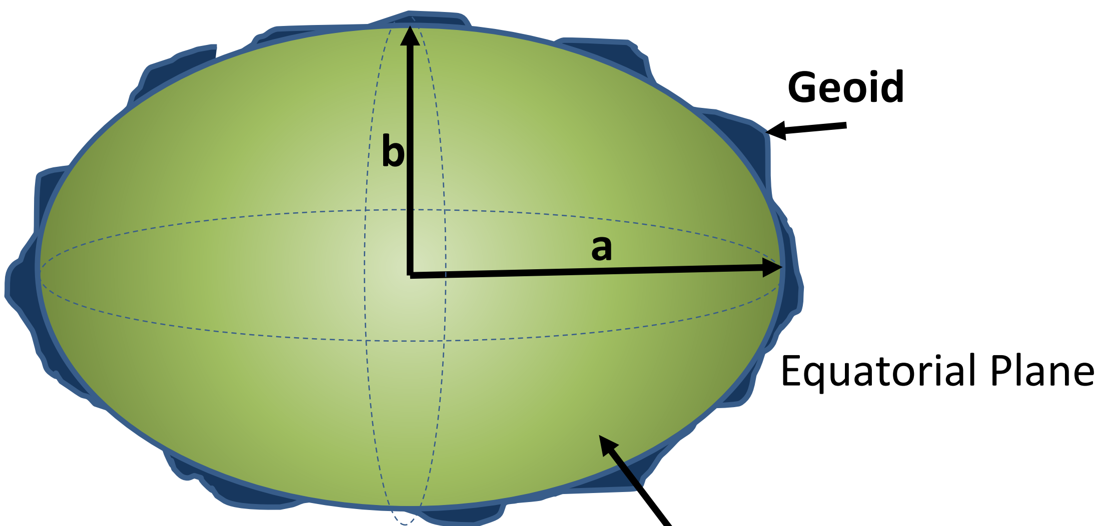
A.2. Ellipsoids

- A solid for which all plane sections through one axis are ellipses and through the other are ellipses or circles. If any two of the three axes of that ellipsoid are equal, the figure becomes a spheroid (ellipsoid of revolution).*
- 3 Cases
  - Oblate spheroid (rotated along semi-minor axis)
  - Prolate spheroid (rotated along semi-major axis)
  - Sphere, (circle rotated)

* Source: Smith, James R., Introduction to Geodesy: The history and concepts of modern geodesy. John Wiley & Sons, 1997.

A. Oblate Spheroid

- Ellipsoid of revolution about minor axis
- Most common mathematical approximation describing the shape of the earth.



Elements of the Ellipsoid:

a = semi major axis

b = semi minor axis = a(1-f)

1/f (inverse flattening) = a/(a-b)

A.2. Reference Ellipsoids used in Southern Africa

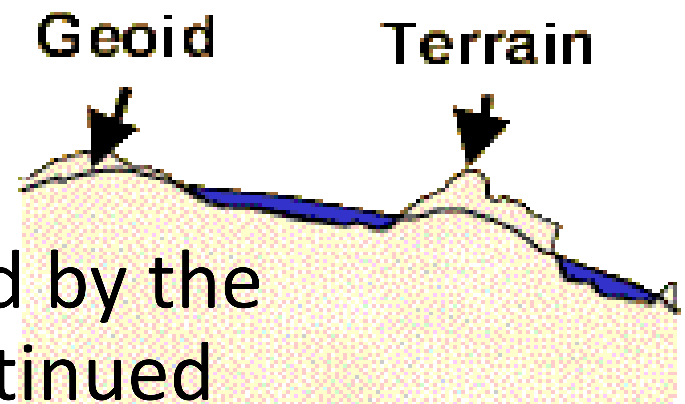
Ellipsoid	Semi-major Axis	Inverse flattening	Unit	Application
Bessel (Namibia)	6377397.155	299.1528128	German legal metre	Namibia
Clarke 1866	6378206.400	294.9786982	International metre	Mozambique
Clarke 1880	6378249.145	293.4650000	International metre	Angola
Mod. Clarke 1880	6378249.145	293.4663077	International metre	Zimbabwe, Zambia, Lesotho, Swaziland
WGS 84	6378137.000	298.257223563	International metre	Globally
GRS 1980	6378137.000	298.257222101	International metre	All modern global reference frames

A.2. WGS84 vs GRS80 Ellipsoid

- Please note that the GRS80 and WGS84 are considered to be the same.
- Actually, **there is a very small difference in the flattening which results in the semi-minor axis, b, being different by 0.0001 meters**. There is no known application for which this difference is significant.

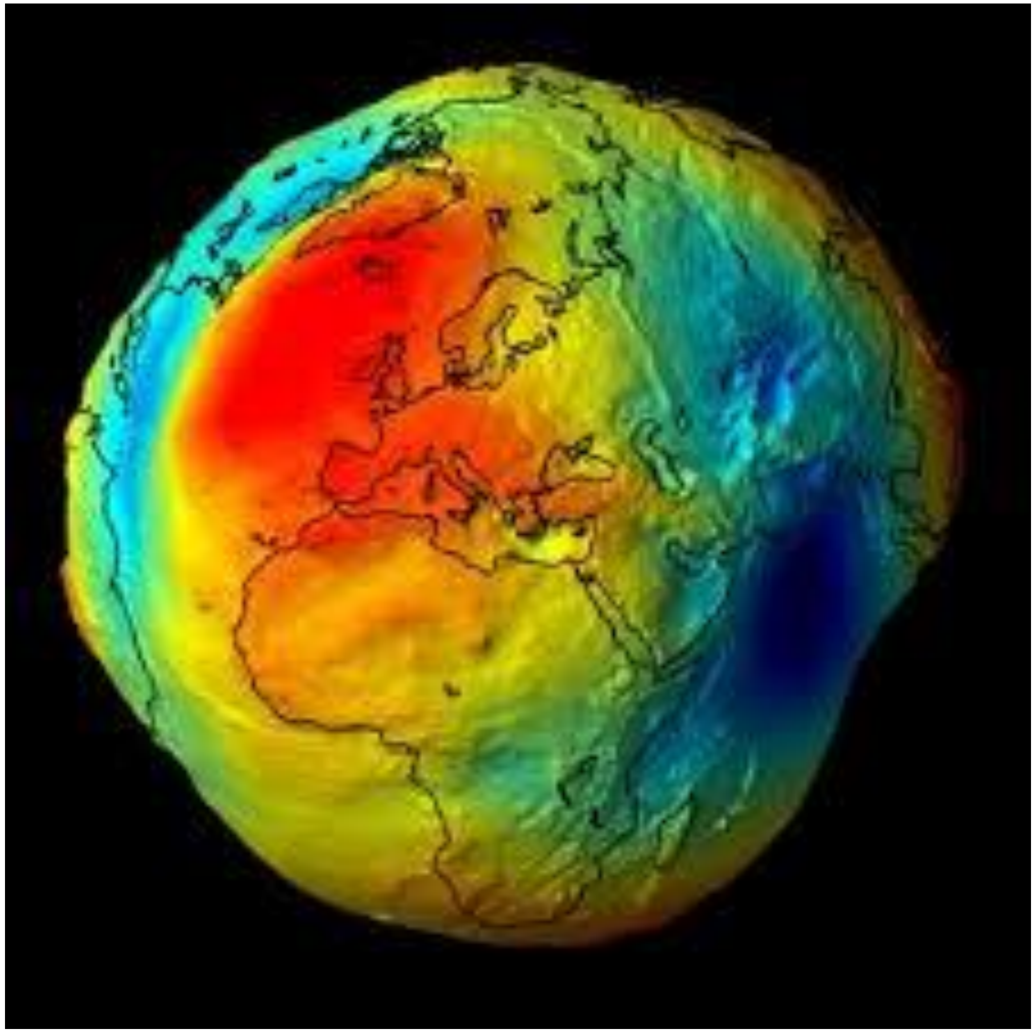
A.3. The Geoid

- The earth's surface highly complex.
- Highly irregular- not suitable as a computational surface.
- A smoother, yet extremely complex representation = Geoid.



- That surface that would be assumed by the undisturbed surface of the sea, continued underneath the continents by means of small frictionless channels.
- That equipotential surface that on average co-incide with mean sea level.

A.3 The Geoid…lumpy potato



https://www.esa.int/ESA_Multimedia/Images/2010/04/Earth_Explorers_The_Earth_s_true_shape

A.3 Approximations of the Geoid (models)

- EGM 96 (used by STRM DEM)
- EGM 2008 (used globally, refined locally)
- SAGEOID 2010
- In Development: Global Geoid Model 2020 (GGM2020)

B

GEOCENTRIC CARTEZIAN & GEOGRAPHIC COORDINATES

B. Spatial/Coordinate Reference Systems (SRS/CRS)

- **CRS = Coordinate Reference System**

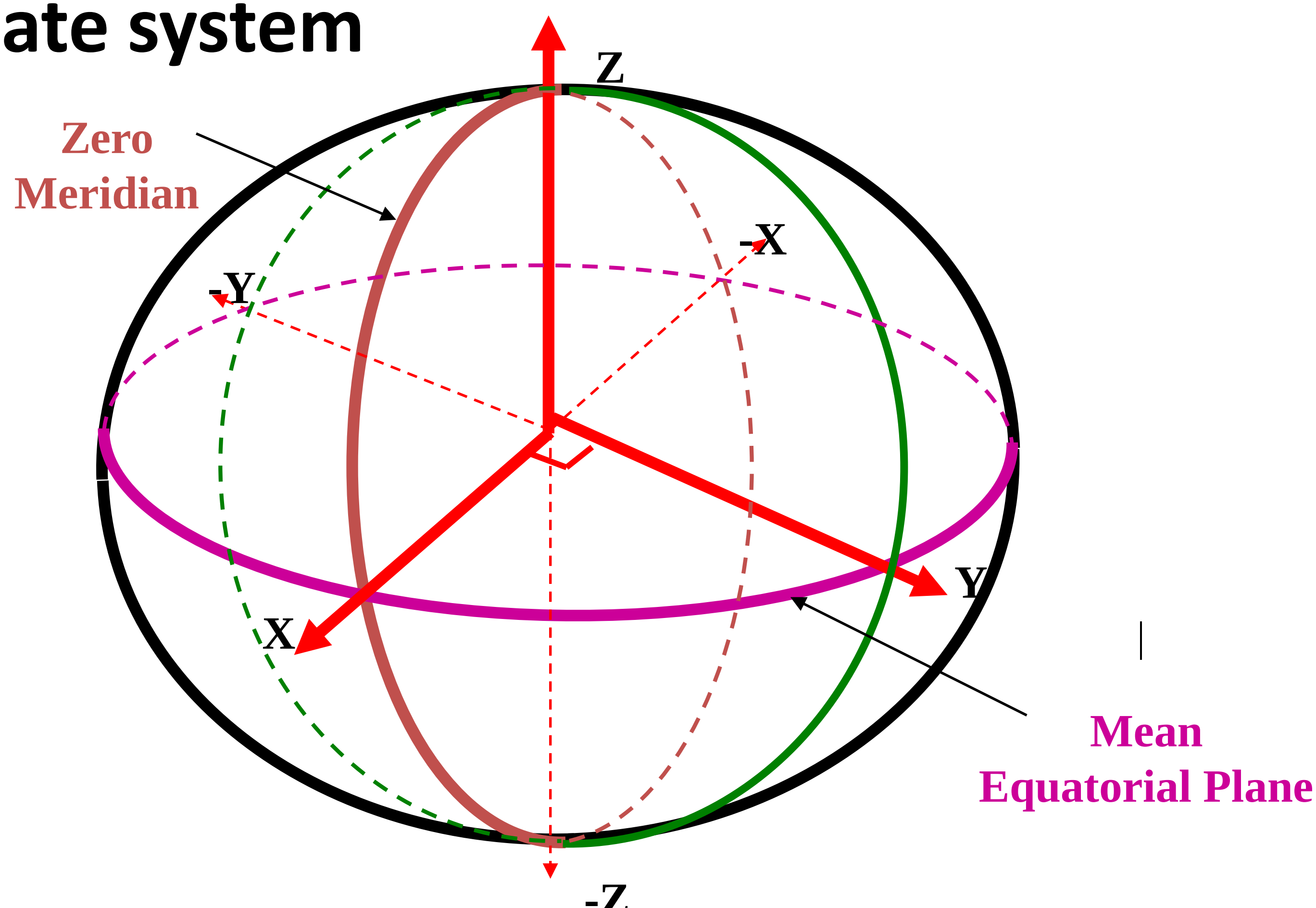
- Set of mathematical rules for specifying how coordinates are to be assigned to points **(coordinate system)** that are related to the real world by a **datum/reference frame**.
- **Coordinate System + Datum**

B. Coordinate Systems

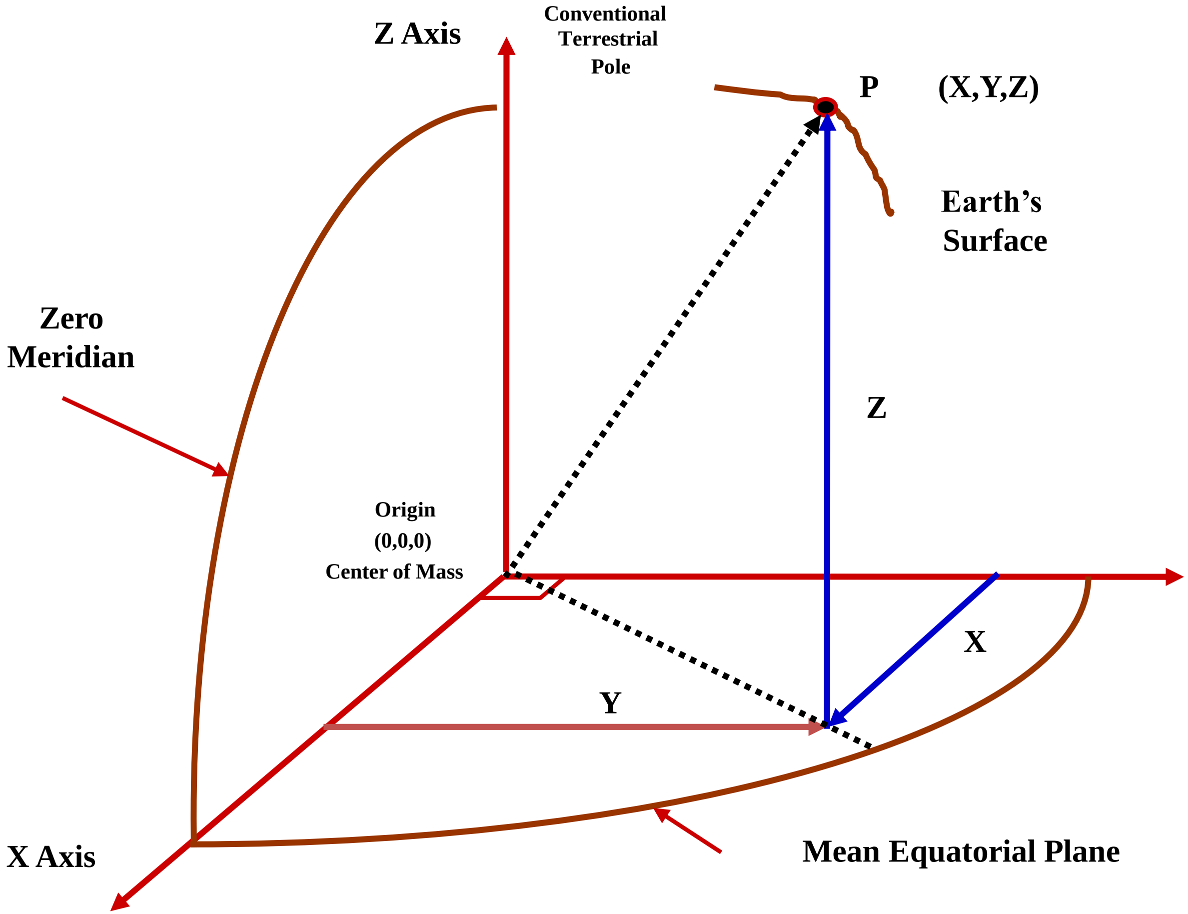
- **3D Cartezian CS**
  - Geocentric earth fixed
  - Or Non-geocentric
- **Ellipsoidal (geographic) CS**
  - 2D , (lat , long only)
  - 3D (lat, long, h)

B.1 Geocentric Cartesian Coordinate /Systems

- The **Earth-centered, Earth-fixed coordinate system** (acronym **ECEF**), also known as the **Geocentric coordinate system**



B.1 Geocentric Cartesian Coordinates



B.1 Geocentric Cartesian Coordinates

Examples of Geocentric Cartesian co-ordinates (X,Y,Z)

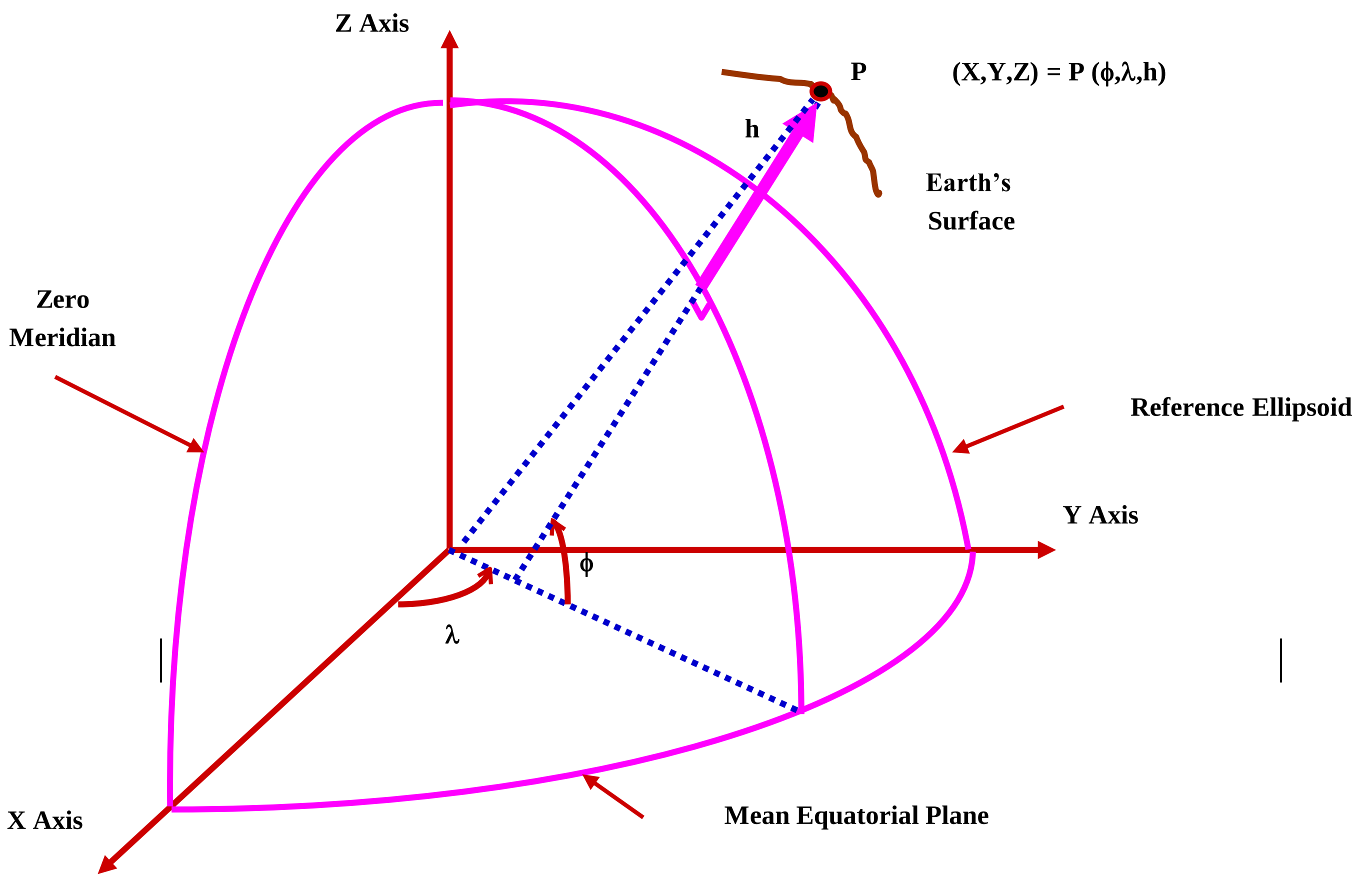
	X (m)	Y (m)	Z (m)
Durban	**4742985.565**	**2843868.499**	**-3167037.434**
Pretoria	**5064032.251**	**2724720.764**	**-2752951.003**
Cape Town	**5023564.635**	**1677795.097**	**-3542026.169**

Why are Geocentric Cartezian Coordinates Important

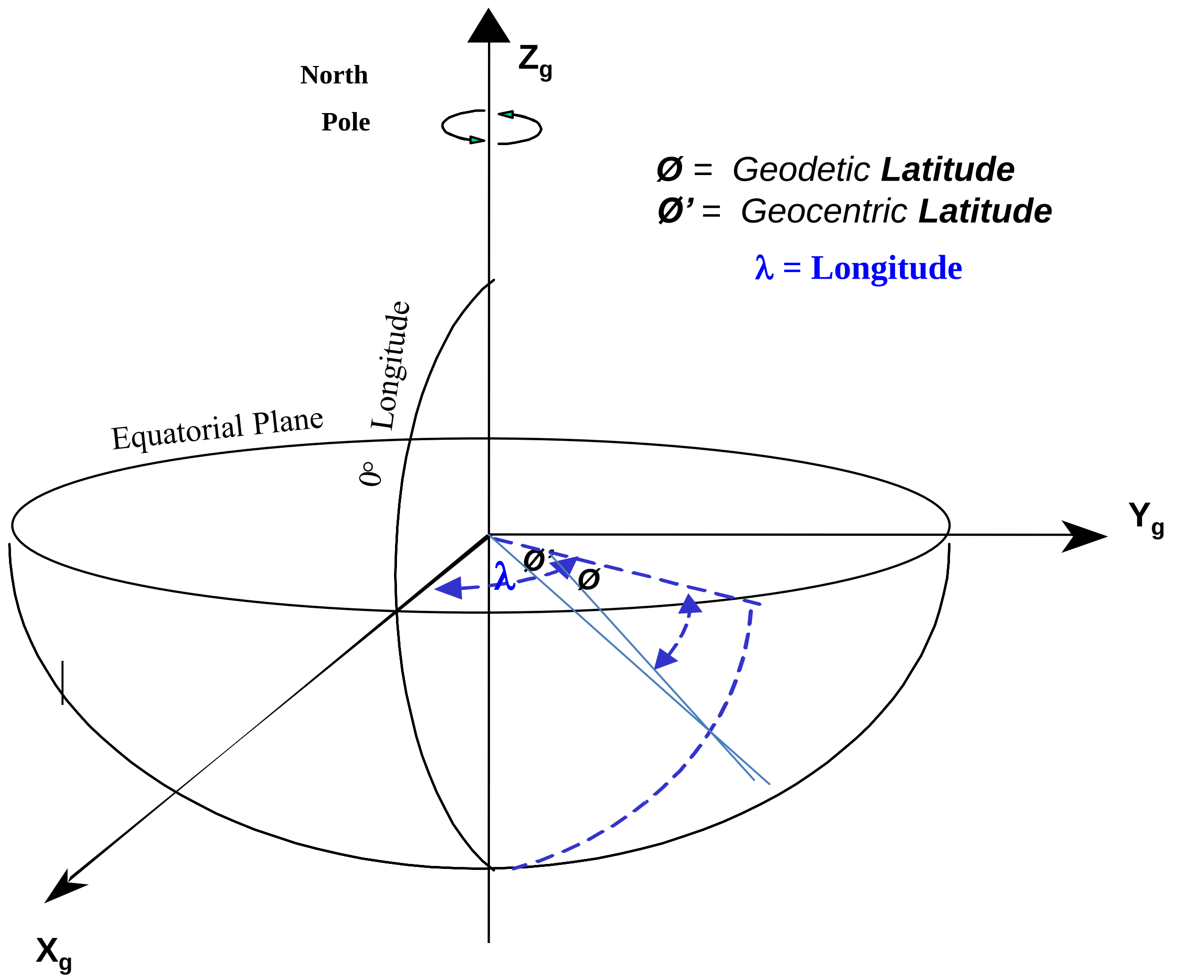
- All GNSS coordinates and calculations done in ECEF geocentric coordinate systems.

- Transformed to user CRS (lat long or projected)

B.1 Geographical Coordinate Systems



B.2 Geographical Coordinates



B.2 Geographical Coordinate System

The three dimensional (real world) co-ordinates of a point on the earth's surface can be defined by ***Geographical co-ordinates***

- Latitude(ϕ) — **Geodetic latitude** is defined as the angle between the equatorial plane and the surface normal at a point on the ellipsoid,
  Geocentric latitude is defined as the angle between the equatorial plane and a radial line connecting the centre of the ellipsoid to a point on the surface
- Longitude(λ) — angular displacement east/west of the prime (reference) meridian).
- Height (H) — either orthometric (height above mean sea level)
  (h) — or ellipsoidal (height above ellipsoid).

B.2 Geographical Coordinate Formats

Geographical (ellipsoidal) coordinate formats

- **dd mm ss.ssss S dd°mm′ss.ssss″E**

  33°58′43.2345″S 18°24′45.6783″E

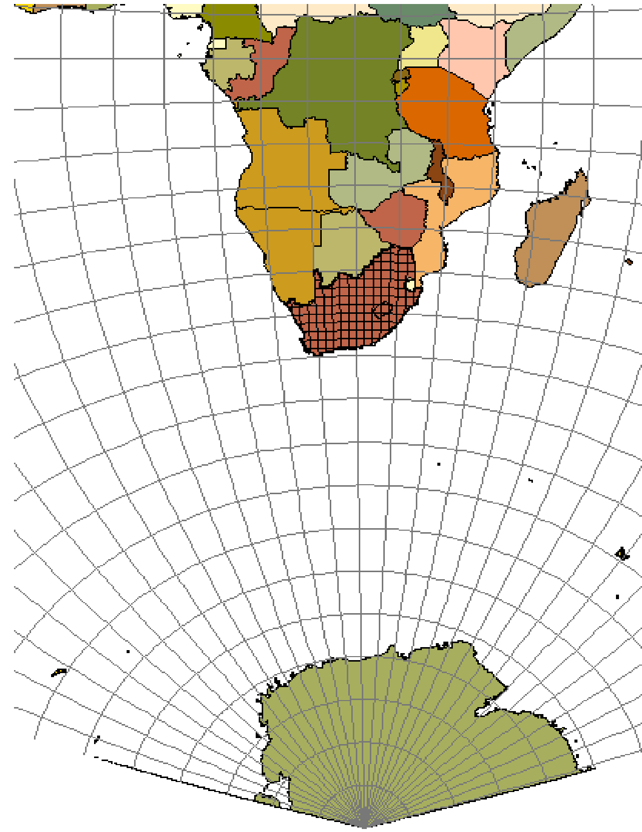
- **dd mm.mmmmmm′S dd°mm.mmmmmm′E**

  33°58.720575′S 18°24.761305′E

- **dd.dddddddd°S dd.dddddddd°E**

  33.97867625°S 18.41268842°E

B.2 Geographical Coordinates



"Rules of Thumb"

– 1° lat ≈110km ; 1' ≈ 1800 m

1" ≈ 30m

– At 22° S, 1° long ≈ 103km, 1" ≈ 29m

– At 33° S, 1° long ≈ 93km, 1" ≈ 25m

– At 89.99999 °S, 1° long ≈ 1cm

B.2 Geographical Coordinates

Examples of Geographical co-ordinates (ϕ,λ,h)

Approx Point Location	ϕ	λ	h
Durban	29° 57’ 54.04249" S	30° 56’ 48.02634" E	46.419
Pretoria	25° 43’ 55.30216" S	28° 16’ 57.47865" E	1387.341
Cape Town	33° 57’ 05.16921" S	18° 28’ 06.76131" E	83.730

- Break
- SESSION TO COMMENCE at 10: 45

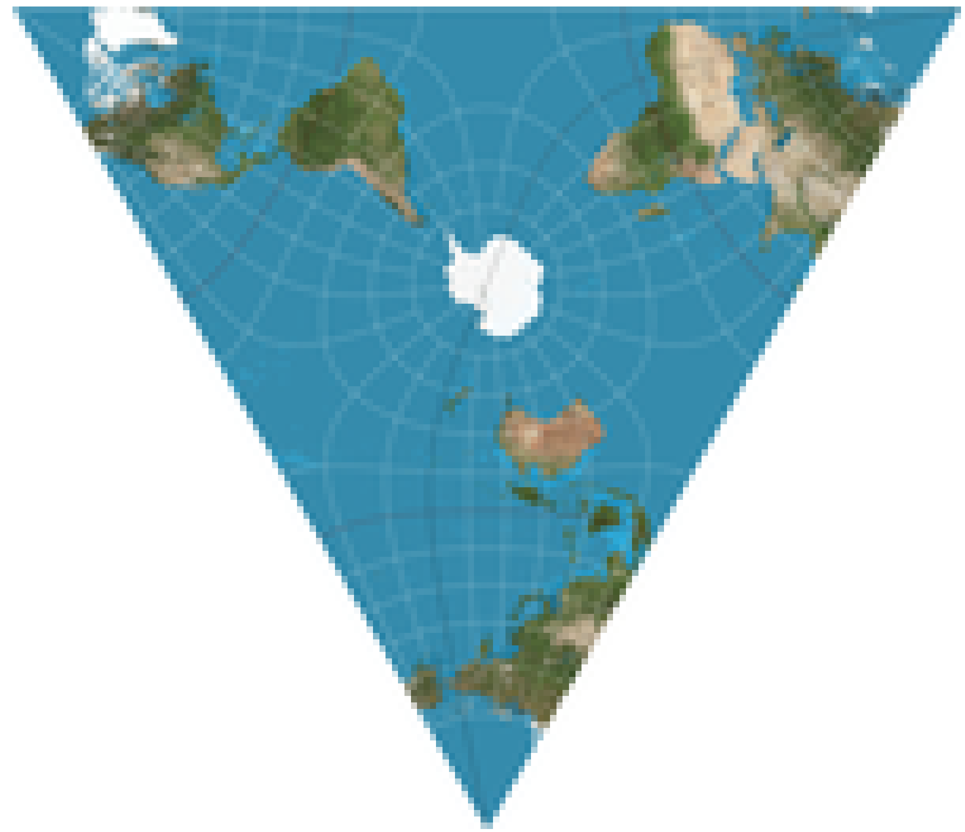
C

PROJECTED COORDINATE SYSTEMS

C: Projected and other Coordinate Systems

- **Cartezian 2D** (Projected) CS
- **1D** Vertical CS (eg LLD)
- **Local** CS

C. Projected Coordinate Systems



C. Projected Coordinate Systems

- The projection is the mathematical algorithm that defines how to present the round earth on a flat map

- A PCS is the full definition of how a specific round earth model is projected onto a flat map.

- A PCS includes a projection, reference ellipsoid, a unit (often meters), and a set of parameter values which vary depending on the projection (false easting, central meridian, standard parallel, and so on). These can be used to center the PCS on different parts of the world.

C.1 Map Projections

- Attempts to portray the surface of the earth or a portion of the earth on a flat surface.
- Some distortions of conformality, distance, direction, scale, and area always result from this process.
- Some projections minimize distortions in some of these properties at the expense of maximizing errors in others.
- Some projection are attempts to only moderately distort all of these properties

C.2. Projection Properties

- Conformality
  - When the scale of a map at any point on the map is the same in any direction, the projection is conformal. Meridians (lines of longitude) and parallels (lines of latitude) intersect at right angles. Shape is preserved locally on conformal maps.
- Distance
  - A map is equidistant when it portrays distances from the center of the projection to any other place on the map.

C.2 Map Projection Properties

- Direction
  - A map preserves direction when azimuths (angles from a point on a line to another point) are portrayed correctly in all directions.
- Scale
  - Scale is the relationship between a distance portrayed on a map and the same distance on the Earth.
- Area
  - When a map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an equal-area map.

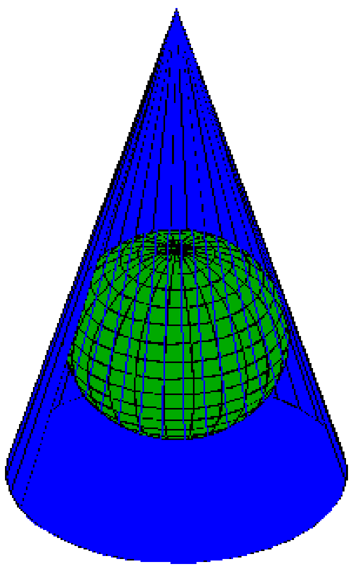
C. Map Projections Classes

- Map projections fall into four general classes:
  - Conic projections
  - Cylindrical projections
  - Azimuthal projections
  - Miscellaneous projections

C. 1. Conic Projections

- A Conic projections result from projecting a spherical surface onto a cone.

- When the cone is tangent to the sphere contact is along a small circle.

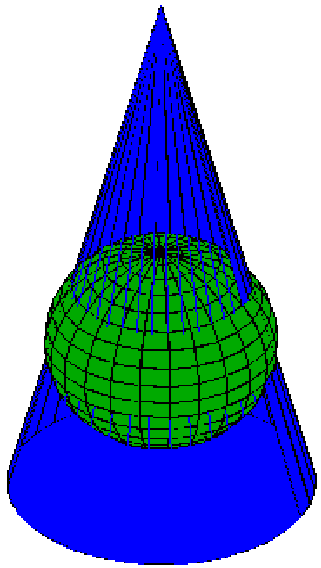


Conical Projection Surface

C.1. Conic Projections(cont.)

- A Conic projections result from projecting a spherical surface onto a cone.

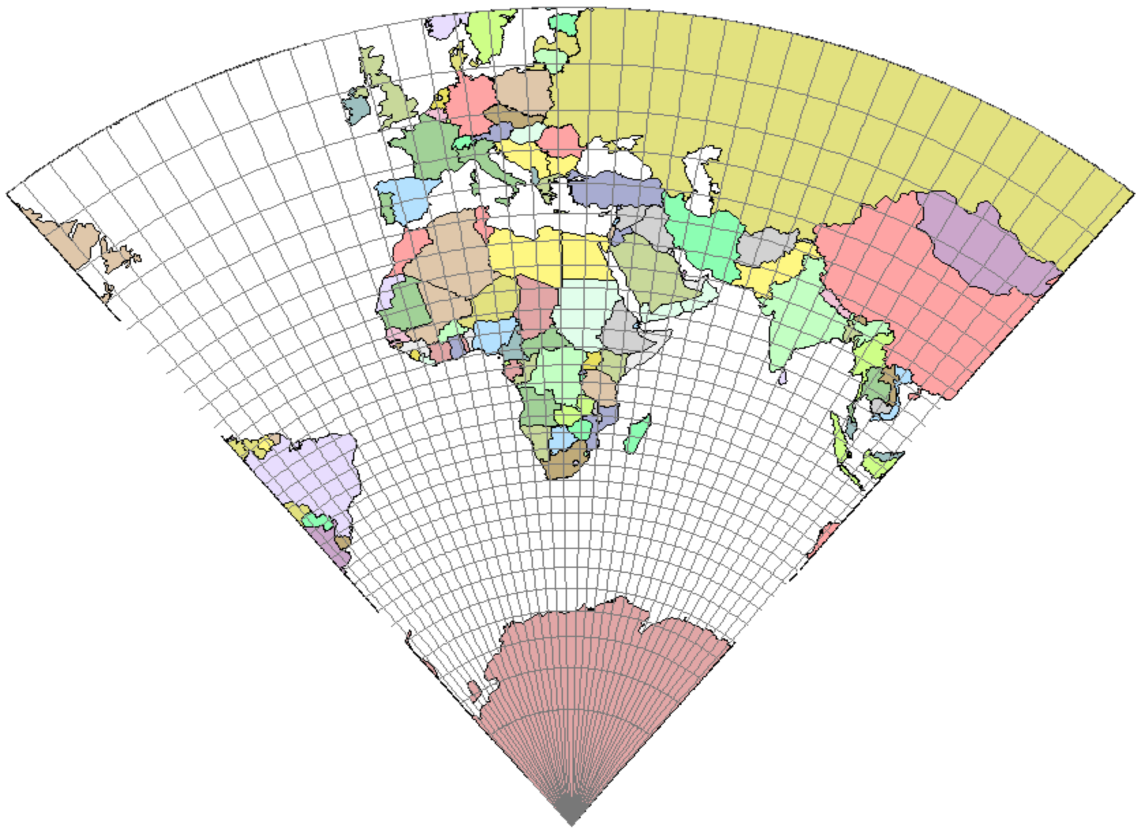
- In the secant case, the cone touches the sphere along two lines, one a great circle, the other a small circle.



Secant Conic Projection

C.1. Conic Projections

Eg: Lambers Conformal Conic with 2 standard parallels



C.1. Lamberts Conformal Conic

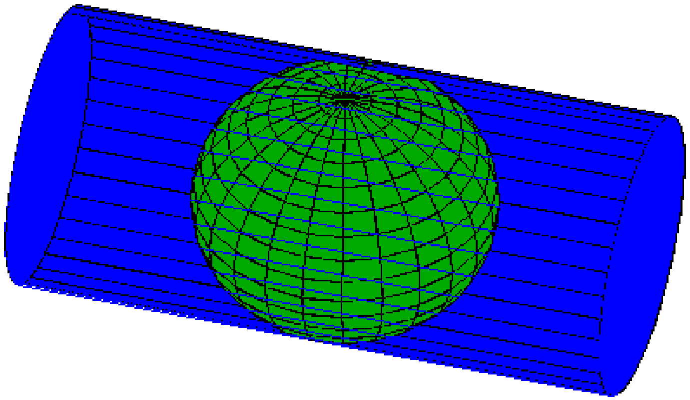
- A projection is conformal if the angles in the original features are preserved

- the transformation is made to the surface of a cone tangent at a small circle (tangent case) or intersecting at two small circles (secant case) on a globe

C.2 Cylindrical Projections

Cylindrical projections result from projecting a spherical surface onto a cylinder.

- When the cylinder upon which the sphere is projected is at right angles to the poles, the cylinder and resulting projection are transverse.

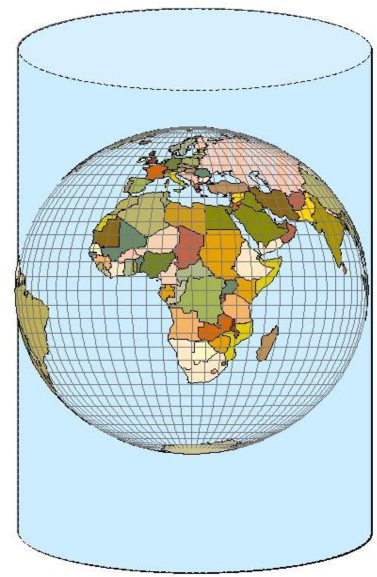


Transverse Cylindrical Projection Surface

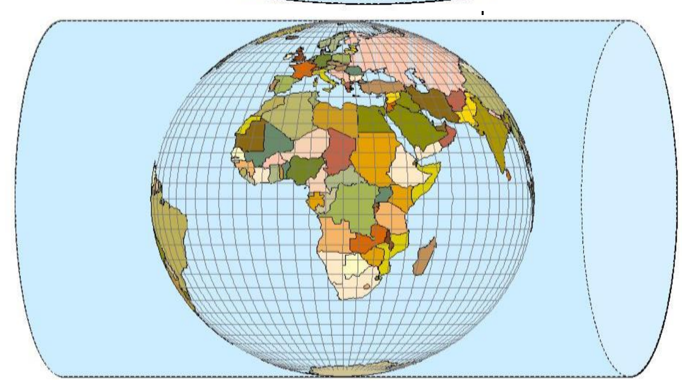
C.2.Cylindrical Projections (cont)

Eg: Transverse Mercator

Normal aspect of the Cylindrical Projection, eg: Mercator



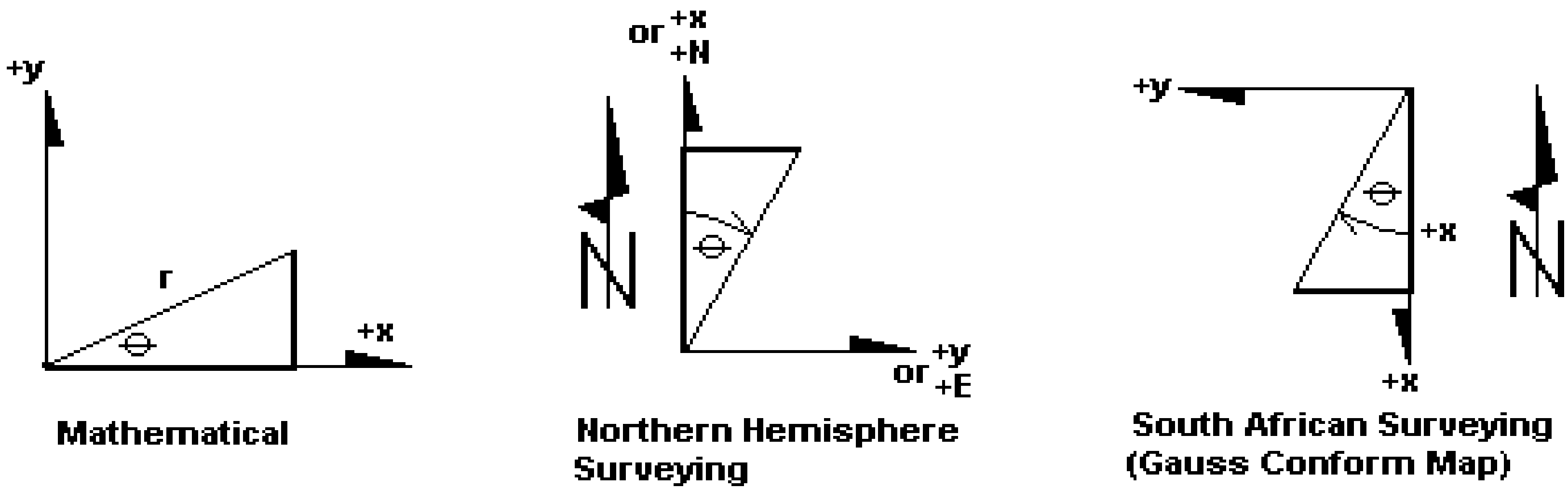
Transverse aspect of the Cylindrical Projection, eg: Mercator



C.Cylindrical Projections (cont)

- Transverse Mercator
  - Transverse aspect of the Mercator projection (which is a cylindrical projection, turned about 90° so that the projection is based on meridians and not the parallels).

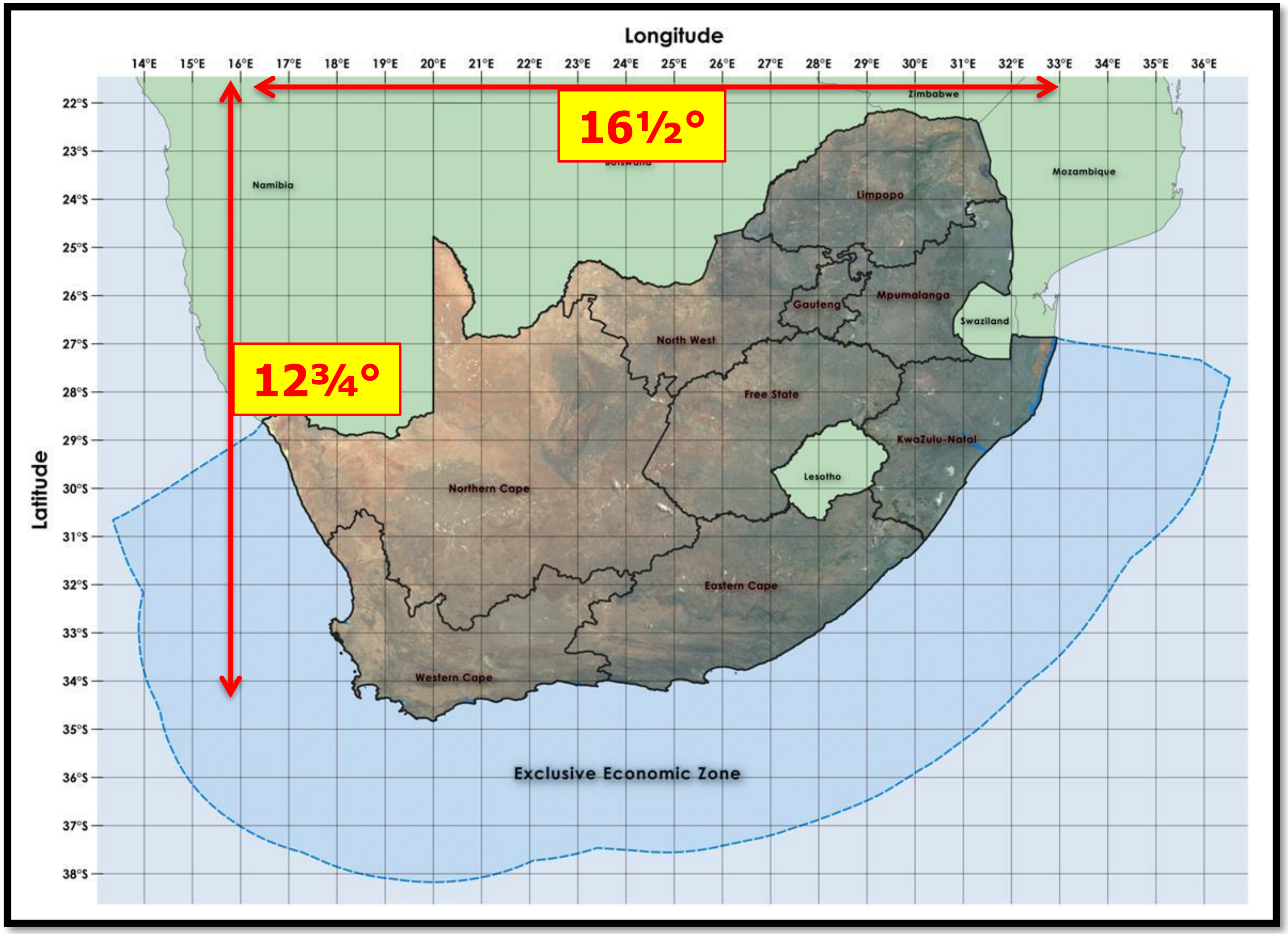
C. Coordinate conventions



South African Gauss Conformal Coordinate System

- CS = Map Projection + Rules and conventions
  - Map Projection = Transverse Mercator
  - Unit of measure = metre
  - Scale at CM (‘s) = 1
  - Lat\ Long of origin = (0°S) \ (15°-33° E) and 37 °E
  - False origin = 0m (zero)
  - Axis orientation = + west , +south
  - Coordinate order, = westings, southings (W,S)
  - Coordinate label = y (m),x (m)
  - Direction zero azimuth= 0° south
  - Zone width = 2 deg

Continental South Africa's : Extent



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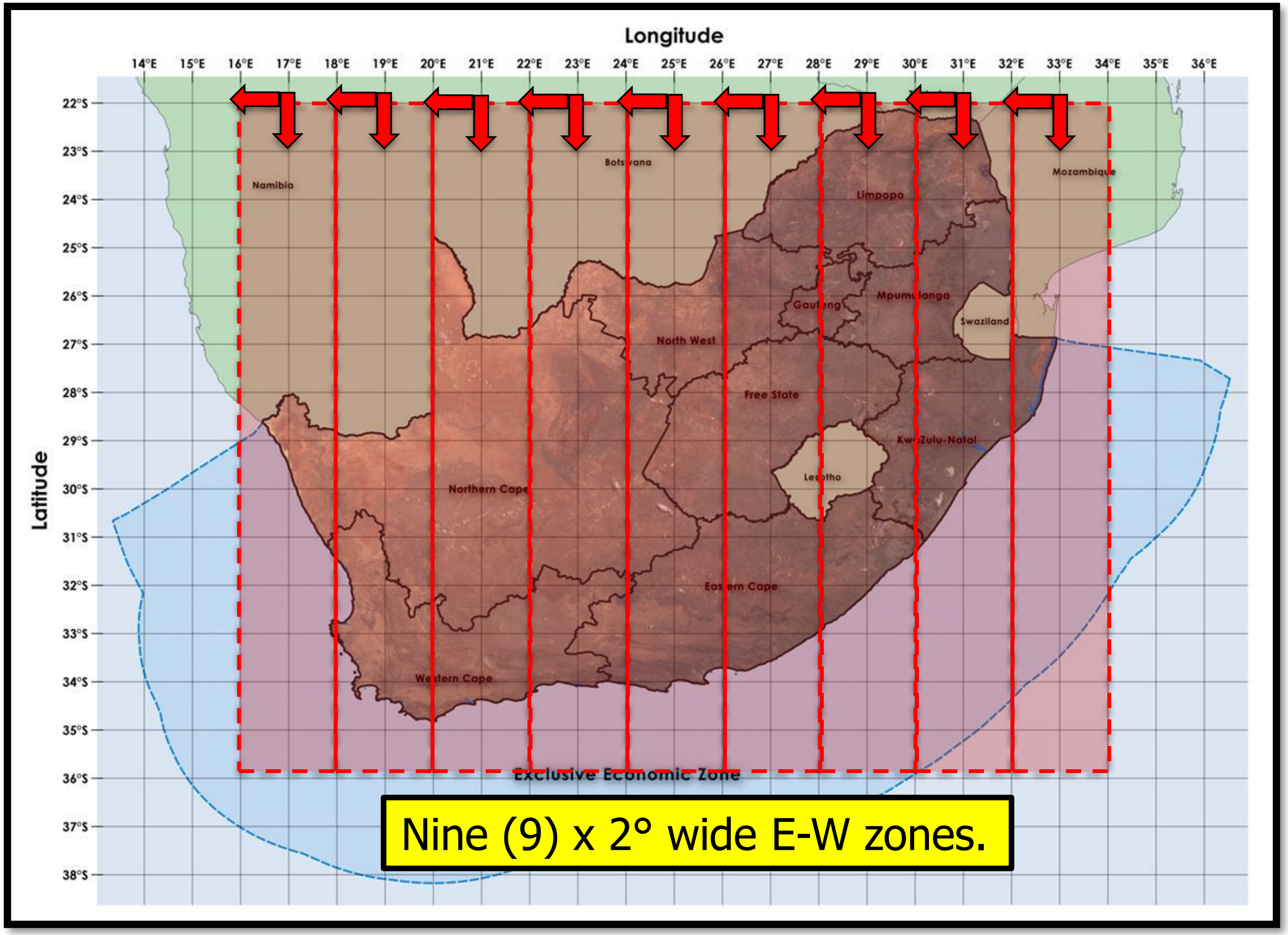
SA GAUSS CONFORM CS (Lo.)



C. SA Gauss Conform Coordinate System

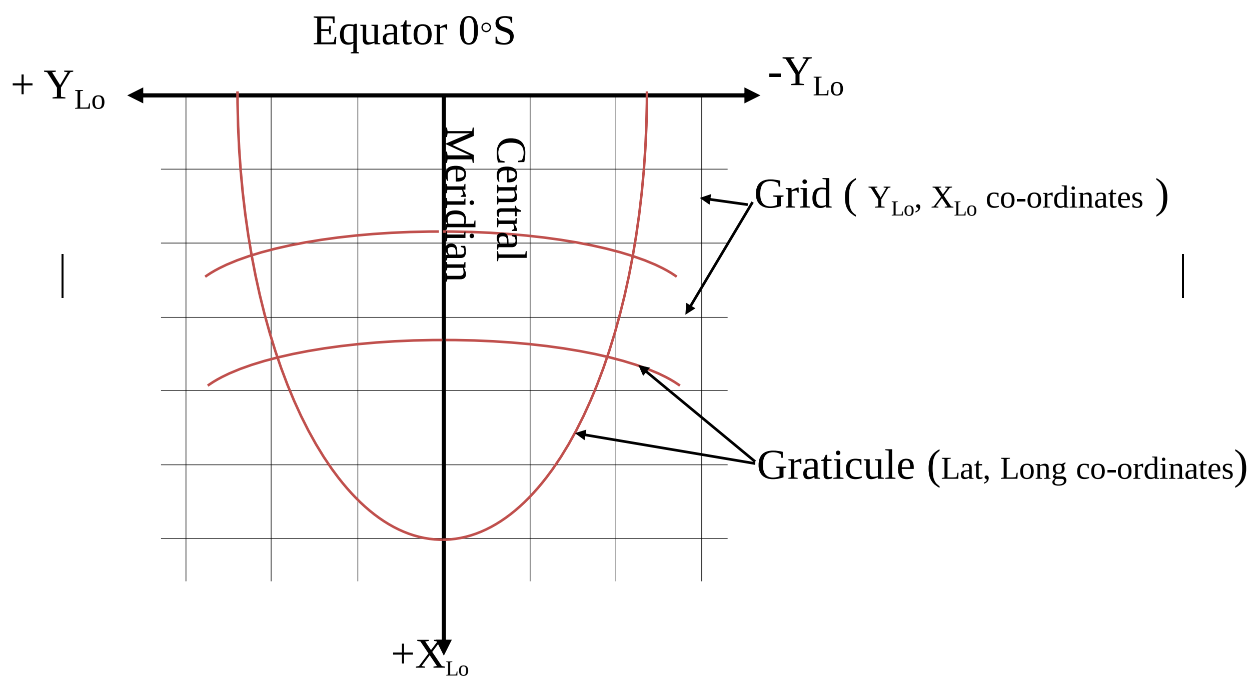
(not standard Transverse Mercator)

yyyyy.yyy xxxxxxx.xxx

wwwww.www sssssss.sss

+54272.568m 3761451.628m

(Central meridian: 19°)



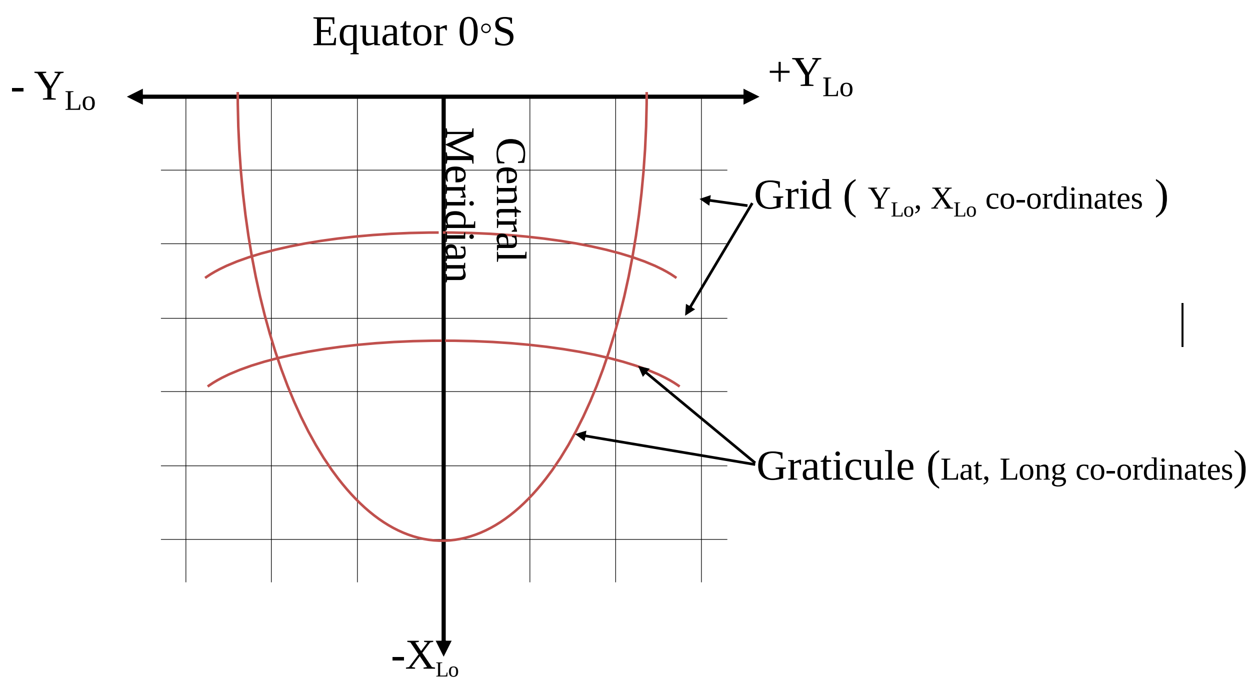
C. Standard Transverse Mercator Projection

xxxxxxx.xxx yyyyy.yyy

NNNNNNN.NNN EEEEE.EEE

-3761451.628m -54272.568m

(Central meridian: 19°)



C. SA Gauss Conform vs Standard Transverse Mercator

- Easy to detect (for continental Republic of South Africa)

- Look at x/N(northing) value
  - If Gauss Conform, 2400000m < x < 3800000m, y will be positive west of CM
  - If TM, - 3800000m < x < -2400000m, y will be positive east of CM

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C. Diagrams of SA

7 0 0 0/7 6

SYE meter ~~Kaapse Voet~~		RIGTINGS -HOEKE		Y		X
		Konstante		±	0,00	+3 760 000 , 00
AB	136,0~~9~~ 3	284.34.10	A	+	21 511,75	+ 3 105,22
BC	1 221,67	300.40.47	B	+	21 380,09	+ 3 139,44
CD	773,58	358.21.20	C	+	20 329,41	+ 3 762,78
DE	524,82	277.53.00	D	+	20 307 , 22	+ 4 536 , 04
EF	895,16	40.10.40	E	+	19 787,36	+ 4 608,03
FG	315,73	124.36.20	F	+	20 364,88	+ 5 291,97
GH	1 400,49	125.16.09	G	+	20 624,75	+ 5 112,65
HJ	124,80	77.27.00	H	+	21 768,18	+ 4 303,98
JK	15,17	100.40.13	J	+	21 890,00	+ 4 331,10
KA	1 284,71	197.49.13	K	+	21 904,91	+ 4 328,29
aAa		104.34.10				
kKk		100.40.13				
		△ Stel 3		+	21 203,35	+ 7 024,93
		△ Eerste Rivier		+	23 325,7~~9~~ 3	+ 2 532,70

Co-ordinates System Lo 19°

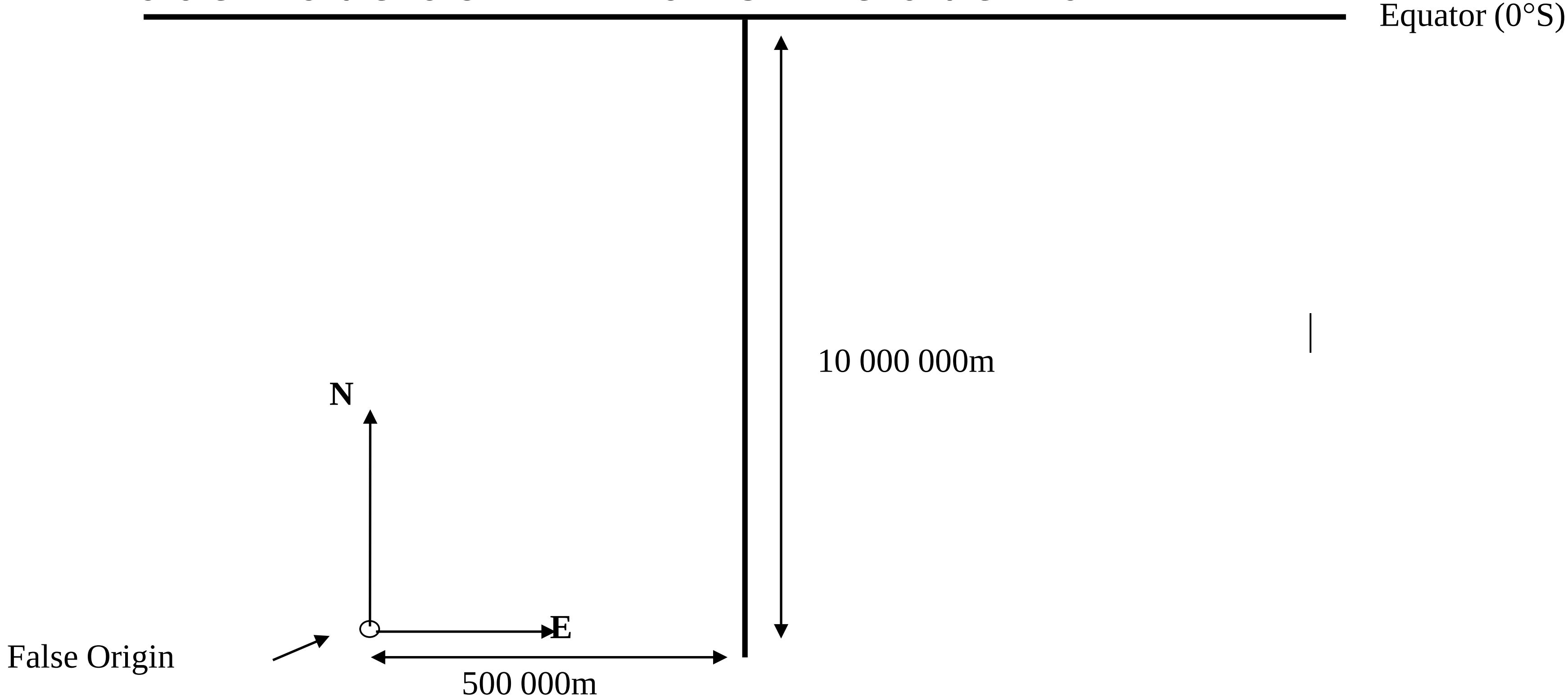
C. Universal Transverse Mercator CS

Universal Transverse Mercator CS

(Central meridian: 21°, zone 34)

– EEEEEE.EEE NNNNNNN.NNN

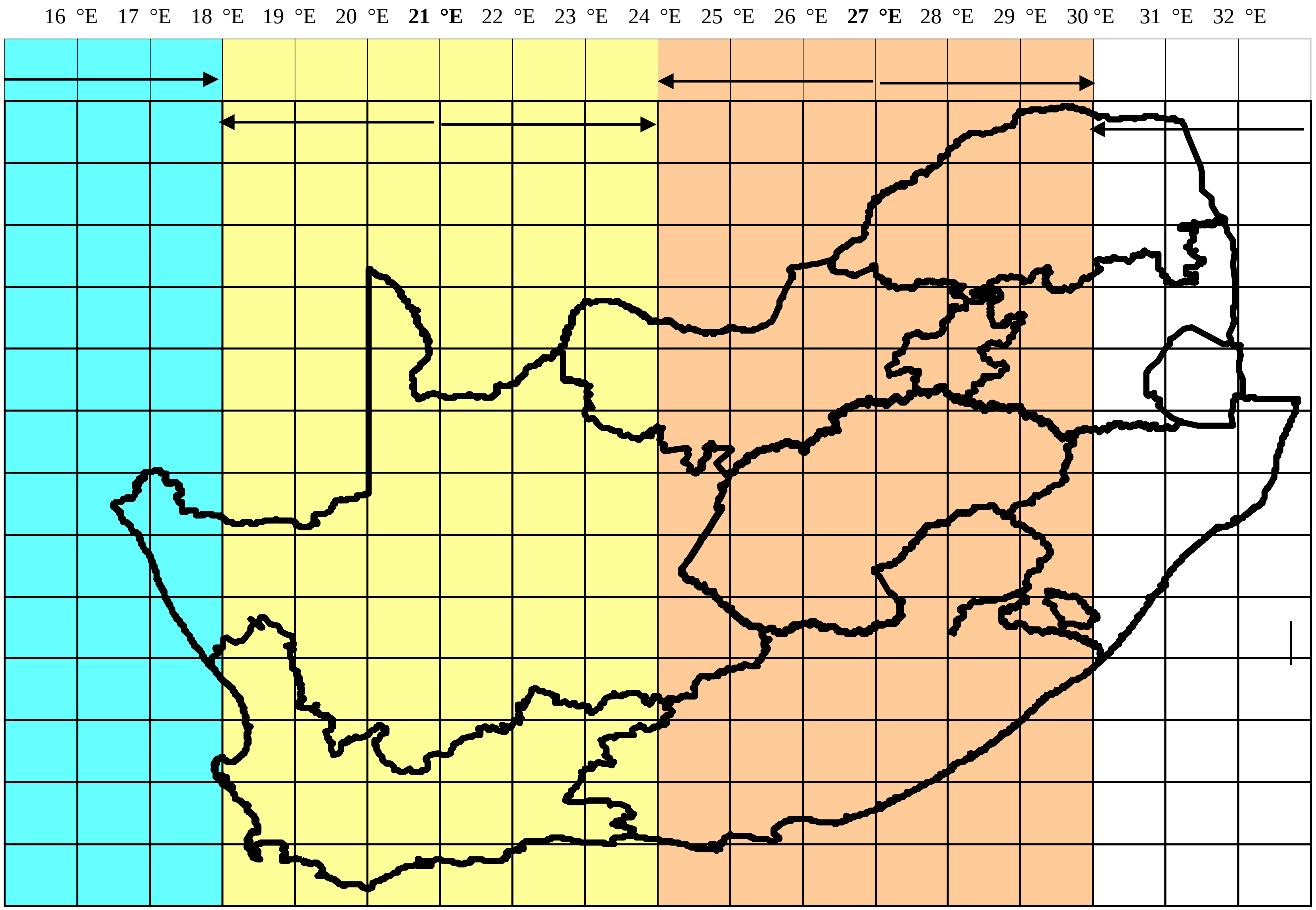
260976.968m 6237190.940m



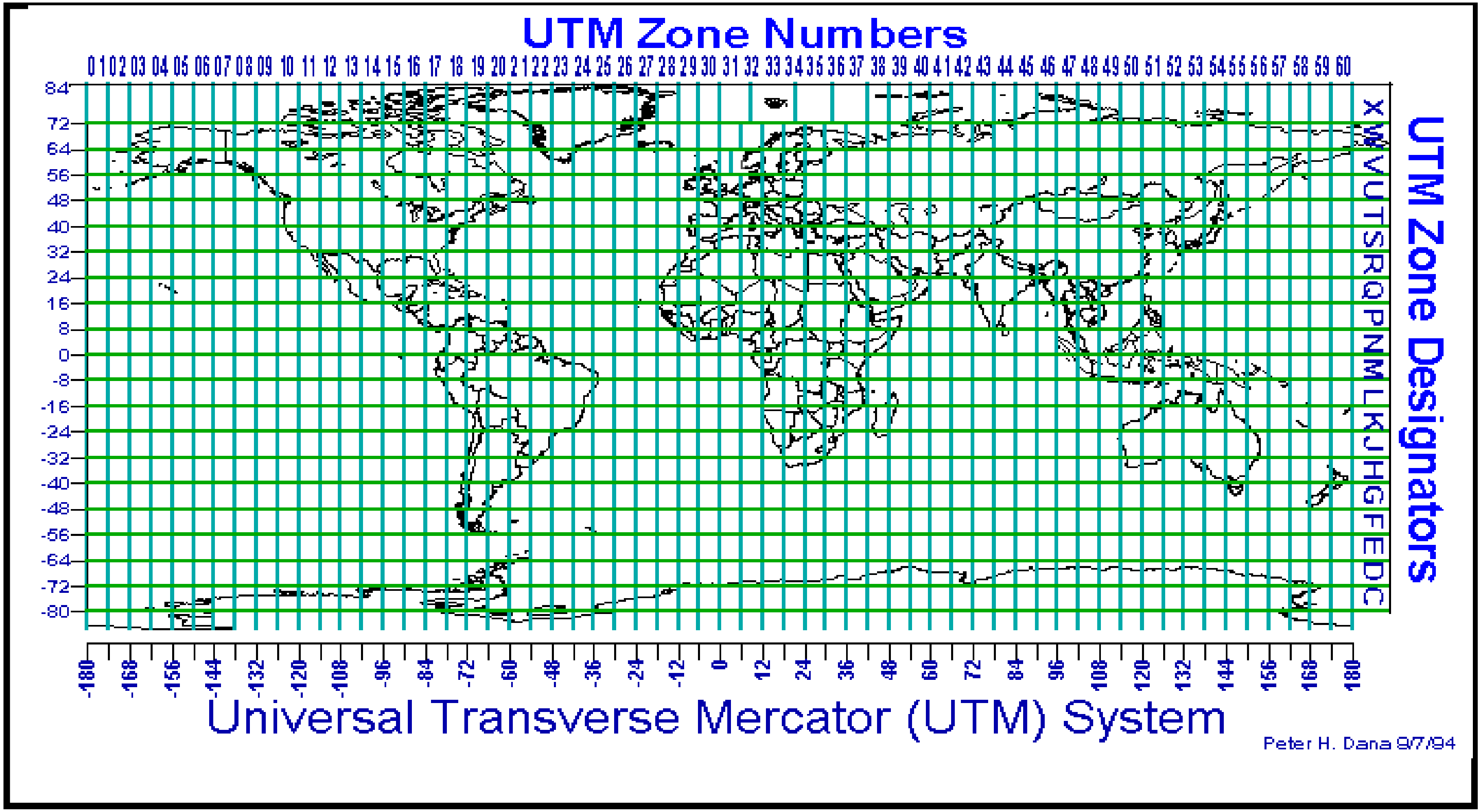
C. UTM

- Also a special case of the Transverse Mercator Projection
- 6 ° bands
- In South Africa (CM = 15°E-zone 33, 21 ° -zone 34; 27 °E – zone 35).
- Most satellite imagery referenced to UTM
- Military uses UTM

C. UTM Zones


16 °E
17 °E
18 °E
19 °E
20 °E
21 °E
22 °E
23 °E
24 °E
25 °E
26 °E
27 °E
28 °E
29 °E
30 °E
31 °E
32 °E

C. UTM Zones


UTM Zone Numbers
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
84 72 64 56 48 40 32 24 16 8 0 -8 -16 -24 -32 -40 -48 -56 -64 -72 -80
X W V U T S R Q P N M L K J H G F E D C
UTM Zone Designators
-180 -168 -156 -144 -132 -120 -108 -96 -84 -72 -60 -48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108 120 132 144 156 168 180
Universal Transverse Mercator (UTM) System
Peter H. Dana 9/7/94

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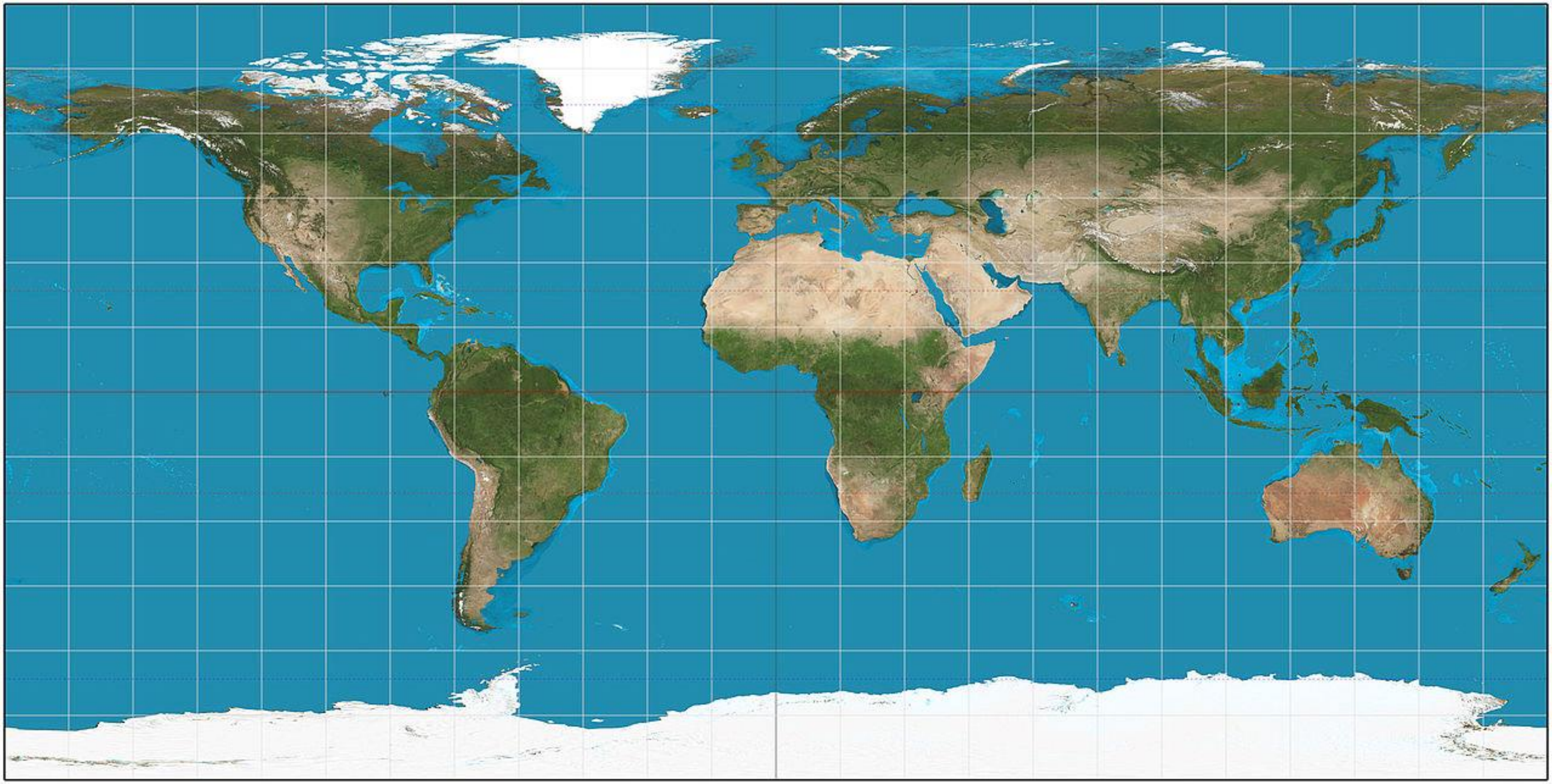
"Lat Long / Equi-rectangular /Geographic Projection"



D

TERRESTRIAL REFERENCE SYSTEMS, FRAMES AND DATUMS

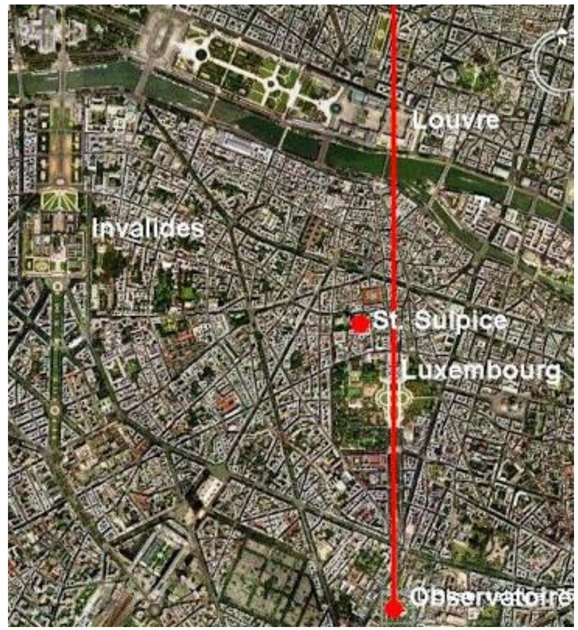
Outline

- Terrestrial Reference Systems
- Terrestrial Reference Frames
  - Global Terrestrial Reference Frames
  - Regional Terrestrial Reference Frames
  - Local Terrestrial Reference Frames (Datums)
    - Local Geocentric Datums (e.g Hartebeesthoek94)
    - Local non-geocentric Datums (Cape Datum)
    - SA Land Leveling Datum

Terrestrial Reference Systems

- Where is the equator (equatorial plane?)

- Where is the Prime Meridian , 0°E/W… is it Greenwich, or Paris, or IERS ref meridian 105m away?



- Geocentric or not?


The modern reference meridian indicating zero longitude using GPS
334ft (101 metres)
Greenwich Park
Peter Harrison Planetarium
Royal Observatory Greenwich
The Airy meridian marked as the Prime Meridian of the World

Terrestrial Reference Systems

- Terrestrial Reference Systems describes procedures for creating reference frames suitable for use with measurements on or near the Earth's surface.
- This is done in much the same way that a physical standard might be described as a set of procedures for creating a *realization* of that standard.

Terrestrial Reference Systems

Terrestrial Reference Systems

- Physical Constants
  - Geocentric gravitational constant
  - angular velocity of the Earth
- Gravity Field
- Reference Ellipsoid
  - Semi-major axis
  - 1/f or b
- Scale
- Origin
- Axis
- Epoch
- Time Evolution /Velocity Field

Global Terrestrial Reference Systems

- World Geodetic System 84 (WGS 84)

- Geodetic Reference System 80 (GRS80)
  and its successor
- International Terrestrial Reference System (ITRS).

International Union of Geodesy and Geophysics
IUGG
UGGI
Union Géodésique et Géophysique Internationale

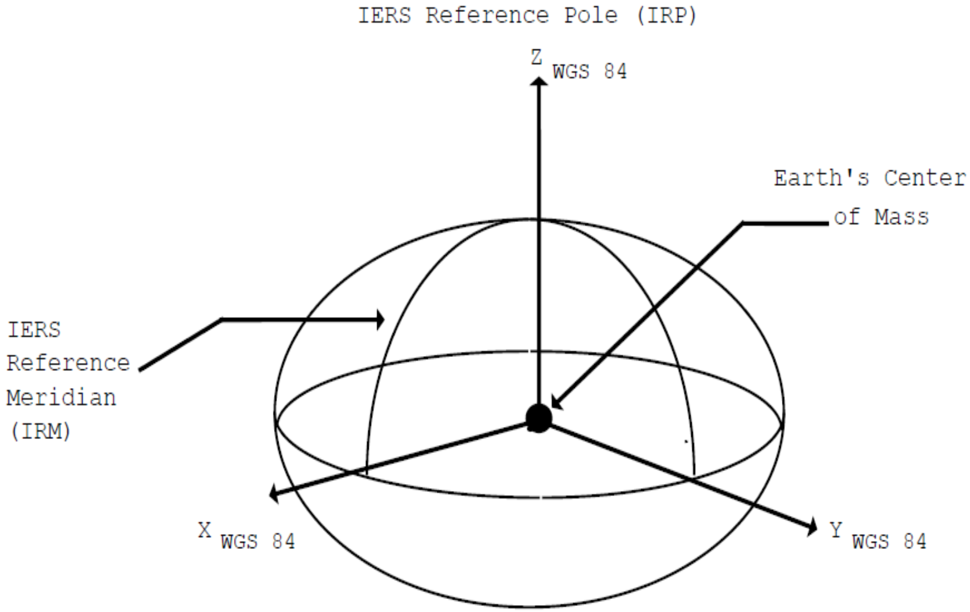
- *Systema koordinat 42 (SK42)*

TRS: World Geodetic System 84

- WGS 84 is a geodetic reference system consisting of a global reference ellipsoid and a gravity field model.
- The definition of the **W**orld **G**eodetic **S**ystem has evolved within NGA .. from the initial WGS 60 through subsequent improvements embodied in WGS 66, WGS 72, and finally **WGS 84**.

World Geodetic System 84

- Geocentric
- EGM2008 gravity field and geoid model
- Defining parameters:



Parameter	Notation	Value
Semi-major Axis	a	6378137.0 meters
Flattening Factor of the Earth	1/f	298.257223563
Nominal Mean Angular Velocity of the Earth	ω	7292115×10^{-11} radians/second
Geocentric Gravitational Constant (Mass of Earth's Atmosphere Included)	GM**	$3.986004418 \times 10^{14}$ $meter^3/second^2$

**The value of GM for GPS users is 3.9860050×10^{14} m^3/sec^2 as specified in the references below.

GRS 80 and ITRS

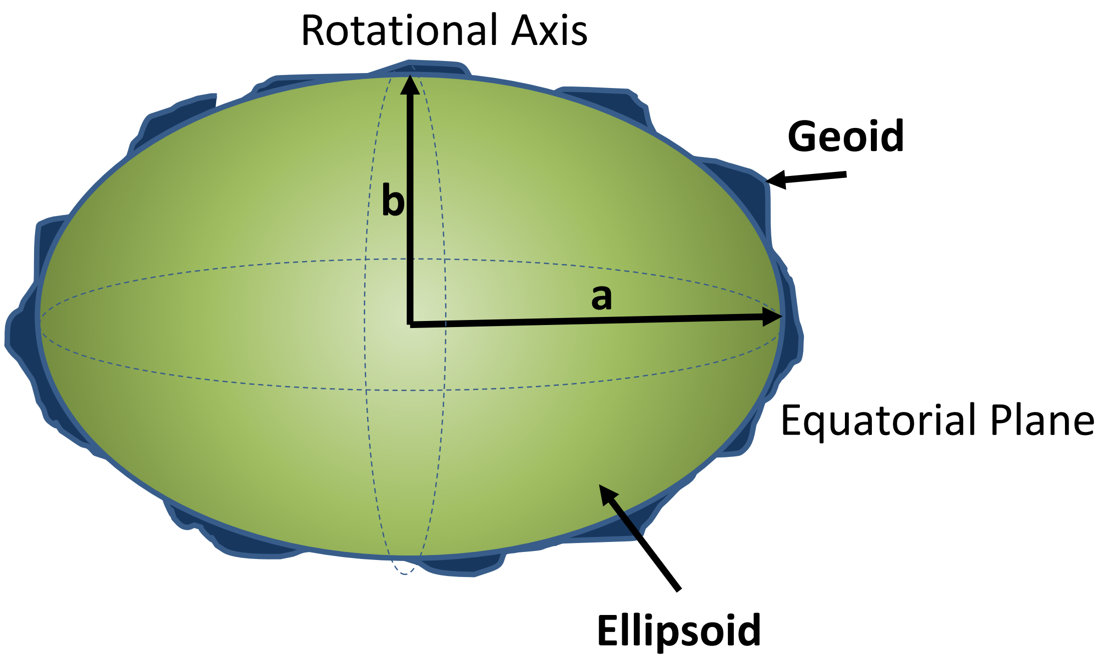
- The Global Geodetic Reference System 80 and its "successor", the International Terrestrial Reference System (ITRS).
- The ITRS is a world spatial reference system co-rotating with the Earth in its diurnal motion in space, associated with GRS80 reference ellipsoid.
- The International Earth Rotation Service (IERS), in charge of providing global references to the astronomical, geodetic and geophysical communities, supervises the realization of the ITRS.

TRF’s are realizations of Terrestrial Reference Systems

TERRESTRIAL REFERENCE FRAMES

A. Spheroid (oblate ellipsoid of revolution)

- Most common mathematical approximation describing the shape of the earth.



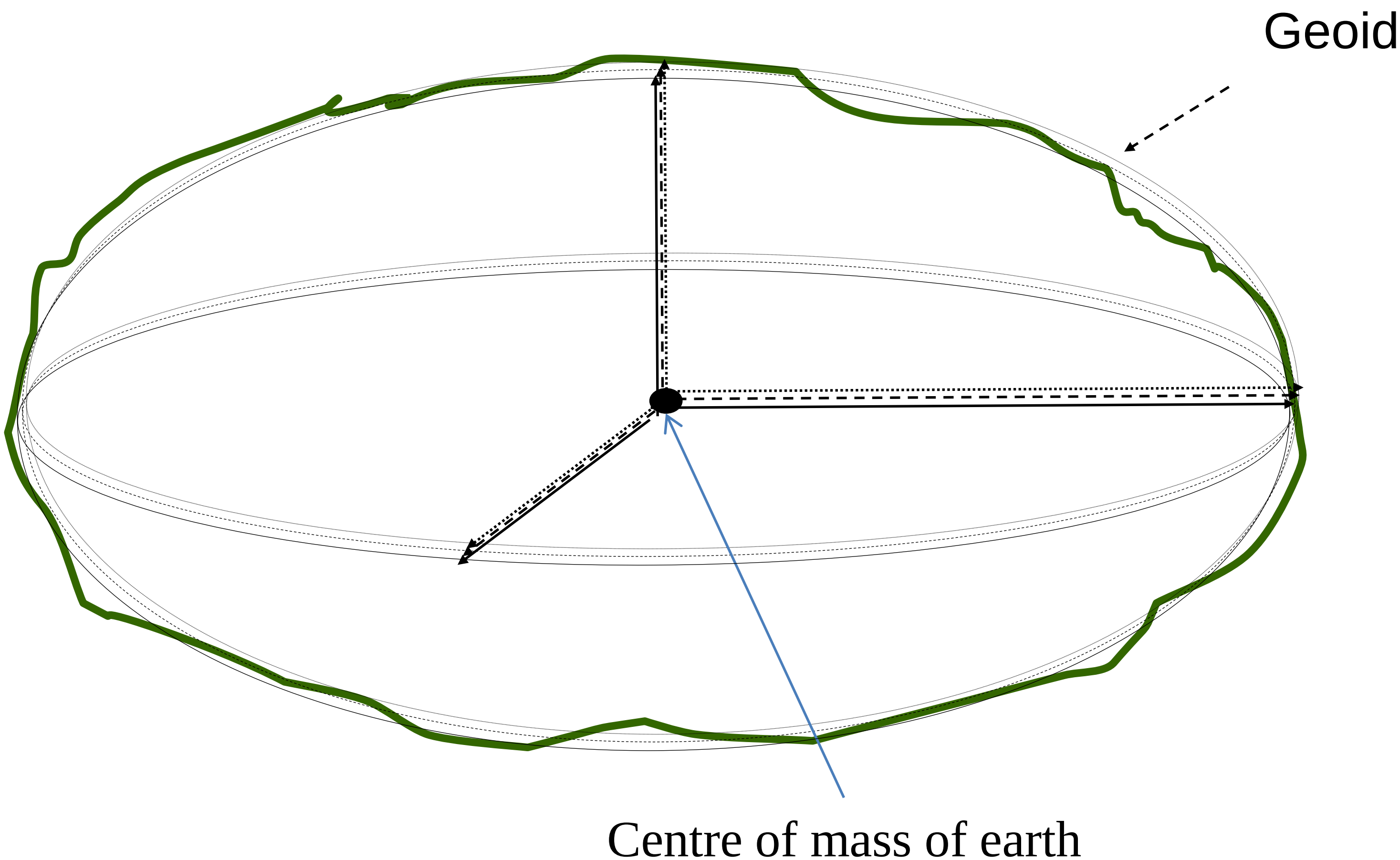
<u>Elements of the Ellipsoid:</u>

a = semi major axis

b = semi minor axis = a(1-f)

1/f (inverse flattening) = a/(a-b)

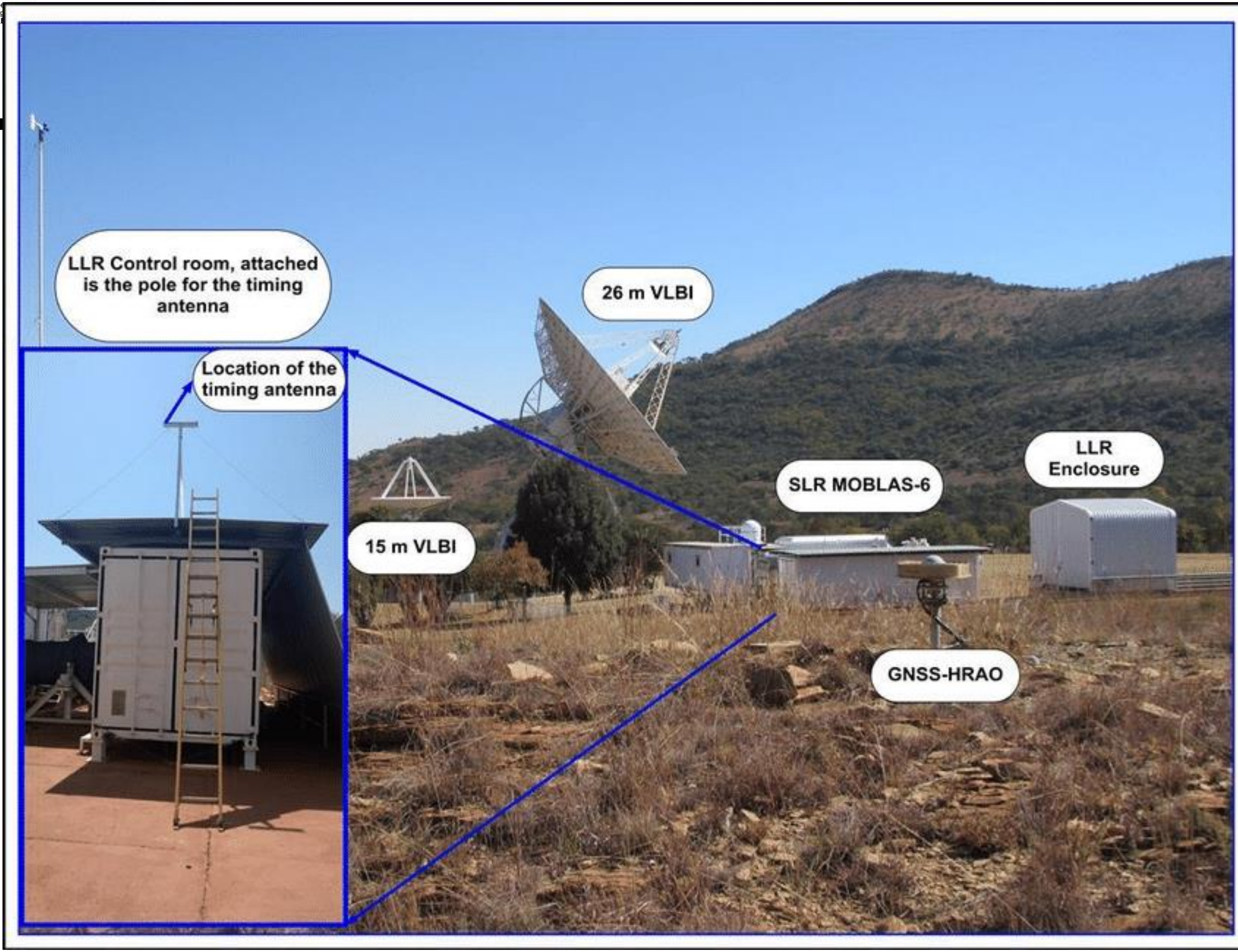
Geocentric Reference Frames

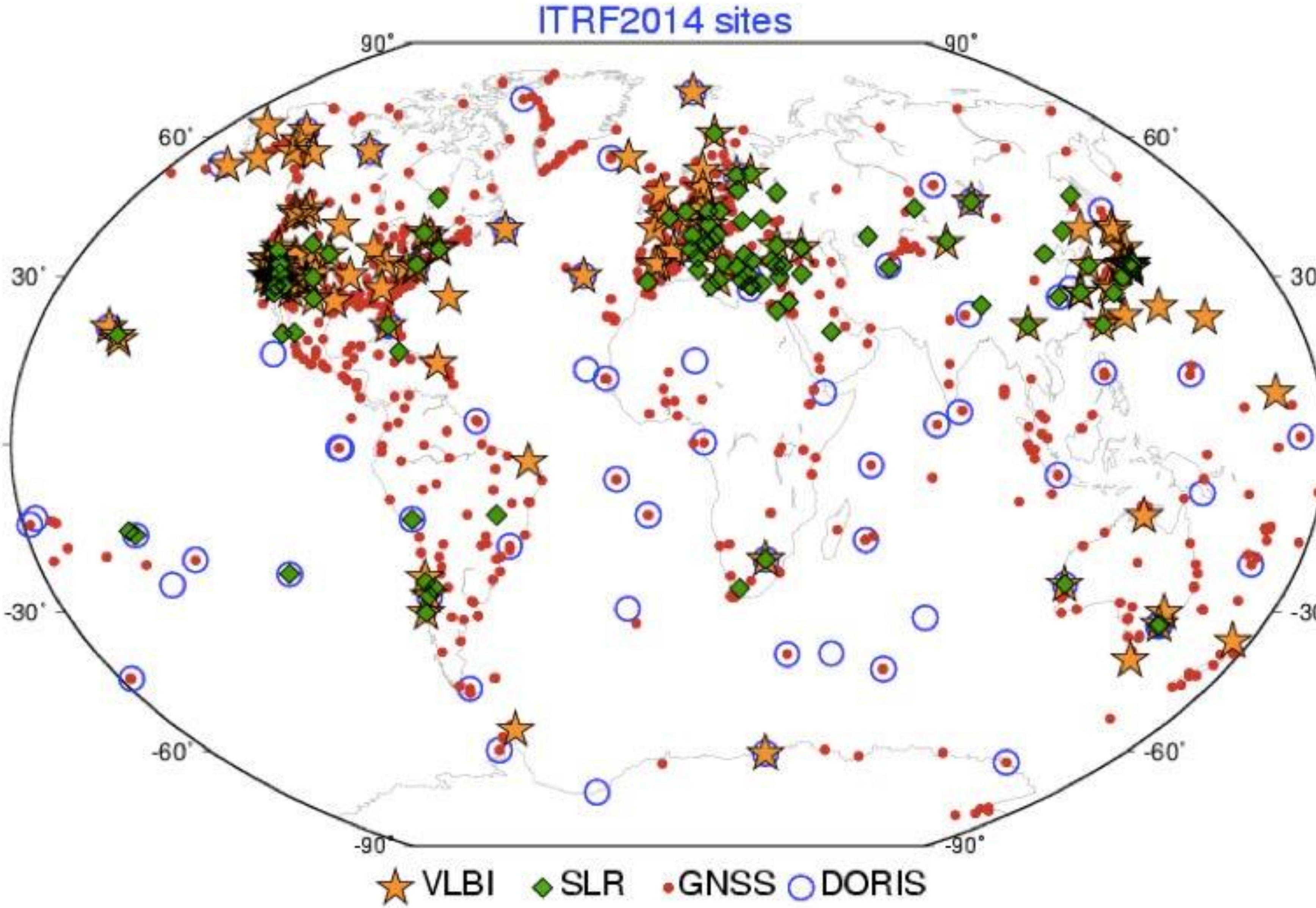


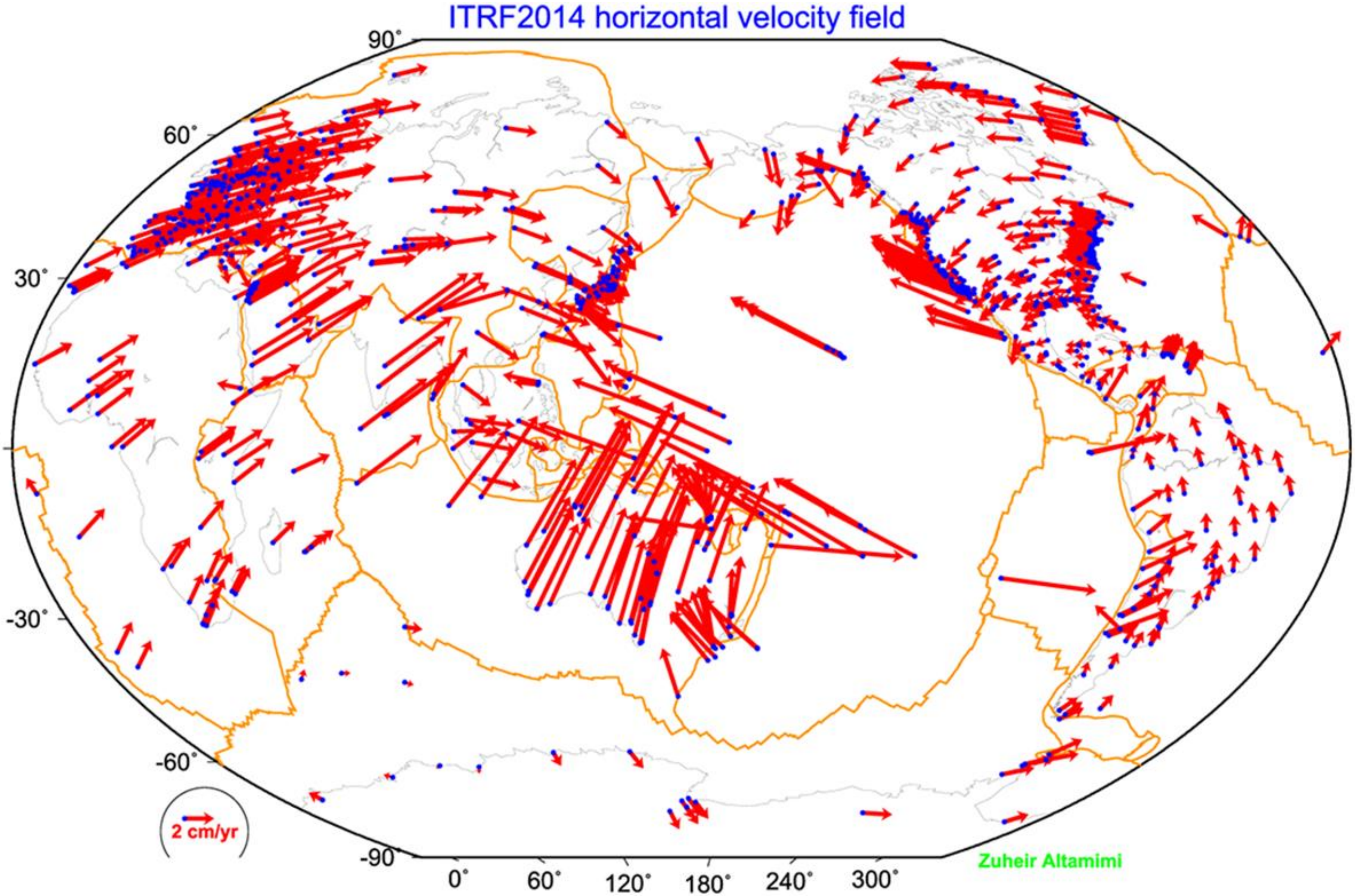
International Terrestrial Reference Frames (Realizations of ITRS)

- International Terrestrial Reference Frames (ITRF's) are realizations of the ITRS.
- Produced by the IERS.
- Coordinates obtained by combination of individual TRF solutions computed by IERS analysis centres using the rigorous combination of observations of Space Geodesy techniques: GNSS , VLBI, SLR, LLR and DORIS.
- Coordinates are provided as Geocentric Cartesian coordinates (XYZ).

SPACE GEODETIC TECHNIQUES CONTRIBUTING TO ITRF


LLR Control room, attached is the pole for the timing antenna
Location of the timing antenna
26 m VLBI
15 m VLBI
SLR MOBLAS-6
LLR Enclosure
GNSS-HRAO


ITRF2014 sites
90°
60°
30°
0°
-30°
-60°
-90°
VLBI
SLR
GNSS
DORIS


ITRF2014 horizontal velocity field
90°
60°
30°
0°
-30°
-60°
-90°
0°
60°
120°
180°
240°
300°
2 cm/yr
Zuheir Altamimi

ITRF (realizations of ITRS)

- ITRF solutions consist of sets of station positions and velocities with their variance/covariance matrices.
- Since the release of the ITRF2005 , Earth Orientation Parameters (EOP's) have simultaneously been combined with station coordinates.
- The numbers (yy) following the designation "ITRF" specify the last year when data was used during frame processing.

Modern ITRF's

- From ppm to ppb
- 1ppb =1mm per billion mm,
- Accuracies and precision at a few ppb
- i.e typically 5mm per 1000km possible with scientific processing.
- All global and non military scientific work done on a realization of ITRF.

ITRF solutions available :

- **ITRF2020**
- **ITRF2014 TrigNet realisation at epoch 2018.18**
- **ITRF2008**
- **ITRF2005 SAGEOID2010 referenced to this (epoch 2010.02)**
- ITRF2000
- ITRF97
- ITRF96
- ITRF94
- ITRF93
- ITRF92
- **ITRF91 Hartebeesthoek94 (SA realisation, epoch 1994.0)**
- ITRF90
- ITRF88
- ITRF89

WGS84 RF's

- The current realization of the WGS 84 Reference System is designated as WGS 84 (G1762) Reference Frame.
- GPS Operational Control Segment (OCS) implemented WGS 84 (G1762) on 16 Oct 2013 with NGA implementation on the same date.
- WGS 84 (G1762) aligns WGS 84 with ITRF 2008 (**epoch 2012.2**) with accuracy better than one cm-per-component, resulting in an overall difference of less than one cm. … based on a subset of IGS stations selected as control points in the reference frame solution.

WGS 84 Realisations

Short Name	Datum Epoch	Remarks	Shift
WGS84	1984	First realization established by DoD in 1987 using Doppler observations. Also known as WGS84 (1987), WGS84 (original), WGS84 (TRANSIT). For surveying purposes, original WGS84 is identical to NAD83 (1986). WGS84 is connected to ITRF90 by a 7-parameter Helmert transformation.	N/A
WGS84 (G730)	1994.0	Realization introduced by DoD on 1994-06-29 based on GPS observations. G stands for 'GPS' and 730 is GPS week number. Based on ITRF91.	0.70 meter
WGS84 (G873)	1997.0	Realization introduced by DoD on 1997-01-29 based on GPS observations. G stands for 'GPS' and 873 is GPS week number. Based on ITRF94.	0.20 meter
WGS84 (G1150)	2001.0	Realization introduced by DoD on 2002-01-20 based on GPS observations. G stands for 'GPS' and 1150 is GPS week number. Based on ITRF2000.	0.06 meter
WGS84 (G1674)	2005.0	Realization introduced by DoD on 2012-02-08 based on GPS observations. G stands for 'GPS' and 1674 is GPS week number. Based on ITRF2008.	0.01 meter
WGS84 (G1762)	2008.0	Realization introduced by DoD on 2013-11-08 based on GPS observations and ITRF2008 (IGb). G stands for 'GPS' and 1762 is GPS week number.	0.02 metre
WGS84 (G2139)	2015.10	Realization introduced by DoD on 2021-01-03 based on GPS observations and ITRF2014 (IGb)., G stands for 'GPS' and 2139 is GPS week number.	0.01 metre

Datum Ensemble

- May I add the definition for Datum Ensemble, published in ISO 19111:2019, see https://www.iso.org/obp/ui/#iso:std:iso:19111:ed-3:v1:en, which is:
- 3.1.16
- datum ensemble
- group of multiple realizations of the same terrestrial or vertical reference system that, for approximate spatial referencing purposes, are not significantly different
- Note 1 to entry: Datasets referenced to the different realizations within a datum ensemble may be merged without coordinate transformation.
- Note 2 to entry: 'Approximate' is for users to define and typically is in the order of under 1 decimetre but may be up to 2 metres.
- EXAMPLE:
- "WGS 84" as an undifferentiated group of realizations including WGS 84 (TRANSIT), WGS 84 (G730), WGS 84 (G873), WGS 84 (G1150), WGS 84 (G1674) and WGS 84 (G1762). At the surface of the Earth these have changed on average by 0.7 m between the TRANSIT and G730 realizations, a further 0.2 m between G730 and G873, 0.06 m between G873 and G1150, 0.2 m between G1150 and G1674 and 0.02 m between G1674 and G1762).

SK 42 Realisations

- Parametry Zemli 1990 goda (PZ 90)
- Revisions
  - **PZ-90.02**
  - **PZ-90.11**
- When using multi-constellation GNSS, the transformation from PZ90 to WGS84/ITRF can introduce additional biases.

REGIONAL REFERENCE FRAMES

Regional Reference Frames

- Denser networks of geodetic stations covering continental areas.
- Eg. African Reference Frame (**AFREF**), European Terrestrial Reference Frame (**EUREF**), North American Datum 1983 (**NAD83**), Sistema de Referencia Geocéntrico para las América (**SIRGAS**) and the Asia-Pacific Reference Frame (**APREF**).
- Regional reference frames are defined by the coordinates and site velocities of contributing stations.
- The key difference with some regional reference frames (e.g. EUREF and NAD83) and ITRF is that the site velocities may be with respect to the dominant tectonic plate encompassed by the frame and not a NNR condition.
- This approach minimizes site velocities. Regional frames not constrained by the motion of a single tectonic plate are closely aligned with ITRF.

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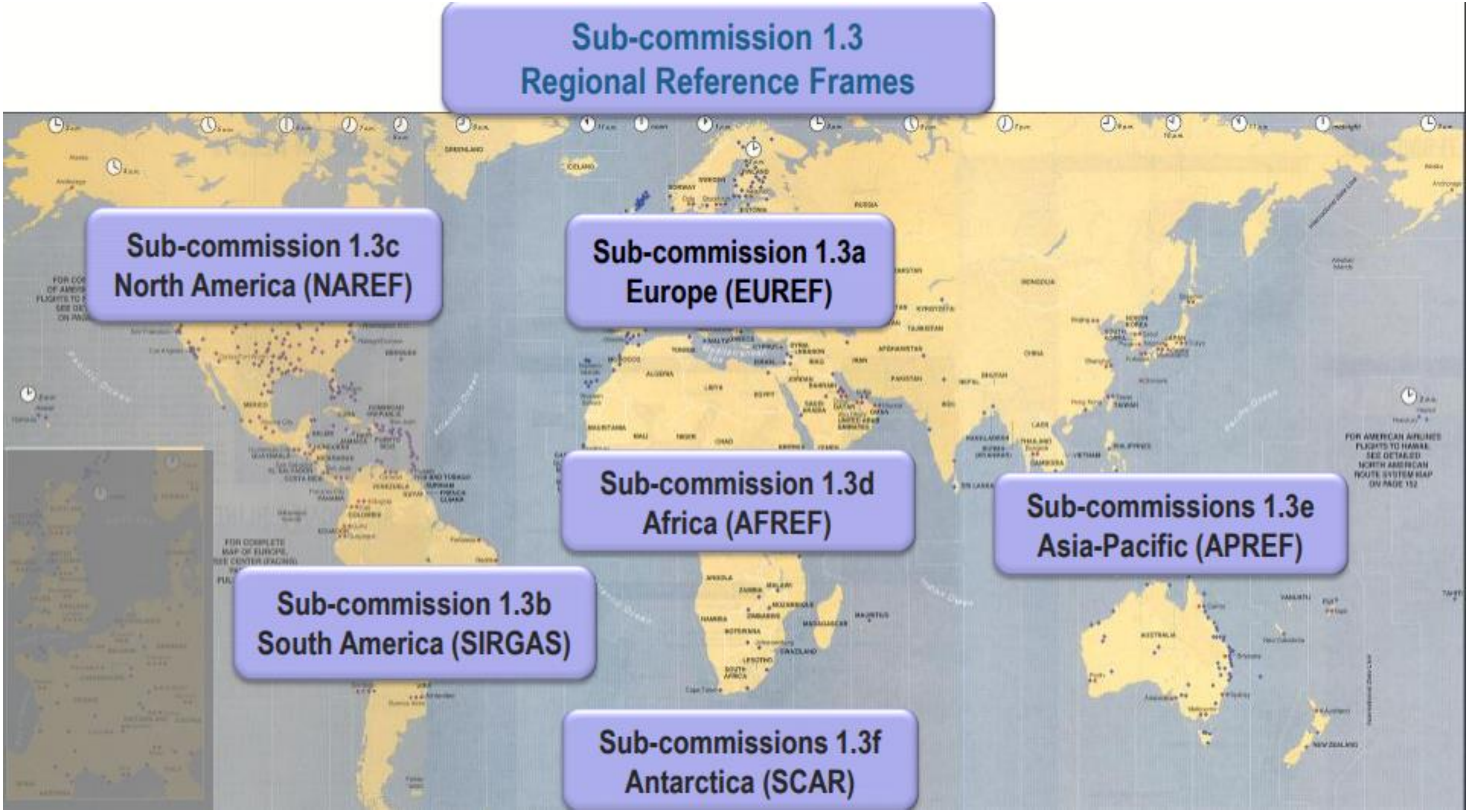
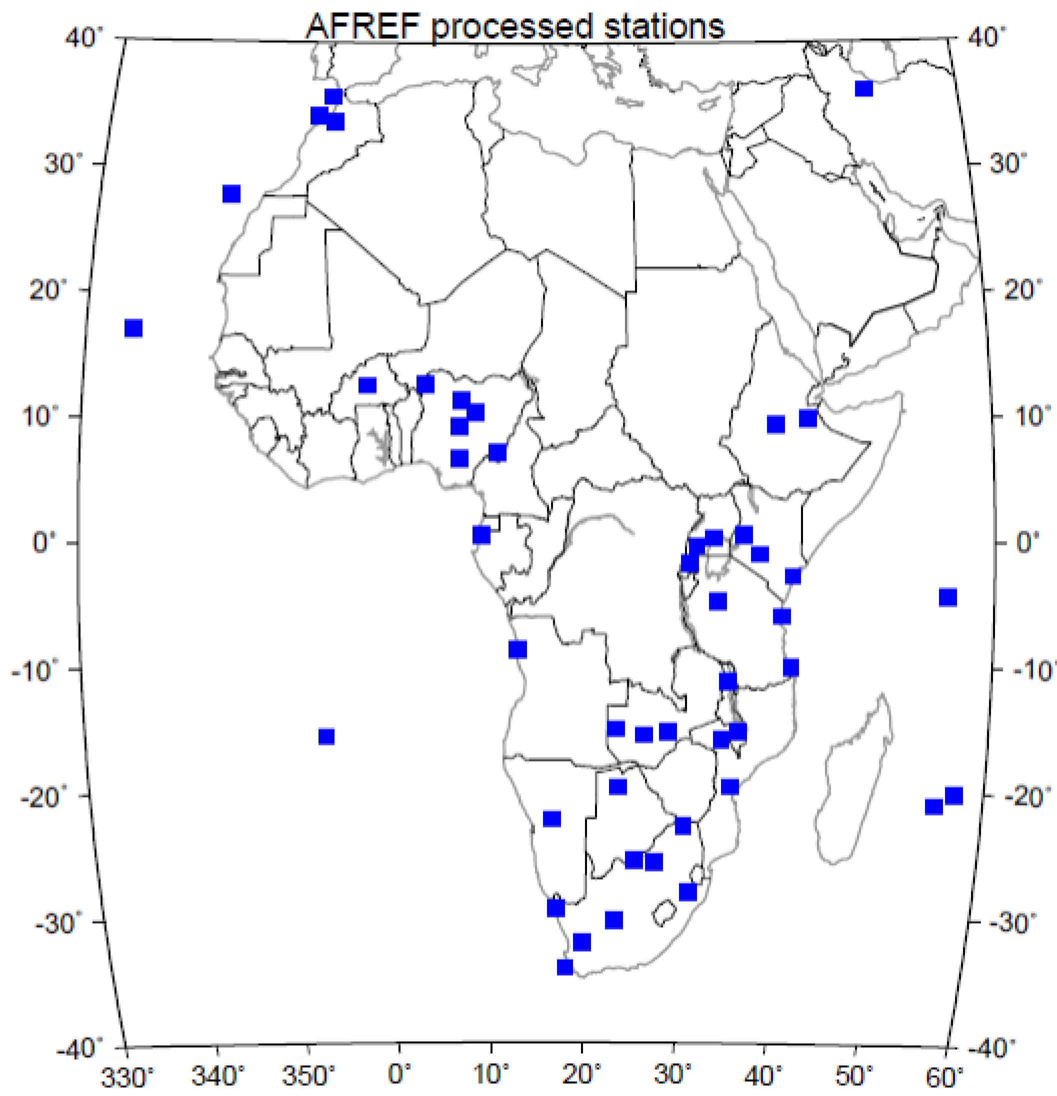
IAG Commission 1: Reference Frames



African Reference Frame

- First AFREF solution fully connected to ITRF

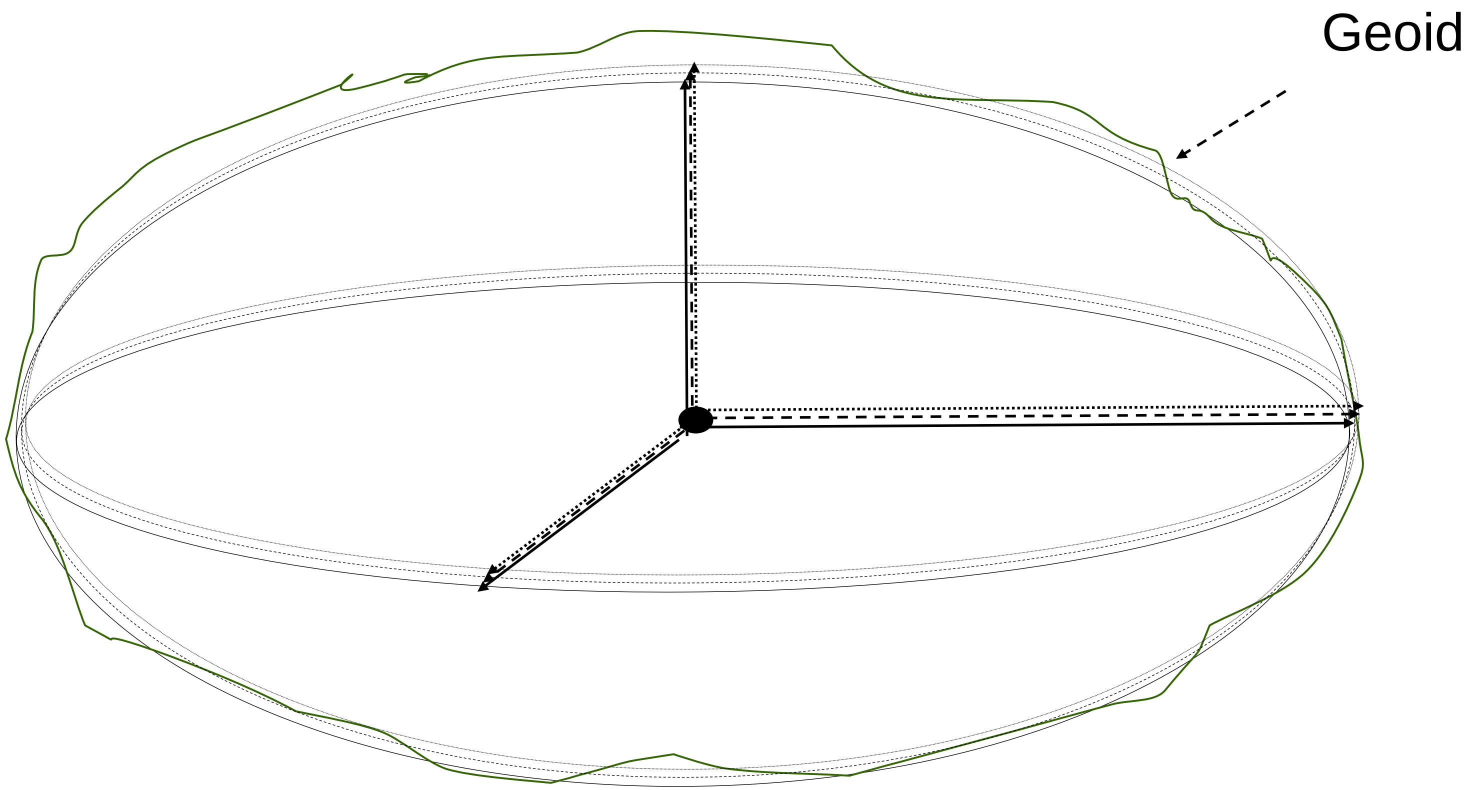


NATIONAL TERRESTRIAL REFERENCE FRAMES / GEODETIC DATUMS

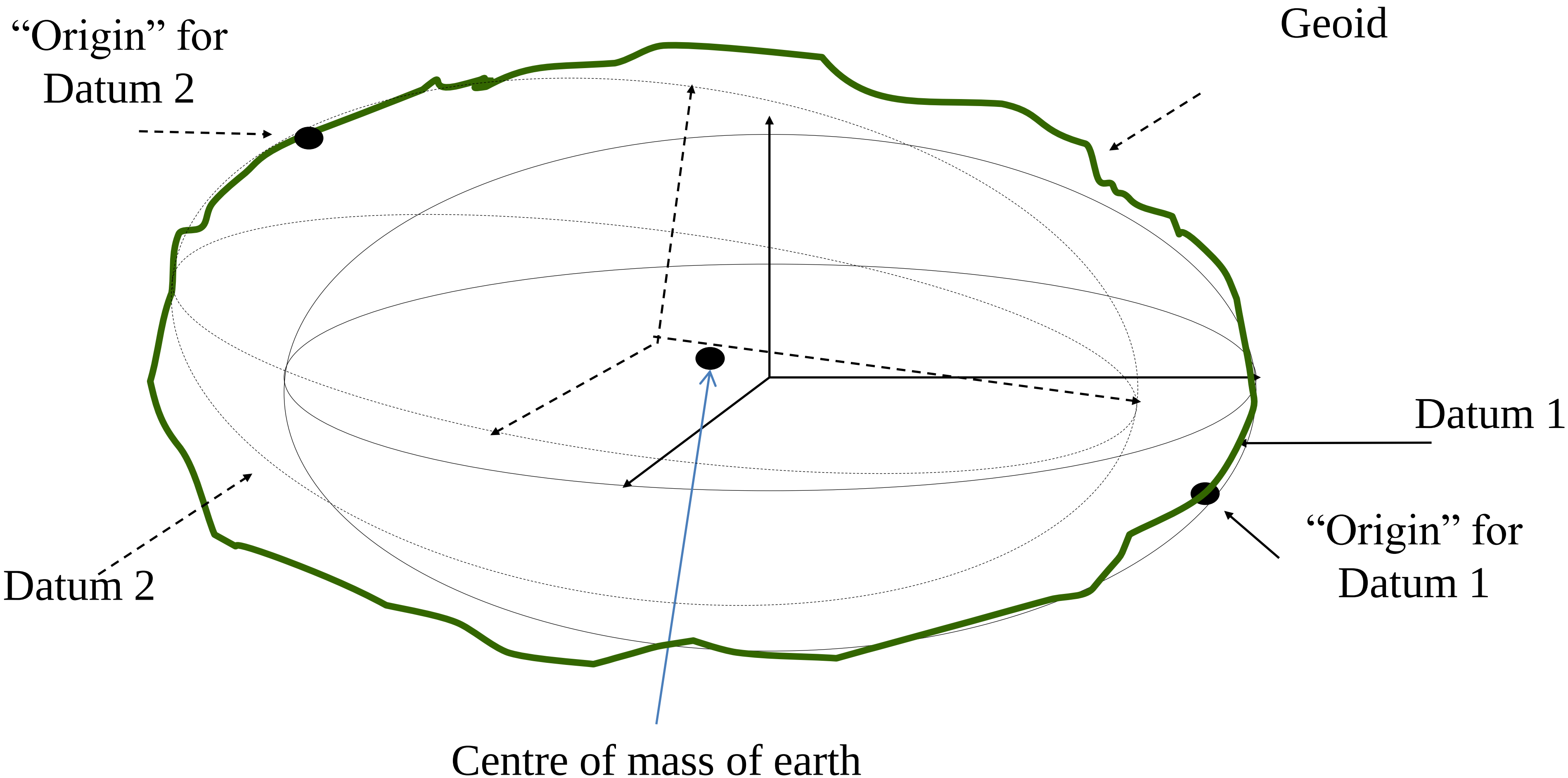
National Reference Frames (Geodetic Datums)

- Modern datums are typically a static realization of ITRF or a regional reference frame.
- In most countries the coordinates of a national reference frame (geodetic datum) form the basis for all surveying, positioning and mapping within national borders.
- Because surveying/ GIS software and spatial data are not generally designed to deal with continuously changing coordinates, the epoch for national datums is fixed and the coordinates are considered to be invariant with time (in Southern Africa).

Geocentric Reference Frames



Non Geo-centric Local Datums



Hartebeesthoek94

- 1 January 1999 ->current day
- Official South African Coordinate Reference System based on the WGS84 ellipsoid and geocentric.
- ITRF91 (epoch 1994.0) co-ordinates of the Hartebeesthoek Radio Astronomy Telescope used as the origin of this system.
- Hartebeesthoek94 Datum

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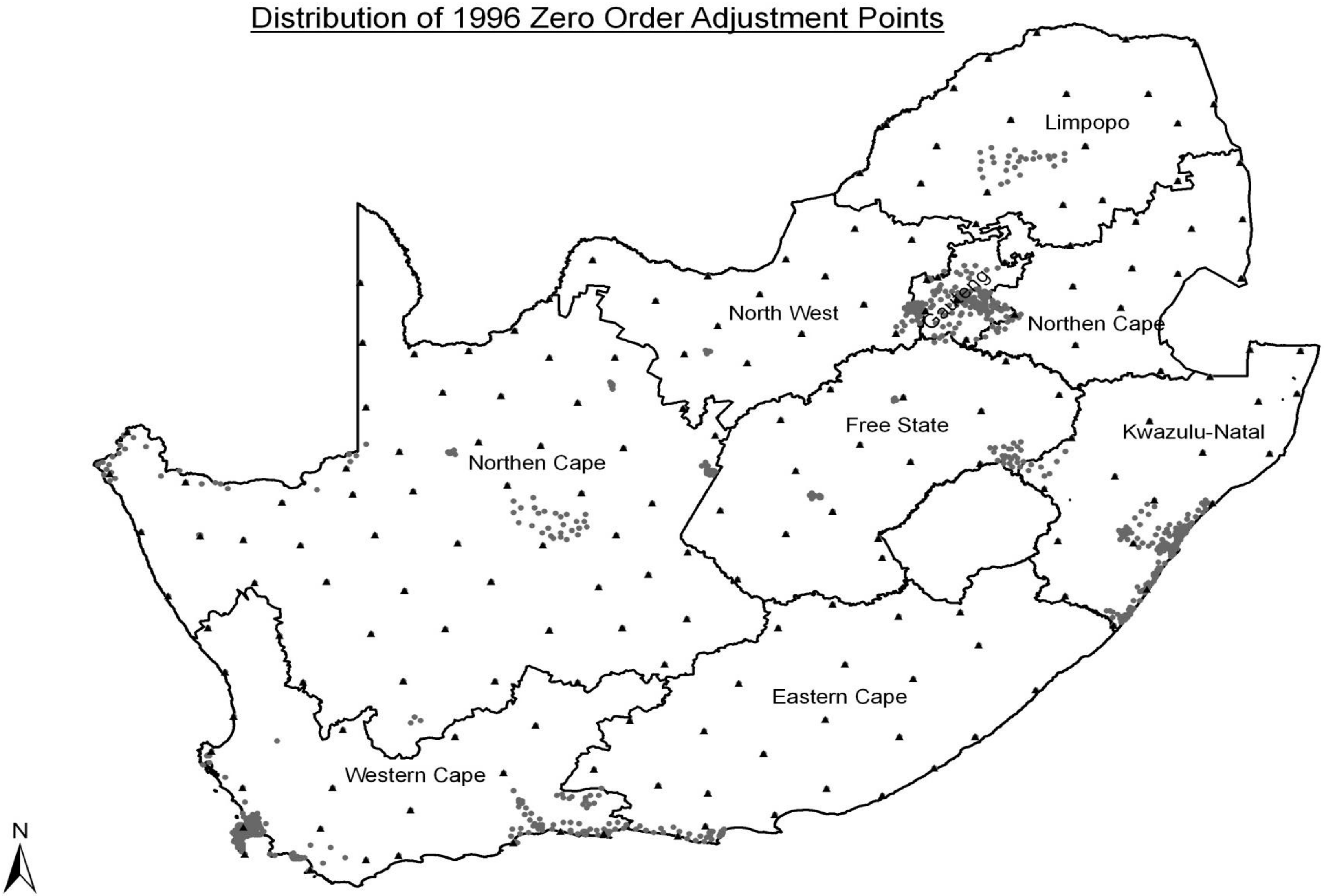
Stage 1: 1996 Zero Order Network



- Hartebeesthoek94 not the same as WGS84 RF
  Break
- SESSION TO COMMENCE at 13: 20

- ITRF (XXX) WGS (GXXXX) – Hartebeesthoek94

- All data must be in WGS84

Realisation of Hartebeesthoek94

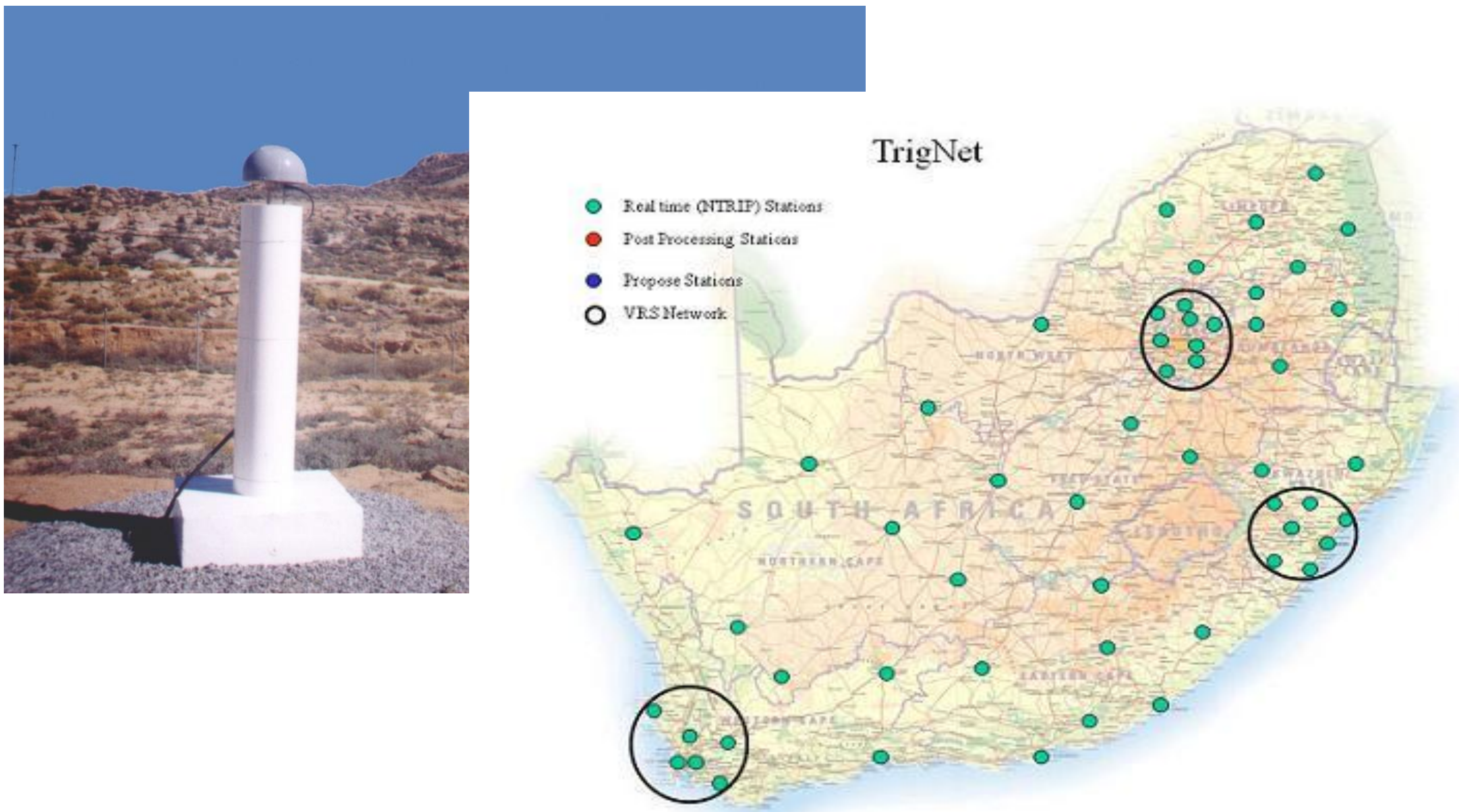
- 29 000 Trigonometrical Beacons

- 24 000 accessible Town Survey Marks

- 62 Permanent GNSS reference stations.

1. National Control Survey Network also realized by Active Network

- Visit www.trignet.co.za for site information



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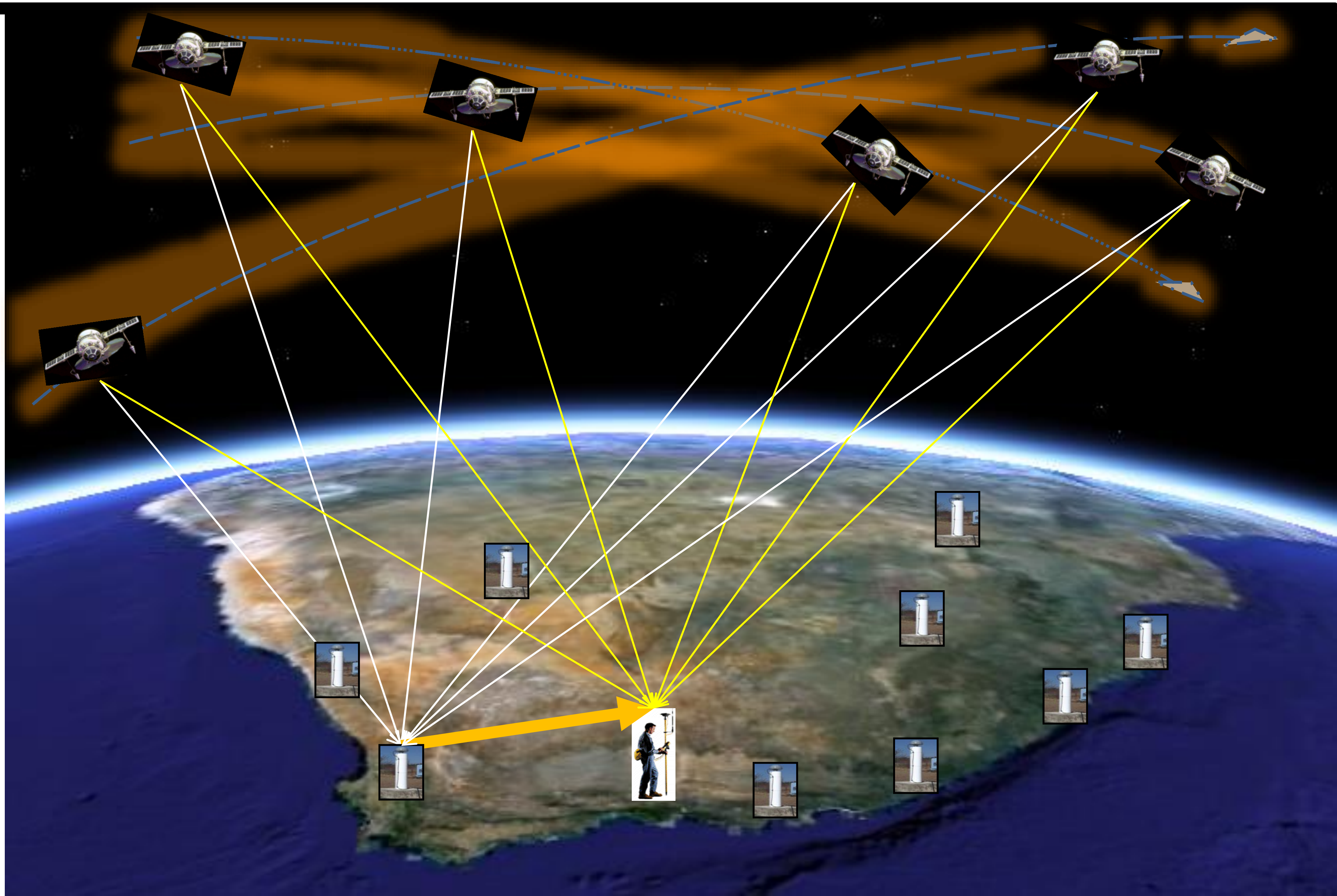
1. National Control Survey Network (TrigNet)



Hartebeesthoek94 Accuracy

- Hartebeesthoek94 accuracy about 10cm over 1000km = roughly 100ppb or 0.1ppm
- Massive improvement over old Cape Datum which was 10m over 1000km = 10ppm (100x improvement).
- Not Good enough for precise geophysical, scientific applications and VRS.

TrigNet and Hartebeesthoek94

- TrigNet and Hartebeesthoek94
  - Initially all TrigNet co-ordinates referred to Hartebeesthoek94
  - Hart94 co-ordinates derived from survey using local TSM and Trig
  - Adequate while only providing post processing services although some discrepancies were noted when working over long distances
  - Real time services required far more consistency within TrigNet

TrigNet & later realizations of ITRF

- To achieve greater consistency within TrigNet and to align the co-ordinates with GPS precise final orbits, TrigNet was computed on ITRF 2005 (2007)
- As result distance (baseline) misclosures within TrigNet changed from about 0.10m to less than 0.01m
- In 2010 (ITRF 2005), 2012 and 2014 recalculations were done on the then latest realization of ITRF viz ITRF 2008. Latest is ITRF 2014 epoch 2018.18
- TrigNet co-ordinates to be recalculated and updated periodically

ITRF 2014 & Hartebeesthoek94

Differences between:

ITRF 2014 (epoch 2014.02)

and

Hart94 (ITRF91 epoch 1994.0)

(NB Gauss Conform "Lo co-ordinates)"

ITRF 2014 - Hart 94		
Station	**dy**	**dx**
ANTH	-0.120	-0.462
BENI	-0.303	-0.425
BETH	-0.219	-0.450
BFTN	-0.069	-0.425
BISO	-0.221	-0.560
BRIT	-0.277	-0.421
BRNK	-0.283	-0.379
BWES	-0.179	-0.501
CALV	-0.288	-0.512
-		
-		
Mean	-0.277	-0.500
Std Dev	0.096	0.061
Max	-0.089	-0.361
Min	-0.386	-0.670
Max-Min	0.297	0.309
Vector	~0.64	~238

A. Datums and Ellipsoids in Southern Africa

Datum	Ellipsoid	a	b	Unit	Used
Tete, Observatoria and Madzansua	Clarke 1866	6378206.4000	6356584.4670	International meters	Mozambique
Campo de Aviaco	Clarke (1880)	6378249.1450	6356514.8700	International meters	Angola
Arc 1950	Mod. Clarke 1880	6378249.1450	6356514.9670	International meters	Botswana, Zimbabwe, Lesotho, Swaziland
Swarzeck	Bessel	6377397.1550	6356078.9630	German Legal meters	Namibia
Hartebeesthoek94	WGS 84	6378137.0000	6356752.3140	International meters	RSA

The Cape Datum

- Prior to 1 January 1999
- Non-geocentric
- Modified Clarke 1880 ellipsoid
- Multiple adjustments with coordinates varying tens of meters relative to final adjustment.
- Origin point at Buffelsfontein, near Port Elizabeth
- Established using traditional surveying techniques (Triangulation, trilateration)
- Flaws and distortions - easily detectable using modern techniques such as GNSS

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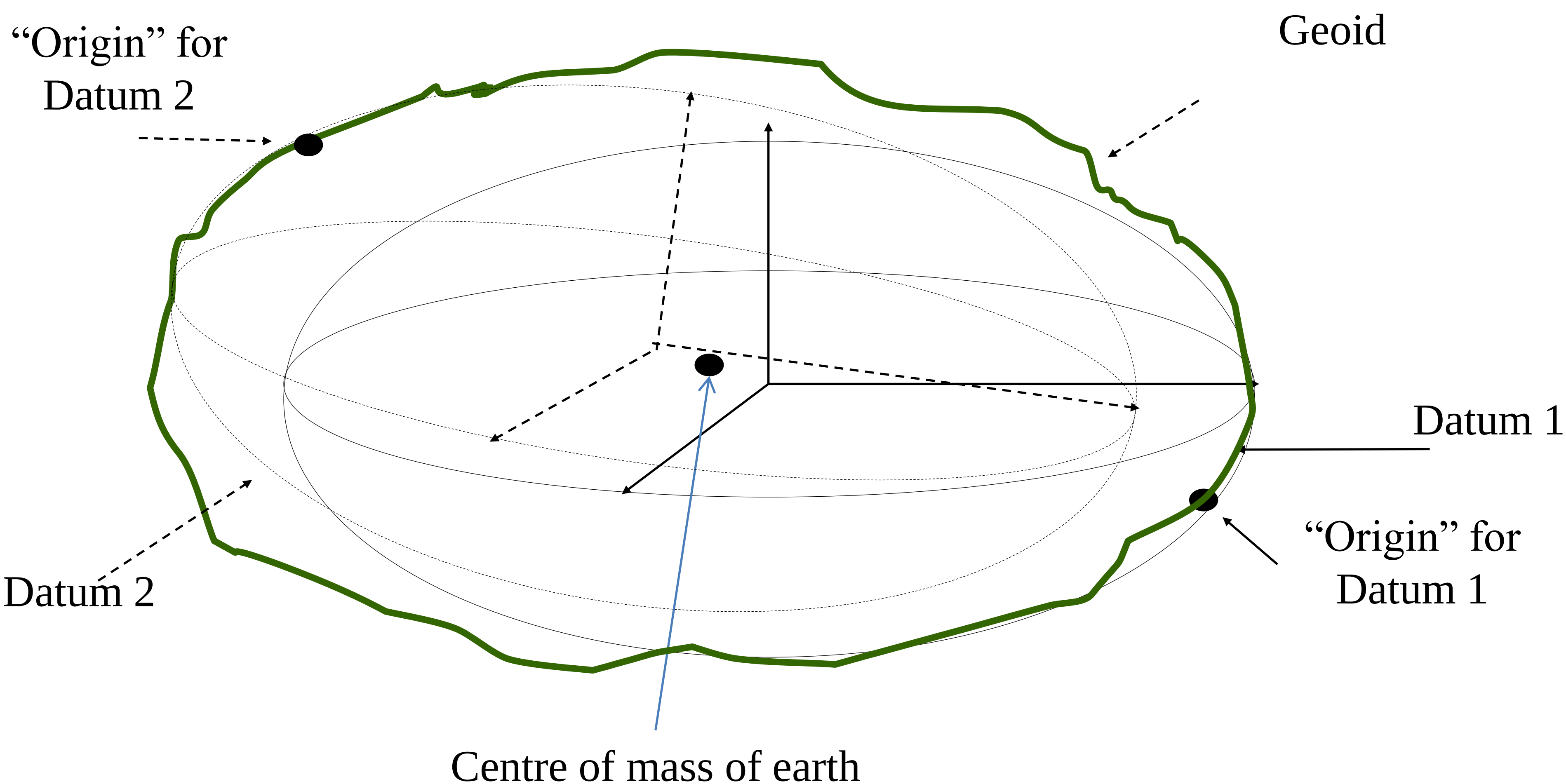
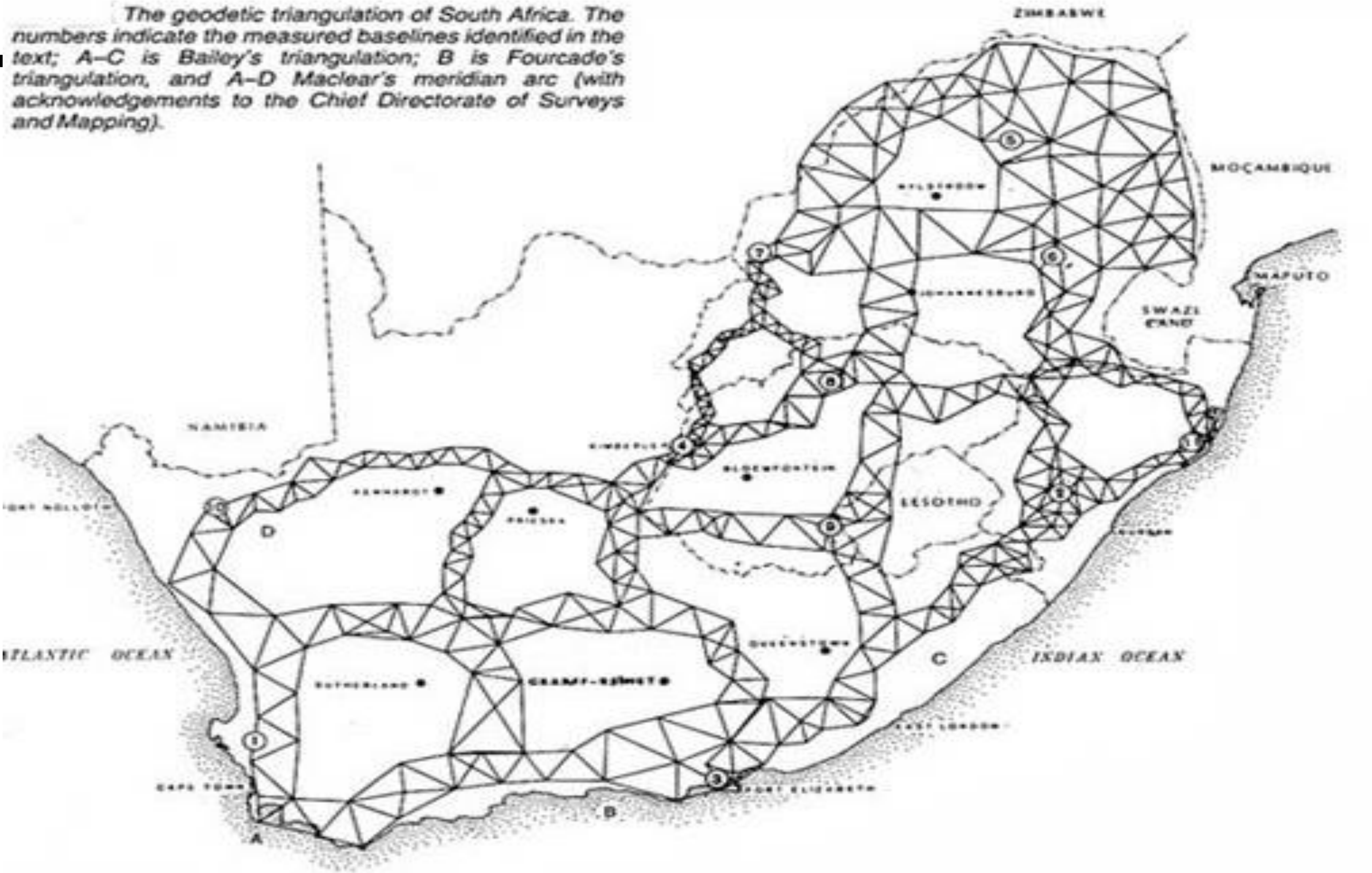
Non Geo-centric Local Datums



Cape Datum

- Modified Clarke 1880.
- The initial point = Buffelsfontein trigonometrical beacon, near Port Elizabeth.
- The orientation and scale characteristics were defined by periodic astronomic azimuth and base line measurements.

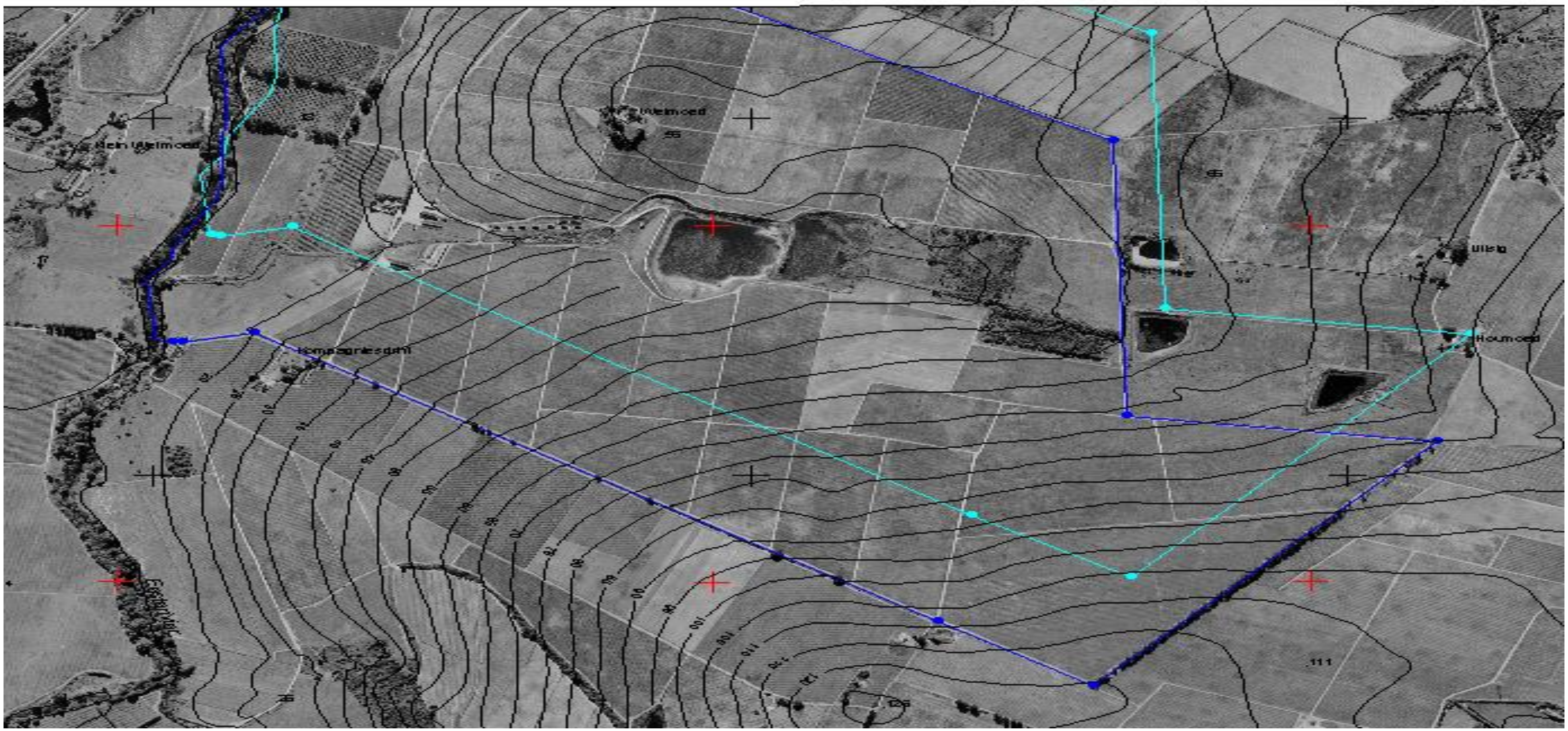


The geodetic triangulation of South Africa. The numbers indicate the measured baselines identified in the text; A–C is Bailey's triangulation; B is Fourcade's triangulation, and A–D Maclear's meridian arc (with acknowledgements to the Chief Directorate of Surveys and Mapping).

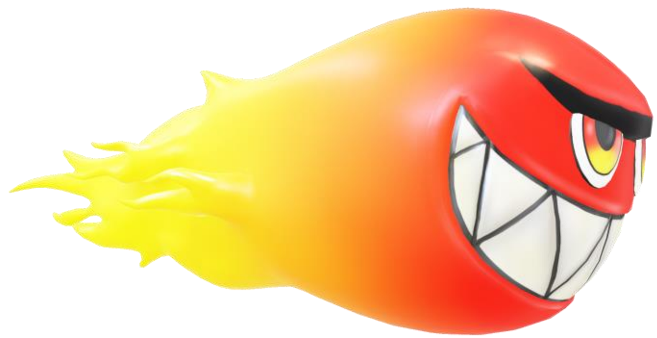
Cape Datum & Hartebeesthoek94

Shift for degree square 3418

△y: 63m ; △x: 300m

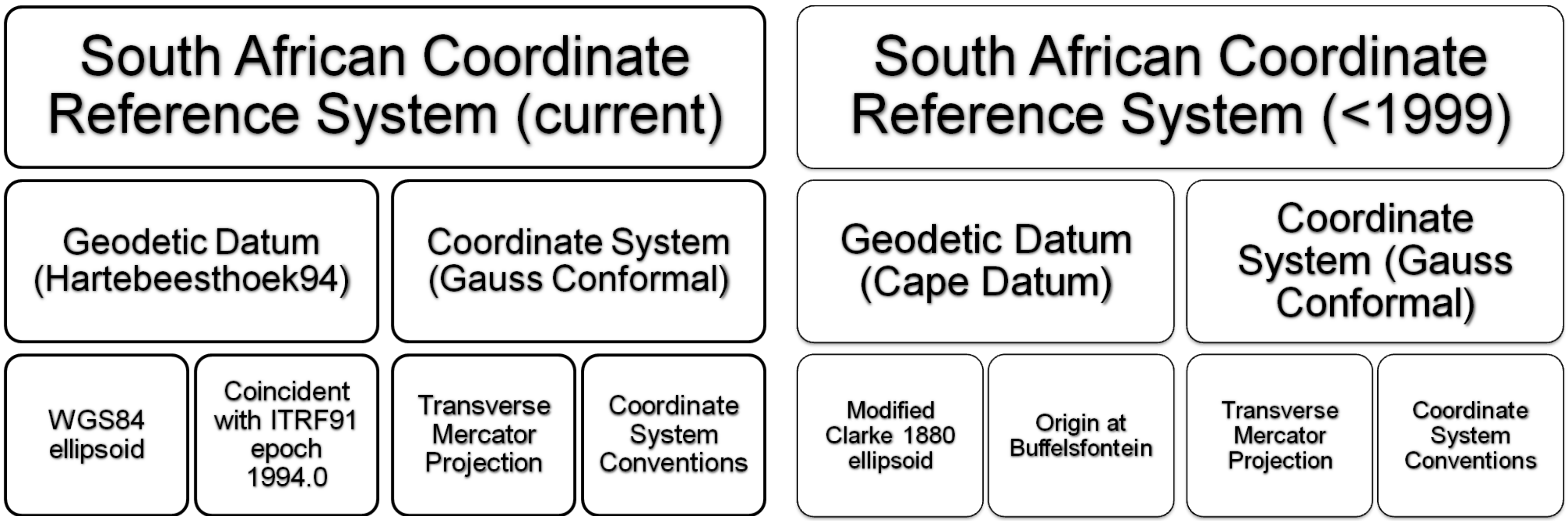


WGS84



E: THE SOUTH AFRICAN COORDINATE REFERENCE SYSTEM

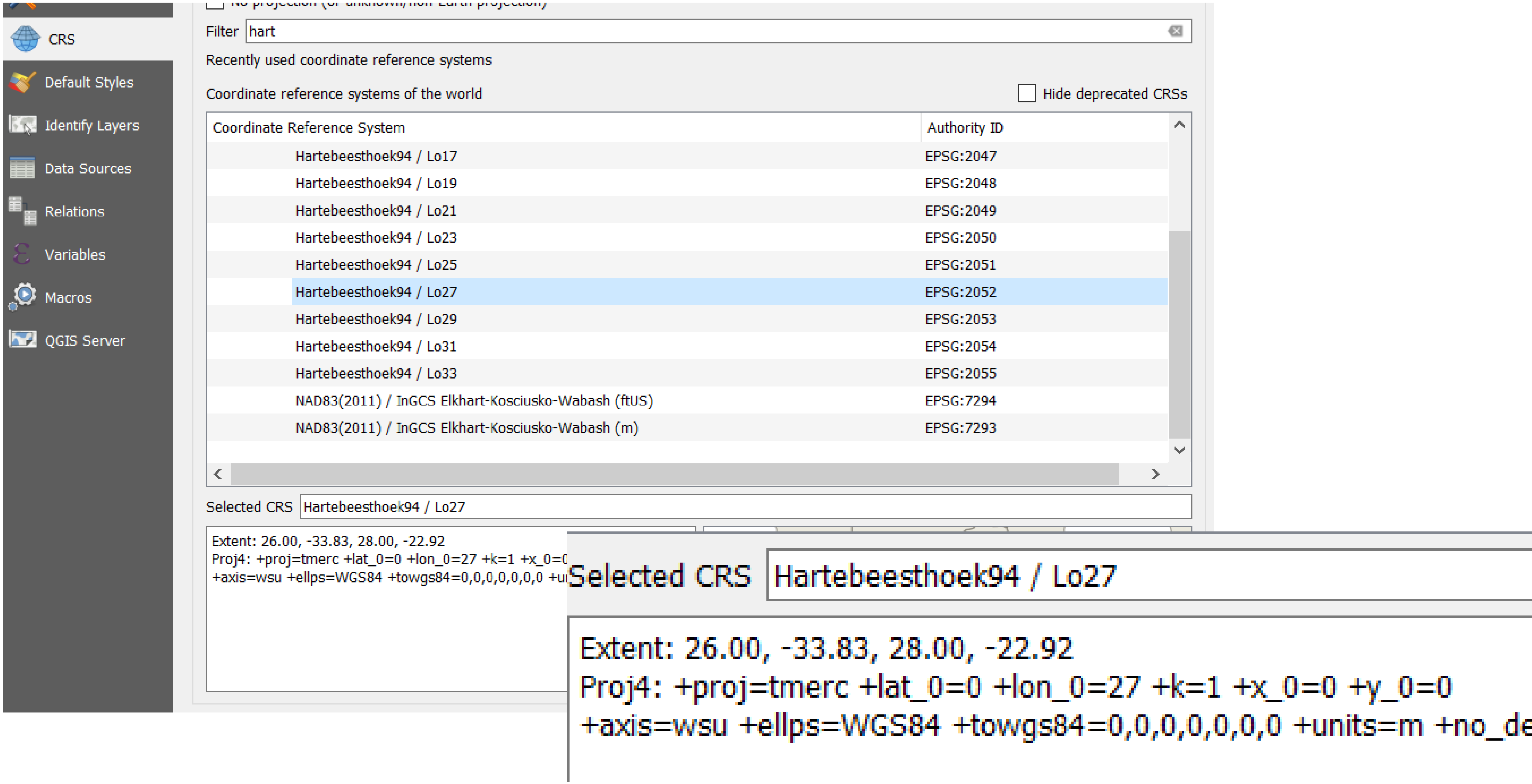
THE SA COORDINATE REFERENCE SYSTEM



Current SACRS definition

SACRS definition prior to January 1999

Datum definition in GIS CRS

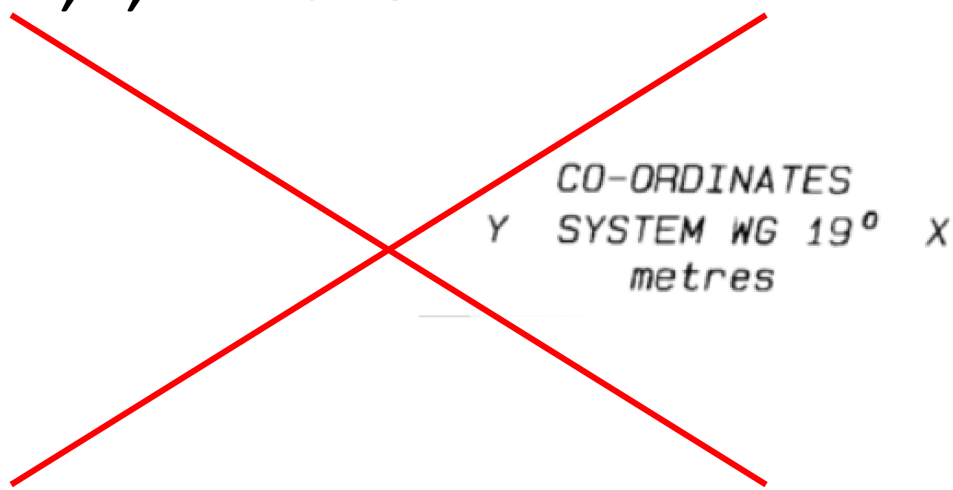


Lesson

- Westings, Southings, Orthometric Height
- Hartebeesthoek94 / Lo19
- y,x,H or y,x,h (ellipsoidal)

NOT

Y,X,Z WG19



SA Land Levelling Datum (SALLD)

- Reference surface: Adopted mean sea level at Cape Town (referenced to BM 1).
- Origin: constrained to mean sea level as determined from average tidal observations at Cape Town harbour in 1900 and 1907.
- Precise levelling commenced in 1904 and the first provisional adjustment between Cape Town, Pretoria and Durban occurred in 1943.
- From time to time, as the levelling progressed, provisional heights of bench marks were derived in a number of separate stages. Not the result of a simultaneous adjustment of the whole primary network.

Realisation of LLD

- The LLD is realised by:
- Numerous precisely levelled bench marks,
- ± 20 000 Town survey marks (> unofficial) ,
- Approximately 29 000 Trigonometrical beacons

Challenges NCSS

- Only 8000 of the trig beacons are maintained,
- Tower beacons possible hazard
- Municipalities not aware of legal obligation to install and maintain TSM schemes.
- Reduces cost of relocation and improves accuracy.
- No benchmarks since 1980's, vast stretches destroyed during road widening.

National Control Survey Network (Active)

- Trignet operates in ITRF2014 reference frame and not Hartebeesthoek94 (ITRF91)
- These days many drones operators use the PPP service which produces results in ITRF2014 and ITRF2020.
- Users will have to calibrate (apply transformation)

Why GGRF

- Geodesy: Quantification of Earth changes in space and time, expressed in (related to) a Global Geodetic Reference Frame (GGRF):
  - Sea Level variations in space and time
  - Tectonic Motion & crustal deformation
  - Dislocations due to Earthquakes
  - Tsunamis and Natural Hazards, rescue and safety of life
  - Positioning, locations & navigations (ocean, land, air & space)
  - National territory & land managements, precision agriculture

National Control Survey System

- Defined Coordinate Reference System:
  - Hartebeesthoek94: geodetic datum for coordinates (horizontal) positioning
    - **Note Hartebeesthoek94 ≠ WGS84**
  - South African Gauss Conformal Coordinate System
- SA Land Levelling Datum (heights)
  - Associated SAGEOID2010

Obligations to connect to NCSS

- The Land Survey Act (Regulations) requires all cadastral surveys to be connected to the NCSS.
- Indirectly most geospatial data in South Africa connected to NCSS. … or NOT
- All registered real rights (dimensions, angles and areas in NCSS).
- Standard for NCSS available on https://ngi.dalrrd.gov.za/index.php/technical-information/standards-menu

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UN resolution – Global Geodetic Reference Frame and the development of a Roadmap

Adopted by the General Assembly on 26 February 2015

UN resolution – Global Geodetic Reference Frame and the development of a Roadmap

- A unique opportunity for geodesy "The momentum the adoption of the UN resolution has created will position the global geodetic community well for the complex task ahead, developing a roadmap for GGRF enhancement."
    - Gary Johnston, co-chair UN-GGIM/GGRF Working Group

Future Plans

- Develop roadmap for Global Geodetic Reference Frame implementation
- Modernise geodetic datum to align to a newer realisation of ITRF (ITRF2020) Collaborate towards having a single reference frame from Africa (AFREF)
- Improve SAGEOID further.
- Integrate TrigNet and neighbouring CORS into an interoperable network.

agriculture, land reform
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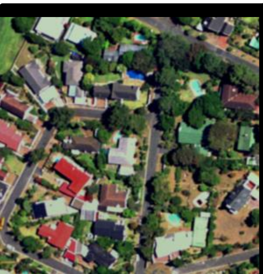

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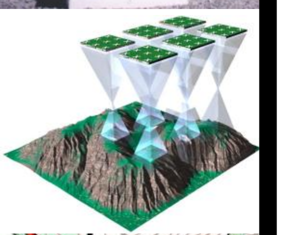

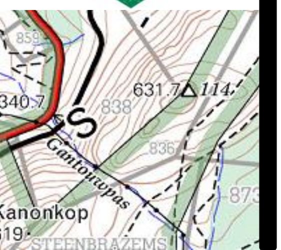

Thank You

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