# THE IMPLEMENTATION OF THE HARTEBEESTHOEK94 CO-ORDINATE SYSTEM IN SOUTH AFRICA

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## ABSTRACT :

The Hartebeesthoek94 co-ordinate system became the official system in South Africa on 1 January 1999 and supersceded the previous Cape Datum system of co-ordinates. The new system is based on the ITRF91 (epoch 1994.0) co-ordinates for the Hartebeesthoek Radio Astronomy Observatory (HartRAO) and uses the WGS84 reference system.

This paper gives a brief background to the reasons for the conversion and the methods used to achieve the new system. The differences between the old and the new co-ordinate systems and methods to convert between the two are suggested.

## BACKGROUND

The geodetic network which was used as the basis for all surveying, mapping, navigation and other related aplications up until the end of 1998, was based primarily on work commenced during the middle of the 19$^{th}$ century by Sir Thomas Maclear using the techniques of baseline measurement and extension, triangulation and positional astronomy. Over a period of nearly 150 years the network was extended and broken down to the extent where there are very few parts of the country where the separation between the control points exceeds 20 km and, in the case of trigonometrical beacons, is generally 5 kms. Today there are nearly 29 000 trigonometrical beacons throughout the country and over 24 000 fourth order town survey marks in about 120 towns and cities all of which have been computed on the same basic geodetic network.

Almost every surveying or mapping project carried out in South Africa is based on the national control survey network and in fact all cadastral surveys are required in terms of legislation since 1927 to be connected to the network. It is, therefore, relatively easy to create geo-spatially referenced information databases based on one reference framework from a variety of survey projects and sources. This would not be the case where no integrated national control survey network existed but rather a haphazard network of “local” systems.

## SATELLITE BASED POSITIONING TECHNIQUES

Up until about the late 1950’s all positioning and computation was done using optomechanical theodolites, tapes and wires and trigonometrical tables and mechanical calculators or log tables. These devices and the techniques and methods used to create a geodetic network were adequate for most surveying and mapping applications at that time. Because of the limitations of computing tools and methods, the networks were computed and adjusted in a patchwise fashion and with the limitation of widely spaced absolute control to contain the adjustment, errors were carried forward from one “patch” to the next.

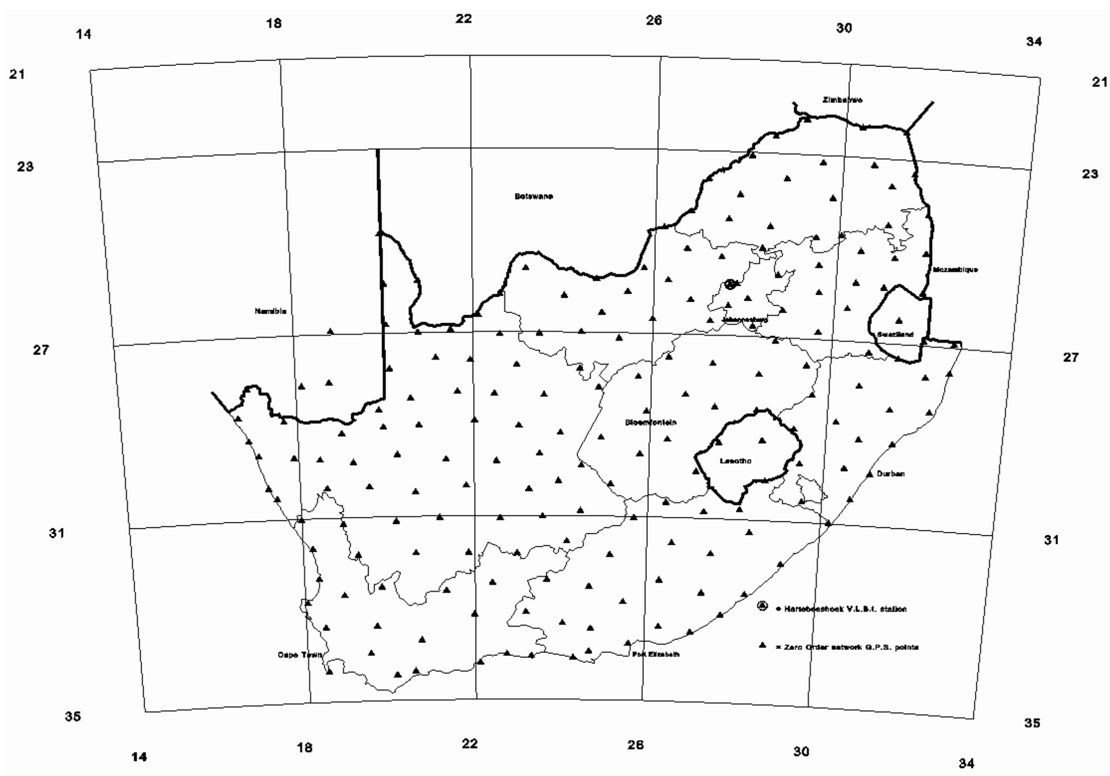
The introduction of electronic distance measuring equipment in the early 1960’s was the first of the electronic age technologies which was able to identify and rectify flaws the geodetic networks directly since distances could be easily measured between control points. At the same time, electronic computers made it possible to compute and rigorously adjust large networks. It was at this stage that projects were initiated to upgrade and improve the national control survey networks in South Africa and which made extensive use of EDM for traversing and triangulation. The problem of the lack of widely spaced high relative accuracy absolute control on which to base the computation and adjustment remained a thorn in the side of the geodisist.

In the late 1970’s the Chief Directorate of Surveys and Mapping made use of satellite based positioning techniques for geodetic applications for the first time when five Doppler satellite receivers were purchased. These receivers were used to determine the position of 23 points of the geodetic network using translocation techniques. The points were spaced at approximately 300 km intervals and formed a uniform network with an estimated precision of 2 to 3 ppm covering the entire country. Although not significantly better than the estimated precision of the geodetic network, the problem of creating a widely spaced absolute or reference network had been solved to a certain degree.

The results of the survey could not be used to create a zero order network upon which to base a readjustment of the geodetic network primarily because of the wide spacing between Doppler positioned points (300 km) and the uncertainty of the behaviour of the network between these points network. The network of 23 points could, however, be used to identify areas of weakness or severe distortion in the geodetic network where scales as poor as 1:25000 were detected in the western and north western areas of the country.

Perhaps the most significant influence on geodesy and surveying in recent times has been the introduction of the Global Positioning System (GPS). Surveyors using GPS are now even better equipped to detect flaws in traditionally established geodetic networks. At the same time national survey organizations responsible for the establishment and maintenance of these networks are equally better equipped to fulfill these functions. Additionally, the techniques of Satellite Laser Ranging (SLR) and Very Long Baseline Interferometer (VLBI) are available to the geodesist as alternative techniques of positioning at a continental or intercontinental level.

The Chief Directorate of Surveys and Mapping purchased six dual frequency geodetic GPS receivers in 1991. After extensive trials and testing to determine the most appropriate method in which to use the receivers to improve and rectify the national geodetic network, a network of a little more than 200 geodetic stations was selected with an approximate spacing of about 100 km between stations (Fig 1). All stations in the network were existing geodetic stations which were connected to surrounding network points by means of traditional triangulation methods. This entire GPS network was adjusted in two stages – firstly each session of six points was adjusted as a group and then later combined and all sessions adjusted by allowing each session to shift in X, Y and Z but retaining the relativity between points in each session. The final adjusted network of GPS points has become known as the “zero order” network. It has been estimated that the precision of a single 100 km baseline is better than 0,5 ppm in horizontal position (Newling 1993 a).




South African Zero Order GPS Network
Fig. 1

## THE POSITIONING OF THE ZERO ORDER NETWORK

Apart from a comparison with the 23 Doppler derived positions, the absolute position of the zero order GPS network remained unresolved. The Hartebeesthoek Radio Astronomy Observatory (HartRAO) close to Johannesburg has participated in VLBI programmes for a number of years and is of strategic importance in these programmes in that the observatory is the only one of its kind in Africa and one of only a few in the Southern Hemisphere. It was decided, therefore, to use the ITRF co-ordinates of HartRAO as the datum for the zero order network which was connected to the observatory telescope via a high precision terrestrial survey, the results of which were later confirmed by GPS. At the time of computing the network the ITRF91 co-ordinates updated to epoch 1994.0 were the most recent available and have, therefore, been used to position the network. *(Newling 1993 a and b).*

The scale and orientation of the zero order network was verified in the latter half of 1994 when the Bundesampt fur Kartografie und Geodasie (BfKG) (formerly IfAG) determined the position of a point close to the VLBI antenna and another at the South African Astronomical Observatory (SAAO) at Sutherland using SLR techniques. Both sites were also connected to the zero order network and a comparison of the 1000 km GPS derived baseline and the SLR measurements indicate a difference of less than 0,06m in horizontal position and 0,44 m in height *(Pinker 1995).*

Similar differences have been determined using GPS measurements over a baseline length of 1 200 km between Cape Town and Hartebeesthoek during six hour measurement periods using the precise ephemeris *(Merry 1996).*

## THE HARTEBEESTHOEK 94 CO-ORDINATE SYSTEM

Having established a zero order GPS derived network with a high relative precision within itself as well as having a high relative position globally it was decided to use the network to refine the South African co-ordinate system. It was clearly impractical and uneconomical to occupy every single trigonometrical beacon (29 000) using GPS. A project had been underway for a number of years prior to the commencement of the GPS programme to capture all the available terrestrial observations at each point in the geodetic network. Using this project and after all observation data had been captured and verified, a recomputation and rigorous readjustment of the entire network was carried out using the zero order network plus additional available GPS derived positions as a foundation. The readjustment of each of the 119 town survey schemes was treated separately but based on the co-ordinates of the readjusted first to third order network.

The co-ordinates of the entire geodetic network of 29 000 beacons and approximately 24 000 town survey marks are now based on the ITRF94 (epoch 1994.0) co-ordinates of HartRAO and the elements of the WGS84 reference system. The same co-ordinate projection system i.e. the Gauss Conform Projection using two degree longitude belts as used on the old Cape Datum (Clarke 1880) system have been retained with the origin of each belt at the intersection of the central meridian and the equation.

On the 1st January 1999, the Hartebeesthoek94 co-ordinate system as very briefly described above became the new official co-ordinate system for South Africa.

## THE RELATIONSHIP BETWEEN THE CAPE DATUM AND HARTEBEESTHOEK CO-ORDINATE SYSTEMS

In general terms, the differences between the Cape Datum and Hartebeesthoek 94 range between 20 m and 90 m for Y co-ordinates (Westings) and 292 m and 300 m for X co-ordinates (Southings). Geographical co-ordinate differences range between 0,5 secs and 2,8 secs for longitude and latitude. The new grids and graticules have moved North and East relative to the Cape datum grids and graticules.

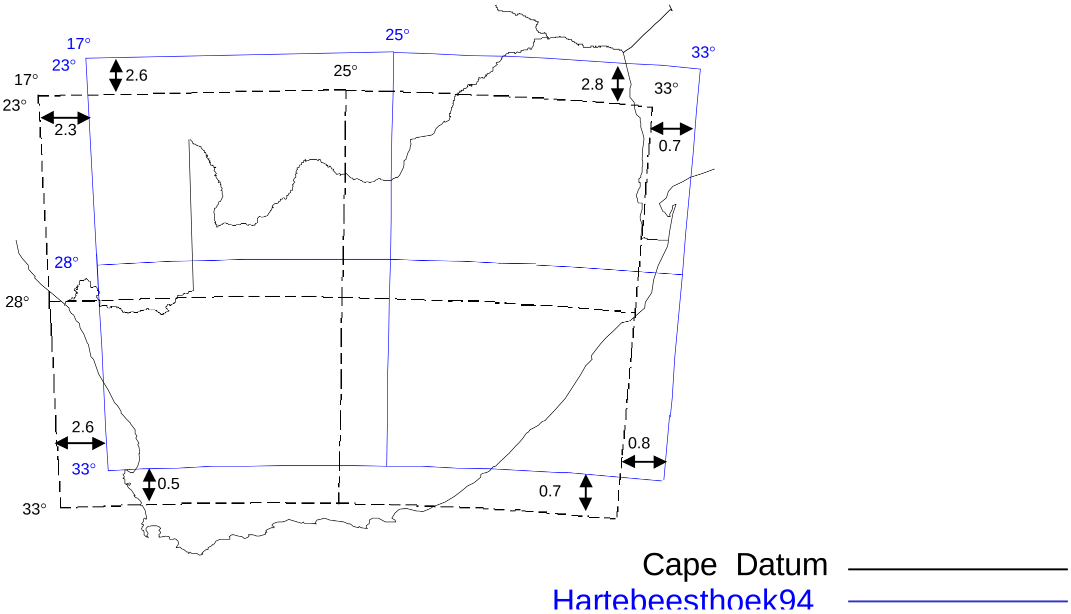



**Fig 2. Shift between Cape Datum and Hartebeesthoek94 co-ordinates in terms of geographical co-ordinates**

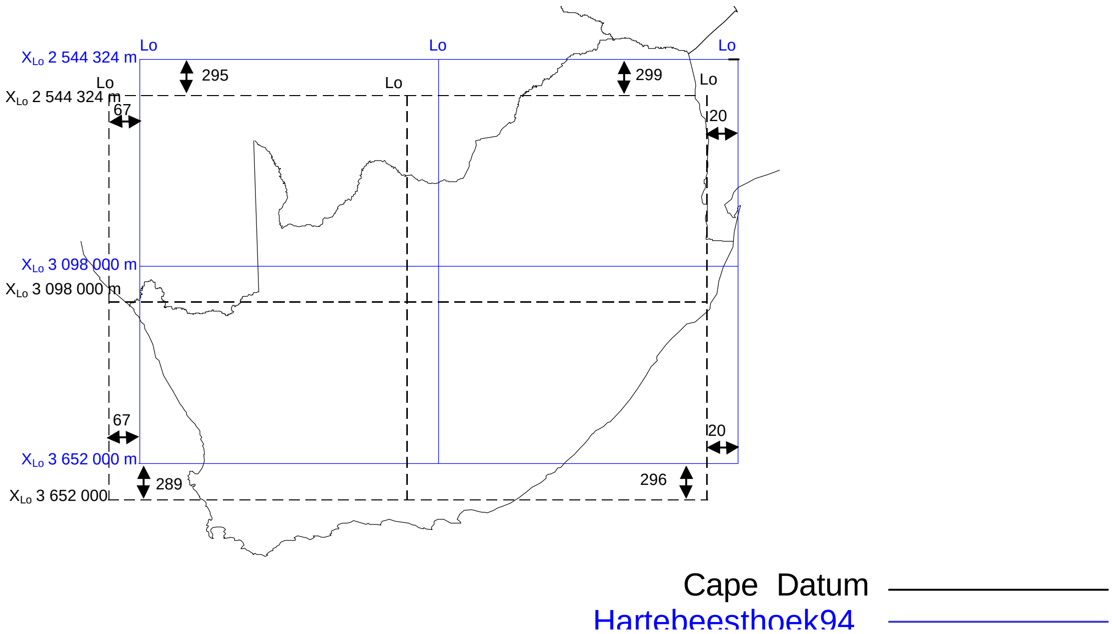



**Fig 3. Shift between Cape Datum and Hartebeesthoek94 co-ordinates in terms of Cartesian co-ordinates.**

These general shifts are not constant and at the submetre level are subject to local network distortions primarily in the old Cape datum system. A comparison of the residuals derived from a plain Helmert Transformation between the old and new systems for ¼ degree square blocks of co-ordinates indicates residuals exceeding 0,2 m can be found in about 14,5 % of these blocks. This includes a large area for which official Cape Datum co-ordinates were never finalised. Excluding this area, the number of ¼ square blocks with residuals exceeding 0,2 m amounts to approximately 7 % of the total area of the country.

In the case of high density town survey schemes the residuals are much lower. In a test case carried out in Port Elizabeth a comparison between transformed town survey mark co-ordinates and recomputed co-ordinates once again using a simple Helmert transformation between old and new trig points has shown differences very rarely exceeding 0,10 m and generally below 0,05 m.

It is felt that for the conversion of most GIS databases covering a ¼ degree square or larger, a simple Helmert transformation will be adequate to ensure a precision of within 0,2 m and for this purpose a set of transformation parameters has been generated by the Chief Directorate : Surveys and Mapping. For site or project surveys covering smaller areas and in which co-ordinates from the old and new system have to be used together, surveyors are advised to generate their own set of transformation parameters using the co-ordinates of trigonometric beacons as defined at the time of the old survey.

It should be pointed out here that over the years the Cape datum co-ordinates were refined and readjusted as additional observations and distance measurements became available with the result that some points may have a number of Cape datum co-ordinates which vary by as much as 1 m which were "issued" over the years. Surveyors wishing to convert databases within 0,1 m using a single set of parameters should, therefore, be aware of these variations of co-ordinates.

## THE BENEFITS OF THE CONVERSION TO HARTEBEESTHOEK 94 AND WGS84

The recomputation of the national geodetic network has been driven by the introduction of initially EDM and more recently GPS positioning technology for day to day surveying. The distortions which were present in the Cape Datum network became more and more apparent to users of this technology. In order to fit GPS based surveys into the old distorted co-ordinate system, the achievable accuracies of GPS were negated. Of prime benefit to the user has been the uniformity and near distortion-free quality of the recomputed network. This could have been achieved irrespective of the reference ellipsoid or datum which may have been chosen on which to base the computation. In the case of the Hartebeesthoek 94 co-ordinate system, the added bonus is that the WGS84 reference system has been used for the recomputation and that the system is well placed in the global sense through the ITRF co-ordinates of HartRAO thus making the system virtually compatible with the GPS reference frame.

In addition to the benefits which the South African surveyors will derive from the recomputed network, the potential to use the network as a foundation to create a uniform Southern African network is very real. Such a network would include Namibia, Botswana, Zimbabwe, Mozambique, Lesotho and Swaziland and would go a long way to simplify and build confidence in the planning and execution of large regional projects requiring a sound uniform geospatial reference system. Preliminary discussions and projects to realise this aim have been conducted with Namibia, Botswana and Zimbabwe. *(Wonnacott 1997)*.

## CONCLUSION

The recomputed Hartebeesthoek 94 co-ordinate system for South Africa has resulted in a uniform and near distortion free reference network which can be easily used with modern positioning technology. Being based on the ITRF91 (epoch 1994.0) co-ordinates for HartRAO, the system can easily be referred to later versions of ITRF co-ordinates.

Depending on the user requirements, most pre-1999 GIS databases can be converted reasonably easily to the Hartebeesthoek 94 co-ordinate system. The major problem with such conversions is the management of the conversion process.

## REFERENCES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