# The South African Coordinate Reference System (Part 1)

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*This article will define the various elements of the South African Coordinate Reference System (SACRS) in detail and, in particular, distinguish between a coordinate system (projected) and a geodetic datum.*

The Chief Directorate: National Geo-spatial Information (CD:NGI) is mandated, in terms of section 3A(1)(d) of the Land Survey Act (Act 8 of 1997) to "establish and maintain a national control survey network". All cadastral parcels and surveys, as well as most engineering surveys and geographic information system (GIS) based projects are referenced to this national control survey network.

Numerous map projections and coordinate systems are used in South Africa, especially for mapping purposes. The official "issue" coordinates of the national control survey network (and hence most surveys) are reported in the Gauss Conform coordinate system referenced to the Hartebeesthoek94 datum.

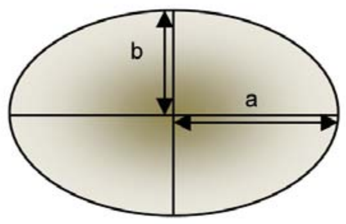
This coordinate system/geodetic datum combination is known as the South African Coordinate Reference System (SACRS). These two components are inseparable in the definition of SACRS and a different datum, for example, would constitute a different coordinate reference system.

There is a widely held misconception that the coordinate system changed in 1999, when in fact the geodetic datum changed, resulting in a new definition of the SACRS. This is perpetuated by the use of the words "Lo" and "WG" for coordinates referenced to Cape Datum and Hartebeesthoek94 respectively.

| Definitions* | |
|---|---|
| **Coordinate reference system** | Set of mathematical rules for specifying how coordinates are to be assigned to points that are related to the real world by a datum. |
| **Datum** | Parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system |
| **Easting (E)** | Distance in a coordinate system, eastwards (positive) and westwards (negative) from a north-south reference line. |
| **Ellipsoid** | Surface formed by the rotation of an ellipse about a main axis. |
| **Geodetic coordinate system** | Coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three-dimensional case) ellipsoidal height. |
| **Geodetic datum** | Datum describing the relationship of a coordinate system to the Earth.<br><br>A set of constants specifying the coordinate system used for geodetic control. A complete geodetic datum provides, as a minimum, definition for orientation, scale and dimensions for the reference ellipsoid. The concept is generally expanded to include the published coordinates of control stations within the system [1]. |
| **Map projection** | Coordinate conversion from a geodetic/ellipsoidal coordinate system to a plane. |
| **Northing (N)** | Distance in a coordinate system, northwards (positive) or southwards (negative) from an east-west reference line |
| **Projected coordinate system** | Two-dimensional coordinate system resulting from a map projection. |
| **Southing (x)** | Distance in a coordinate system, southwards (positive) and northwards (negative) from an east-west reference line. |
| **Vertical datum** | Datum describing the relation of gravity-related heights to the earth. In most cases the vertical datum will be related to a defined mean sea level. Ellipsoidal heights are treated as related to a three-dimensional ellipsoidal coordinate system referenced to a geodetic datum. |
| **Westing (y)** | Distance in a coordinate system, westwards (positive) and eastwards (negative) from a north-south reference line. |
| * All definitions from (ISO 19111:2007(E)), unless otherwise stated, | |

### Geodetic datum: Hartebeesthoek94

Prior to 1 January 1999, the coordinate reference system, used in South Africa as the foundation for all surveying, engineering and georeferenced projects and programmes, was referenced to the Cape Datum. This datum was referenced to the Modified Clarke 1880 ellipsoid and had its origin point at Buffelsfontein, near Port Elizabeth. The Cape Datum was based on the work of HM Astronomers: Sir Thomas Maclear, between 1833 and 1870, and Sir David Gill, between 1879 and 1907, whose




a = Semi major axis

b = Semi minor axis

f = Flattening = (a - b)/a

*Fig 1: Elements of an ellipsoid.*

initial geodetic objectives were to verify the size and shape of the earth in the southern hemisphere and later to provide geodetic control for topographic maps and navigation charts.

From these beginnings this initial network was extended to eventually cover the entire country and now comprises approximately 29 000 highly visible trigonometrical beacons on mountains, high buildings and water towers, as well as approximately 20 000 easily accessible town survey marks. As with other national control survey networks throughout the world, which were established using traditional surveying techniques, flaws and distortions in these networks have become easily detectable using modern positioning techniques such as the Global Positioning System (GPS). In addition to these flaws and distortions, most national geodetic networks do not have the centre of their reference ellipsoids co-incident with the centre of the Earth, thus making it applicable to the relevant geographic area only. The upgrading, recomputation and repositioning of the South African coordinate system has thus been driven by the advancement of modern positioning technologies and the globalisation of these techniques for navigation and surveying.

Since 1 January 1999, the official co-ordinate system for South Africa is based on the World Geodetic System 1984 ellipsoid, commonly known as WGS84, with the International Terrestrial Reference Frame 91 (ITRF91, epoch 1994.0) coordinates of the Hartebeesthoek Radio Astronomy Telescope used as the origin of this system. This system is known as the Hartebeesthoek94 Datum. At this stage all heights still remain referenced to mean sea level, as determined in Cape Town and verified at tide gauges in Port Elizabeth, East London and Durban.

*Reference surface*

Details of the reference surface are as follows:

- *Name:* World Geodetic System 1984 ellipsoid
- *Defining parameters:* (NIMA 2000)
  - Semi-major axis (a): 6378137.0 m
  - Ellipsoid flattening (f): 1/298.257223563

*Three-dimensional origin and orientation*

Details of the three-dimensional origin and orientation are as follows:

- *Name:* 30302S001 Hartebeesthoek VLBI 7232 (Hartebeesthoek Radio Astronomy Telescope, Pretoria)
- *Position:* International Terrestrial Frame 1991 (ITRF1991) epoch 1994.0 (0h00 SAST, 1 January 1994); [X=5085442.778, Y=2668263.699, Z=2768696.825]
- *Orientation:* Global Positioning System (GPS) broadcast ephemeris.
- *Scale:* 1 (no scale factor applied).

*Datum realisation*

The Hartebeesthoek94 datum is realised by:

- The approximately 57 000 precisely coordinated points in the passive (trigonometrical beacons and town survey mark).
- The network of permanent active GNSS reference stations (TrigNet).

*Hartebeesthoek94 and other ITRF realisations*

It is important to be aware of the following:

- The Earth is constantly changing shape. To be understood in context, when the motion of the Earth's crust is observed, it must be referenced. A Terrestrial Reference frame provides a set of coordinates of some points located on the Earth's surface. It can be used to measure plate tectonics, regional subsidence or loading and/or used to represent the Earth when measuring its rotation in space. This rotation is measured with respect to a frame tied to stellar objects, called a celestial reference frame.
- The International Earth Rotation and Reference Systems Service (IERS) was created in 1988 to establish and maintain a Celestial Reference Frame, the ICRF, and a Terrestrial Reference Frame, the ITRF. The Earth Orientation Parameters (EOPs) connect these two frames together. These frames provide a common reference to compare observations and results from different locations.
- The ITRF is constantly being updated. Eleven realisations of the ITRS were set up from 1988. The latest is the ITRF2008 (June 2010). All these realisations include station positions and velocities.
- Hartebeesthoek94 coordinates do not take cognisance of the velocities associated with stations contributing to ITRF91 and other realisations.
- The coordinates of the Hartebeesthoek94 datum are, therefore, locked in time at the given epoch, being 1994.0.
- Hartebeesthoek94 coordinates may be transformed to other realisations of ITRF by accessing the coordinates of fiducial ITRF stations and their associated velocity vectors, published by the IERS, at the epoch of interest.
- The extent of the difference between these two reference frames (in South Africa) can

| Point | Datum | Epoch | Time since | Position (Gauss Conform projection) | | | Central meridian |
|---|---|---|---|---|---|---|---|
| | | | Reference Epoch | y (westing) m | x (southing) m | Ellip. Height m | |
| 30302S001 Hartebeesthoek VLBI 7232 | ITRF91 | 1994.0 | 6.0 | -68684.896 | 2864799.998 | 1415.755 | 27 E° |
| | ITRF2005 | 2010.02 | 10.02 | -68685.114 | 2864799.625 | 1415.714 | 27 E° |
| ITRF91(epoch 1994.0) - ITRF2005 (epoch 2010.02) | | | | 0.218 | 0.373 | 0.041 | |

*Table 1: Coordinate difference of 30302S001 Hartebeesthoek VLBI 7232.*

be gauged by comparing the coordinates of the only fiducial station that has existed since the introduction of Hartebeesthoek94 (VLBI 7232), which yields the difference seen in Table 1.

- This transformation can also be achieved by applying a seven parameter Helmert transformation. See http://lareg.ensg.ign.fr/ITRF/.

*Hartebeesthoek94 and the WGS84 Reference Frame*

Key facts relating to Hatebeesthoek94 and the WGS84 Reference frame are outlined below:

- The World Geodetic System 1984 (WGS84) is a Conventional Terrestrial Reference System that includes in its definition a reference frame, a reference ellipsoid, a consistent set of fundamental constants, and an Earth Gravitational Model (EGM) with a related global geoid [4].
- The global geocentric reference frame and collection of models known as the World Geodetic System 1984 Reference Frame (WGS84RF) has evolved significantly since its creation in the mid-1980s. The WGS84RF has been redefined periodically.
- GPS satellite orbits and control segment positions operate in the WGS84RF.
- The WGS84RF should not be confused with the WGS84 ellipsoid.
- Since 1997, the WGS84RF has been maintained within 10 cm, and more recently within 5 cm of the current ITRF. The latest realisation of the WGS84RF is G1150 [5].
- Hence, the differences between Hartebeesthoek94 and the WGS84RF would be of the same magnitude as Hartebeesthoek94 and the current ITRF realisation (see "*Hartebeesthoek94 and other ITRF realisations*" above).

*Connecting/referencing to Hartebeesthoek94*

There are two methods for a point/data to be referenced to Hartebeesthoek94 datum:

- *Direct connection:* the position/s must be determined relative to any point in the national control survey network (horizontal), such as the 29 000 trigonometrical beacons and 20 000 town survey marks. This would constitute direct connection.
- *Indirect connection:* can be achieved by determining positions relative to points that have already been directly connected.

*Note:* When data is collected using autonomous GPS (which operates in the WGS84RF, and has a typical accuracy of 5 m), it can be deemed to be referenced to Hartebeesthoek94. This is because the uncertainty in position is an order of magnitude larger than the difference in position of a point in the respective datums.

When using real-time TrigNet services (which is referenced to ITRF2005), users will have to occupy points referenced to Hartebeesthoek94 to establish a localised relationship (calibration) between the respective datums. This is a requirement especially in cadastral surveys.

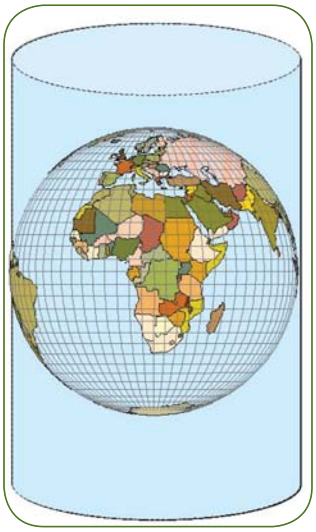


*Fig. 2: Normal aspect of the Cylindrical Projection, eg: Mercator.*

*Fig. 3: Transverse aspect of the Cylindrical Projection, eg: Transverse Mercator.*

| Name | Areas used | Central meridian(s) | Latitude of origin | CM Scale factor | Zone width | False easting at origin | False northing at origin |
|---|---|---|---|---|---|---|---|
| Transverse Mercator | Various, world wide | Various | Various | Various | Usually less than 6° | Various | Various |
| **Gauss Conform (Transverse Mercator south oriented)** | **South Africa** | **2° intervals E of 11°E** | **0°** | **1** | **2°** | **0 m** | **0 m** |
| UTM North hemisphere | Worldwide | 6° intervals E & W of 3° E & W | Always 0° | Always 0.9996 | Always 6° | 500 000 m | 0 m |
| UTM South hemisphere | Worldwide | 6° intervals E & W of 3° E & W | Always 0° | Always 0.9996 | Always 6° | 500 000 m | 10 000 000 m |
| Gauss-Kruger | Former USSR, Germany, S. America | Various, according to area of cover | Usually 0° | Usually 1.000000 | Usually less than 6°, often less than 4° | Various but often 500 000 prefixed by zone number | Various |

*Table 2 : Different forms of the Transverse Mercator Projection.*

**The Transverse Mercator projection**

Johann Heinrich Lambert was a German/French mathematician and scientist. His mathematics was considered revolutionary for its time and is still considered important today. In 1772 he released both his Conformal Conic projection and the Transverse Mercator projection. The Transverse Mercator projection is the 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 (see Figs. 2 and 3).

The Transverse Mercator projection, in its various forms, is the most widely used projected coordinate system for world topographical and offshore mapping. All versions (e.g. Gauss Conform, Gauss Kruger, and Universal Transverse Mercator) have the same basic characteristics and formulas.

The differences which distinguish the different forms of the projection, and which are applied in different countries arise from variations in the choice of the coordinate transformation parameters, namely the latitude of the origin, the longitude of the origin (central meridian), the scale factor at the origin (on the central meridian), and the values of false easting and false northing, which embody the units of measurement, given to the origin. Additionally there are variations in the width of the longitudinal zones for the projections used in different territories.

Table 2 indicates the variations in the projection parameters which distinguish the different forms of the Transverse Mercator projection:

Part 2 of this article will focus on the Gauss Conform Coordinate System, projection formulae and the South Africa Coordinate Reference System. It will be published in the Jan/Feb 2012 edition of *PositionIT.*

**References**

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