International Journal of Geosciences, 2016, 7, 631-636
Published Online May 2016 in SciRes. http://www.scirp.org/journal/ijg
http://dx.doi.org/10.4236/ijg.2016.75048

Geodetic Datum Transformation Parameters towards WGS84 Applicable to the 1/50k Topographical Map (1981) of Burundi

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Received 5 January 2016; accepted 14 May 2016; published 17 May 2016

Abstract

The knowledge of the geodetic reference datum of maps or data is required for their use in a GIS. Many older maps are lacking this information, making their use cumbersome. The availability of an aerial coverage at high resolution of Burundi and digital elevation model, based on a novel geodetic network, all calculated on the WGS84 datum, allows to calculate the datum applicable to older maps, for instance the regular 1/50k map of the country. The method, based on the difference in geocentric coordinates between points common to the two systems, yields: $\Delta x = -156.71 \pm 10.2$ m, .$\Delta y = -3.26 \pm 13.2$ m, .$\Delta z = -290.77 \pm 21.06$ m, well in keeping with older values proposed by the NGA.

Keywords

Geodesy, Cartography, Datum Calculation, Burundi

1. Introduction

Interchange and mutual comparison between geo-referenced data sets require the precise knowledge of both the cartographic and the geodetic systems on which they are based. The lack of this type of information is a major obstacle in the integration of information in geographic information system (GIS), precluding its analysis and hence the benefit of mutual comparisons and relationship. The broad (and fully justified) use of Google Earth imagery in surveying requires that external data are brought in the geodetic standard of Google Earth (namely: either geographic or UTM coordinates, with WGS84 as datum).

During the last fifty years, the east-central African republic of Burundi has benefited from systematic and detailed surveys in numerous fields as geophysics (ground or airborne), geology, agronomy/soil science, land-use,

How to cite this paper: Lavreau, J. (2016) Geodetic Datum Transformation Parameters towards WGS84 Applicable to the 1/50k Topographical Map (1981) of Burundi. *International Journal of Geosciences*, **7**, 631-636.
http://dx.doi.org/10.4236/ijg.2016.75048

biology, socio-economics, politics, resulting in maps (local, general), or database records. These data have been collected, and the maps produced using different standards as the latter have been changing with time and the habits of the authors.

The topographical map of Burundi at scale 1/50k [1], made available as from 1981 has been the base for a number of these surveys. Moreover, older surveys, based on maps of a lesser quality or simply older, have often been transferred onto the 1981 map (as for instance the geological maps [2]). The 1981 map is thus a milestone for a wide community of users.

The topographical map of Burundi at scale 1/50,000 in 38 sheets published in 1981 by the IGEBU was established using the Transverse Mercator projection (Central Meridian 30˚E/0˚N, Xo = 500.000 m, Yo = 10.000.000 m, f = not given, but probably 0.9999, as is the usual practice) and the Clarke 1880 modified ellipsoid [1], altitudes being given relatively to sea level (MSL).

The position of the reference geodetic points used for this map have not been published, nor the geodetic datum, *i.e.* the position and orientation of the ellipsoid used relatively to the mass center of the Earth. This latter information became indeed pertinent only after the emergence of satellite-based geodesy and the subsequent use of the mass center of the Earth as geometric center (as does datum WGS84). As long as this information is not available, the 1981 topographical map and other maps derived from it cannot be used in a GIS for comparison with data or maps based on another system.

Burundi is located in the domain of Arc 1950 geodetic network. The only indication published on relations between Arc 1950 and the WGS84 datum is a local datum ("Arc 1950-Burundi, ARF-H Code") based on 3 directly measured geodetic points, with the values Δx = −153 ± 20 m, .ΔY = −5 ± 20 m, .Δz = −292 ± 20 m (NGA 1991 in [3]. It is not known whether these translation parameters are specific to the 1981 map or if they are anterior.

The recent realization [4] of a digital air cover in natural colors with 0.5 m resolution, complemented by a DEM with 10 m resolution, based on the ellipsoid and WGS84 datum, but with a UTM projection (zone 35), ellipsoidal heights (h 1 in the table), tied to a novel geodetic network of 17 points, can provide an adequate estimate of the datum to attribute to the topographic map of 1981.

This information would allow the use the all-important 1981 map in a GIS and engage in comparisons with other geo-referenced data or maps using other datum.

2. Methodology

The determination of the transformation parameters required for passing from a projection using ellipsoid A to another projection using ellipsoid B necessitates the knowledge of not only the shape (length of axes) of ellipsoids A and B, but also the position of their center and angles of rotation around their 3 axes.

By making the simplifying assumption that the difference between the two ellipsoids (Clarke 1880 mod. and WGS84 in this case) results only from a translation (*i.e.* without rotations), this difference can be estimated from the difference in cartesian (=geocentric) *X*, *Y*, *Z* coordinates of a point common to the two standards and calculated in each of them (see [5] or [6]).

$$X = (N + h)\cos(\text{phi})\cos(\text{lambda})$$

$$Y = (N + h)\cos(\text{phi})\sin(\text{lambda})$$

$$Z = \left[N\left(1 - e^2\right) + h\right]\sin(\text{phi})$$

where

h: elevation above ellipsoid;

phi: latitude;

lambda: longitude;

e: eccentricity = $\left(a^2 - b^2\right)^{1/2} / a$;

a, *b*: semi-axes of the ellipsoid;

N: vertical curvature = $a\left[\left(1 - e^2\right)\sin^2(\text{phi})\right]^{-1/2}$.

In order to calculate *X*, *Y*, *Z*, we need, besides the shape of the ellipsoid (*a* and *b*, as above), the geographic coordinates (longitude, latitude) and elevation of the point. Usually, one makes use of geodetic points of the national geodetic network, of known (*i.e.* assumed) coordinates in this (old) system, and re-determines the position of the same points in the (new) WGS84-based system. This latter information is readily obtained from GPS measurements. The transformation parameters are obtained from the difference between the old and the new system, as shown below.

Because the (old) geodetic points are no longer visible in the field (nor displayed on the 1981 map), we will use this map itself instead of the geodetic points on which the map is based and compare featured elements of the map with the same objects on the WGS84 orthorectified imagery.

In the case of the 2013 imagery, the coordinates are derived readily from the image and associated DEM.

The 1981 topographic map, duly geo-referenced in its own system (see above), provides the required geographic (latitude/longitude) coordinates as well as elevation via the presence of leveled points (NB MSL altitude assimilated to the geoid: H in **Table 1**). These leveled points, frequently placed at road intersections, are practically the only ones unequivocally recognizable on both documents.

The topographic map at 1/50 k has a resolution that can be estimated to 5 m, thus differing by an order of magnitude of that of the 2013 image; the map is further symbolized widely, especially as regards buildings (it is quite obsolete in this respect); these are source of inaccuracy. It is also established from multiple aerial photographs, which is a possible source of local and random distortions.

Being random, these errors can be compensated by averaging a number of points spread over a large area (38 in this case). Several points were considered for each site, placed in the vicinity (more or less 1 km) of the 2013 geodetic points, in the hope of minimizing possible distortions in the 2013 image. It would obviously have been more practical to work directly with the 17 geodetic points created by the producer of the 2013 image (readily visible) if these items had been recognizable on the 1981 map, which is not the case.

Regarding the vertical datum, that is to say the distance between the ellipsoid and the geoid used in the 1981 map, it can be assumed that the 1981 geodesist wished to "paste" the reference ellipsoid to the geoid (as this is the norm, resulting in a local datum), and that this distance is consequently zero. We therefore calculate the geocentric coordinates considering that the altitude refers to the ellipsoid.

The arithmetic difference between the geocentric coordinates (x, y and z) in both systems will thus constitute a measure of the value of the parameter for passing from the ellipsoid used for the 1981 map and to the one used for the 2013 image.

The geocentric coordinates can be calculated, with a geodetic calculator, for instance [7] (as we did) or from the formulas above in a spread-sheet.

3. Step-by-Step Procedure

1) The reference map is geo-coded; the latitude, longitude of any point can then be read with an appropriate GIS;

2) A point is selected on the map, preferably a leveled point, thus providing the elevation. The latitude, longitude and elevation are now available;

3) The latitude, longitude of the same point is observed on the WGS84-referenced image and the elevation read on the associated digital elevation model;

4a) The geocentric coordinates of 2 are calculated, NB: The map elevation is considered as being relative to the ellipsoid, not MSL;

4b) The geocentric coordinates of 3 are calculated;

5) The differences in X, Y and Z between the two sets of coordinates are computed. These differences represent the transformation (translation) parameters we are searching for;

6) The working GIS in completed with a new reference system/datum (=shape of ellipsoid and translation parameters) proper to the map.

Steps 2 - 5 are repeated for a number of points, if desired, and the average value is provided to step 6. Step 3 observations can be provided by a Google Earth image.

4. Results

The procedure described above has been repeated for 38 points and the difference calculated. The average and standard deviation for the latter is (**Table 1**):

Table 1. Geographic and geocentric coordinates of points common to the 1981 map and the 2013 image, and difference between the geocentric coordinates. The latter (d), and their average (m), provide the requested transformation parameters.

Site	Image		DEM	WGS84			Carte (TM30, CL80,ARF−H)									
	Lat	Long	h	X	Y	Z	Lat	Long	H	x	y	z	d(X−x)	d(Y−y)	d(Z−z)	N
Karuzi	3 06 12.13S	30 09 59.05E	1601	5,507,693.0	3,201,232.0	−343,075.0	3 06 03,59S	30 09 56,27E	1610	5,507,854	3,201,226	−342,782	−161.0	6.0	−293.0	−9
Karuzi	3 06 02.03S	30 09 22.04E	1635	5,508,311.0	3,200,269.0	−342,767.0	3 05 53,78S	30 09 19,32E	1650	5,508,476	3,200,267	−342,483	−165.0	2.0	−284.0	−15
Muyinga	2 50 51.67S	30 20 15.23E	1731	5,499,484.1	3,218,477.6	−314,839.8	2 50 43,65S	30 20 12,27E	1745	5,499,650	3,218,469	−314,565	−165.9	8.6	−274.8	−14
Muyinga	2 50 15.43S	30 20 03.60E	1691	5,499,678.8	3,218,175.2	−313,725.7	2 50 06,81S	30 20 00,59E	1699	5,499,841	3,218,163	−313,433	−162.2	12.2	−292.7	−8
Kirundo	2 35 28.18S	30 04 54.09E	1479	5,514,749.0	3,194,435.0	−286,487.0	2 35 19,04S	30 04 51,71E	1482	5,514,897	3,194,435	−286,180	−148.0	0.0	−307.0	−3
Kirundo	2 35 16.38S	30 05 29.37E	1379	5,514,130.7	3,195,335.8	−286,120.3	2 35 07,06S	30 05 27,12E	1389	5,514,283	3,195,344	−285,808	−152.3	−8.2	−312.3	−10
Kirundo	2 36 16.44S	30 04 53.98E	1387	5,514,613.4	3,194,351.8	−287,963.9	2 36 07,57S	30 04 51,61E	1399	5,514,769	3,194,357	−287,666	−155.6	−5.2	−297.9	−12
Cankunzo	3 13 31.24S	30 33 10.55E	1600	5,485,329.3	3,237,935.3	−356,545.6	3 13 21,64S	30 33 07,74E	1618	5,485,501	3,237,936	−356,219	−171.7	−0.7	−326.6	−18
Cankunzo	3 12 57.77S	30 33 17.49E	1597	5,485,267.6	3,238,147.7	−355,518.7	3 12 49,16S	30 33 15,28E	1610	5,485,424	3,238,161	−355,223	−156.4	−13.3	−295.7	−13
Ruyigi	3 29 06.40S	30 14 46.12E	1601	5,501,136.1	3,207,671.7	−385,228.1	3 28 58,48S	30 14 43,69E	1620	5,501,301	3,207,681	−384,951	−164.9	−9.3	−277.1	−19
Ruyigi	3 28 42.18S	30 14 55.57E	1584	5,501,012.5	3,207,937.4	−384,503.4	3 28 32,99S	30 14 53,51E	1599	5,501,171	3,207,956	−384,168	−158.5	−18.6	−335.4	−15
Muramvya	3 16 02.89S	29 37 02.85E	1982	5,537,564.0	3,148,006.4	−361,219.2	3 15 54,47S	29 37 00,84E	1995	5,537,717	3,148,022	−360,928	−153.0	−15.6	−291.2	−13
Muramvya	3 15 57.05S	29 37 54.92E	1940	5,536,741.6	3,149,388.6	−361,037.6	3 15 48,45S	29 37 52,33E	1948	5,536,899	3,149,386	−360,741	−157.4	2.6	−296.6	−8
Muramvya	3 16 56.96S	29 36 47.23E	2016	5,537,749.4	3,147,557.0	−362,879.7	3 16 48,31S	29 36 45,17E	2025	5,537,900	3,147,569	−362,582	−150.6	−12.0	−297.7	−9
Mwaro	3 31 21.96S	29 42 21.55E	1910	5,531,178.5	3,155,694.4	−389,404.3	3 31 13,20S	29 42 19,15E	1916	5,531,333	3,155,697	−389,100	−154.5	−2.6	−304.3	−6
Mwaro	3 32 03.89S	29 42 01.24E	1942	5,531,448.0	3,155,126.3	−390,692.1	3 31 55,19S	29 41 59,27E	1948	5,531,596	3,155,141	−390,390	−148.0	−14.7	−302.1	−6
Mwaro	3 31 16.31S	29 41 17.73E	1965	5,532,211.5	3,154,015.4	−389,234.4	3 31 08,30S	29 41 15,85E	1967	5,532,354	3,154,029	−388,953	−142.5	−13.6	−281.4	−2
Bururi	3 55 52.41S	29 36 42.52E	2181	5,534,039.7	3,145,281.2	−434,507.7	3 55 43,53S	29 36 39,77E	2210	5,534,222	3,145,287	−434,198	−182.3	−5.8	−309.7	−29
Makamba	4 08 05.14S	29 48 16.55E	1463	5,521,429.8	3,162,741.0	−456,914.9	4 07 57,37S	29 48 13,85E	1470	5,521,591	3,162,737	−456,635	−161.2	4.0	−279.9	−7
Makamba	4 08 55.61S	29 47 06.07E	1436	5,522,389.6	3,160,785.2	−458,459.5	4 08 46,89S	29 47 03,51E	1442	5,522,550	3,160,786	−458,151	−160.4	−0.8	−308.5	−6
Rutana	3 56 55.88S	29 59 35.72E	1527	5,512,296.5	3,181,660.7	−436,408.3	3 56 47,75S	29 59 33,37E	1534	5,512,452	3,181,667	−436,119	−155.5	−6.3	−289.3	−7
Cibitoke	2 52 38.69S	29 06 57.24E	928	5,566,009.3	3,100,024.5	−318,083.5	2 52 30,17S	29 06 55,14E	938	5,566,160	3,100,034	−317,793	−150.7	−9.5	−290.5	−10
Cibitoke	2 53 18.49S	29 07 24.19E	923	5,565,546.1	3,100,719.3	−319,304.4	2 53 11,70S	29 07 23,28E	923	5,565,668	3,100,755	−319,067	−121.9	−35.7	−237.4	0
Bubanza	3 05 17.25S	29 23 32.02E	1053	5,550,046.0	3,126,298.4	−341,361.9	3 05 08,98S	29 23 28,81E	1062	5,550,213	3,126,279	−341,077	−167.0	19.4	−284.9	−9
Kayanza	2 55 12.65S	29 37 14.80E	1925	5,539,134.5	3,149,323.8	−322,857.9	2 55 03,73S	29 37 11,69E	1936	5,539,302	3,149,308	−322,555	−167.5	15.8	−302.9	−11
Kayanza	2 54 53.89S	29 37 05.50E	1935	5,539,310.7	3,149,093.5	−322,282.8	2 54 44,85S	29 37 02,61E	1943	5,539,472	3,149,083	−321,976	−161.3	10.5	−306.8	−8

Continued

Kayanza	2 54 38.06S	29 37 37.36E	1864	5,538,784.0	3,149,926.3	−321,793.4	2 54 28,47S	29 37 33,67E	1872	5,538,958	3,149,894	−321,470	−174.0	32.3	−323.4	−8
Kayanza	2 56 01.12S	29 37 57.43E	1940	5,538,430.4	3,150,438.4	−324,346.0	2 55 53,01S	29 37 54,89E	1944	5,538,582	3,150,434	−324,068	−151.6	4.4	−278.0	−4
Kayanza	2 54 11.32S	29 37 46.48E	1912	5,538,722.6	3,150,215.5	−320,975.3	2 54 01,41S	29 37 43,38E	1919	5,538,888	3,150,199	−320,642	−165.4	16.5	−333.3	−7
Ngozi	2 54 25.53S	29 49 22.01E	1833	5,527,980.9	3,168,824.0	−321,407.4	2 54 17,22S	29 49 19,67E	1843	5,528,135	3,168,829	−321,123	−154.1	−5.0	−284.4	−10
Ngozi	2 54 22.69S	29 50 29.88E	1723	5,526,846.5	3,170,590.3	−321,314.7	2 54 14,22S	29 50 27,67E	1730	5,526,996	3,170,597	−321,026	−149.5	−6.7	−288.7	−7
Gitega	3 25 42.04S	29 55 29.41E	1680	5,519,434.2	3,176,999.9	−378,965.5	3 25 34,11S	29 55 27,52E	1686	5,519,579	3,177,016	−378,688	−144.8	−16.1	−277.5	−6
Gitega	3 26 00.77S	29 55 08.62E	1604	5,519,658.8	3,176,388.5	−379,535.4	3 25 53,19S	29 55 06,47E	1611	5,519,808	3,176,398	−379,268	−149.2	−9.5	−267.4	−7
Gitega	3 24 52.04S	29 56 04.18E	1659	5,518,959.9	3,177,965.5	−377,430.8	3 24 44,55S	29 56 02,51E	1671	5,519,106	3,177,990	−377,167	−146.1	−24.5	−263.8	−12
Gitega	3 26 28.07S	29 56 09.20E	1681	5,518,748.7	3,178,022.8	−380,377.3	3 26 20,37S	29 56 07,45E	1701	5,518,903	3,178,049	−380,107	−154.3	−26.2	−270.3	−20
Bujumbura	3 19 11.70S	29 19 17.70E	773	5,552,403.5	3,118,614.4	−366,940.9	3 19 04,17S	29 19 14,85E	785	5,552,567	3,118,605	−366,677	−163.5	9.4	−263.9	−12
Bujumbura	3 19 37.82S	29 19 56.96E	771	5,551,767.5	3,119,647.4	−367,741.8	3 19 30,24S	29 19 54,57E	780	5,551,922	3,119,649	−367,476	−154.5	−1.6	−265.8	−9
Bujumbura	3 18 46.24S	29 19 38.72E	772	5,552,124.2	3,119,201.8	−366,160.0	3 18 39,06S	29 19 36,48E	782	5,552,277	3,119,208	−365,907	−152.8	−6.2	−253.0	−10
												m =	−156.71	−3.26	−290.77	−9.97
												s =	10.20	13.30	21.06	5.33

$$\Delta x = -156.71 \pm 10.2 \text{ m}, \ \Delta y = -3.26 \pm 13.2 \text{ m}, \ \Delta z = -290.77 \pm 21.06 \text{ m}.$$

The dispersion of the values is more important than what is obtained from direct measurements on geodetic points (see for instance [8], where error margins are less by an order of magnitude). This is probably the result of combined inexactitudes in the process of map production (exaggerated wideness of roads for instance) and the resolution of the map itself (5 m at best for a 1/50 k map).

Regarding the absolute values, these results are more precise but indeed very close to those proposed by the NGA [3]. Either set of values can thus be used in the process of integrating 1981-based maps in a GIS.

Note that the average value of N (the difference between h and H in WGS84) is −9.97 ± 5.33 m in **Table 1**. When calculating this value from h and H provided by a geodetic computer of [9] for 17 geodetic reference points, −10.39 ± 0.39 m is obtained.

An alternative, but nevertheless very appropriate data set of WGS84 imagery is provided by Google Earth especially in areas where high resolution imagery is available notwithstanding the poor resolution in elevation.

Acknowledgements

An early version of this paper received constructive comments by Pierre Voet (NGI, Belgium).

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