International Journal of Advanced Research in Engineering and Applied Sciences ISSN: 2278-6252

COMMON POINT COORDINATES TRANSFORMATION PARAMETERS BETWEEN ADINDAN (SUDAN) NEW ELLIPSOID AND THE WORLD GEODETIC SYSTEM 1984 (GPS DATUM) COORDINATES COMPARED WITH PARAMETERS OF THE AMERICAN NATIONAL IMAGERY AND MAPPING AGENCY (NIMA)

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Abstract: T*he Clarke 1880 ellipsoid of Adindan-Sudan datum coordinates are two dimensional, because the height which is the third dimension is related to the mean sea level. The surface of the mean sea level approximates the Geoid surface and the vertical height relive to the irregular geoid surface is different from the height related to the ellipsoid. Then accordingly it is intended to iterate the Clarke 1880 ellipsoid coordinates for smoothing the height as the smooth shape of the surface of the ellipsoid. This paper is aiming to evaluate the Adindan (Sudan) new ellipsoid coordinates by comparing its transformation parameters with the parameters of the American National Imagery and Mapping Agency (NIMA).*

Keywords: *NIMA, GPS, WGS84, Adindan, Clarke1880, Ellipsoid*

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1. INTRODUCTION

So as to have a unified network connecting the survey control networks dedicated in Sudan to the Dams projects along and around the Nile river and its tributaries, a set of 10 reference sites regularly spread over the covered area (From Hlfa city at the Northern boarder of Sudan to Kosti city at the Southern Border) have been selected and implemented. This reference network was designed in agreement with the Sudan Dam Implementation Unit (DIU). To ensure a better reliability of the network in terms of durability, 2 safeguard points were set up for each reference site. Based on the GPS observations of these points processed with some International GPS service for geodynamics (IGS) permanent stations data [1], a new Reference Frame was defined related to the IGS05 reference frame. The coordinates were expressed at epoch 2005.0 using a conventional African plate rotation model. In order to have a transformation model between the new reference frame and the Adindan (Sudan local datum related to Clarke 1880 ellipsoid), thirteen trigonometric points with their local (Adindan –Clarke 1880 ellipsoid) coordinates were observed in static mode with geodetic GPS (WGS84) relative to reference points [5]. Anew ellipsoid was established replacing the old two dimensional Clarke 1880 ellipsoid so as to have a new ellipsoid height instead of the mean sea level (trigonometric) height. It is well known that the mean sea level height is approximately equal to the geoid height, which has an irregular surface not suitable for computation of the points geodetic coordinates. The thirteen points with their common (local and WGS84) coordinates have been used for determination of the transformation parameters. The parameters determined were compared with National Imagery and Mapping Agency (NIMA) parameters.

2. GEODETIC SURFACES

There are important three geodetic surfaces, the earth surface, the geoid and the ellipsoid.

2.1 THE EARTH SURFACE

It is the topographic surface of the earth which is extremely uneven and not definable mathematically. It is approximately ellipsoidal in shape, the maximum departures from an ellipsoid being of the order of 8.5 kilometres. The earth surface is important because most of our observations are made on this surface and most of our points lie on this surface.

2.2 THE GEOID

The geoid is defined as the equipotential of the earth's attraction and rotation which coincides, on coverage, with mean sea level in the open ocean. Another way of defining the geoid is to say that it is the surface which coincides with mean sea level assuming that the sea was free to flow under the land in small frictionless channels, but the mean sea level is not quite an equipotential surface owing to a non-gravitational forces (such as ocean current, winds and barometric pressure variation). The geoid has a fundamental important in geodesy because it is the physical shape of the earth which could be determined mathematically and then instead of that the geodesist modelled a mathematical shape (called ellipsoid) which approximate the geoid [4].

2.3 THE ELLIPSOID

An ellipsoid (or spheroid) is an ellipse rotated about its minor axis , mathematically the shape is an oblate spheroid. Ellipsoids are important in geodesy because they present the nearest simple mathematical shape to the geoid. It should noted that unlike the earth's surfaces and the geoid, an ellipsoid does not physically exist. Geodesists use ellipsoids as mathematical models for carrying out computations. There are many different ellipsoids (see tables 1, 2 and 3).

Table 1: Geodetic Reference System 1980 (GRS80) parameters.

Paramètres	**Symbole**	**Value**
Equatorial radius of the Earth	a	6378137.0 m
Geocentric gravitational constant (including the atmosphere)	**GM**	$3986005 \cdot 10^{8}$ $m^{3}s^{-2}$
dynamical form factor (excluding permanent tides)	$\mathbf{J_2}$	$108263 \cdot 10^{-8}$
Angular velocity of the Earth	**W**	$7292115 \cdot 10^{-11}$ rad s^{-1}
semiminor axis (polar radius)	**B**	6356752.3141 m
first excentricity	$\mathbf{e^2}$	0.00669438002290
Flattening	F	1 : 298.257222101

Table 2:Primary parameters of WGS-84.

PARAMETER	NAME	WGS-84
Semi-major axis	a	6378137 m
Flattening	f	1/298.257223563
Angular velocity	ω	7292115 x10 $^{-5}$ rad s $^{-1}$
Geocentric gravitational constant (Mass of earth's atmosphere included)	GM	398600.5 km ^{3} s^{-2}
Normalized 2nd degree zonal harmonic Coefficient of the gravitational potential	$\bar{C}_{20}$	-484.16685 x 10 $^{-6}$

Table 3: Clarke 1880 ellipsoid parameters.

Paramètre	**Symbole**	**Value**
Equatorial radius of the Earth	a	6378249.145 m
Semi minor axis (polar radius)	b	6356514.8695 m
first excentricity	e^2	0. 006803511283
Flattening	f	1 : 293.465

3. ADINDAN DATUM DEFINITION

Adindan datum is the historical local datum of Sudan that all triangulation and traverse network observations in Sudan has subsequently been reduced to it. Adindan base terminal ZY was chosen as the origin of 22º 10' 7.1098" latitude (North) and 31º 29' 21.6079" longitude (East), with azimuth of 58º 14' 28.45" from the north to YY.ZY is now about 10 meters below the surface of Lake Nasser at the Northern boarder of Sudan. On the other hand, Clarke 1880 is that ellipsoid of a semi major axis of 6378249.145m, and 293.465 reciprocal of the flattening (1/f) (see table 3).

4. THE ITRF AND THE IGS

The international reference system for the whole Earth is undoubtedly the International Terrestrial Reference System (ITRS) as defined by the International Earth rotation and Reference systems Service (IERS) [2]. ITRS is an ideal reference system defined through theoretical prescriptions and conventions, and needs to be realized on the basis of coordinates and velocities of a set of physical earth-related points. Such a realization is achieved using different techniques of space geodesy (VLBI, LLR, GPS, SLR and DORIS), it is the so-called ITRFyy (International Terrestrial Reference Frame) where yy stands for the last year of observations taken into account. ITRS is stated to meet the "no net rotation" condition, i.e. the mean displacement due to tectonic plate motion for the whole Earth is zero. Hence, any realization has to provide coordinates and velocities of the involved stations [3]. Therefore a specific epoch must be fixed to express coordinates in an operational geodetic reference set. Moreover, the International GNSS Service (IGS) is currently maintaining the ITRF related to GPS stations through a cumulative weekly solution. Presently, the cumulative solutions are given for the epoch 2005.0 (January 01 2005). The coordinates of the Sudanese new reference stations was first processed at the epoch of the observations in 2007 and then calculated at the epoch 2005.0 using a plate rotation model for Africa [1]. IGS provides data whose main qualities are the precision and the consistency. Some IGS permanent stations observation data with their coordinates, velocities, and the corresponding ephemeris (orbits and earth orientation parameters) were used.

5. THE SUDAN GPS DATUM (WGS84)REFERENCE FRAME

Here is some explanation about the new standard International Terrestrial Reference Frame (ITRF) and the new standard antenna patterns recently recommended by IGS and that it is proposed to calculate a network that will be consistent with these new standards. Namely, It is propose to adopt ITRF2005/IGS05 at epoch 2005.0 as reference frame, and absolute antenna calibrations.

5.1 A REFERENCE FRAME FOR THE SUDAN GEODETIC SURVEYING PROJECTS

5.1.2 DEFINITIONS

The Sudanese new reference points coordinates expressed in IGS05 at the 2005.0 reference epoch which was observed and processed during the 2007 Dam Implementation Unit (DIU) campaign can be considered as a realisation of a new reference frame for geodetic activities in Sudan(see table 4). The associated ellipsoid is the IAG GRS80 by the International Association of Geodesy (IAG) during the General Assembly 1979. Main parameters are in the table 1.

Table 4: The IGS reference points coordinates (Sudan WGS84 network) frame (relative to ITRF2005) for geodetic GPS activities in Sudan

Point No.	X (m) σ_X (m)	Y (m) σ_Y(m)	Z (m) σ_Z (m)
1	5057900.8975 0.0034	3088099.7000 0.0023	2351049.1777 0.0018
2	5193383.0792 0.0036	3053078.1931 0.0023	2088472.7797 0.0018
3	5174209.6005 0.0026	3166798.7431 0.0018	1963902.5000 0.0013
4	5023892.1560 0.0036	3304168.2575 0.0026	2120744.7239 0.0018
5	5032275.0679 0.0026	3367638.8125 0.0018	1998386.6027 0.0013
6	5155734.9409 0.0026	3307786.0880 0.0018	1772450.2462 0.0013
7	5009054.1335 0.0036	3624779.1296 0.0029	1562302.9882 0.0016
8	5149714.1801 0.0026	3411332.2383 0.0023	1584974.0229 0.0010
9	5196606.6395 0.0036	3395248.8981 0.0026	1462721.7020 0.0016
10	5165743.9826 0.0036	3481632.1826 0.0026	1366464.2375 0.0016

6. TYING TO ADINDAN (SUDAN)

6.1 ADINDAN (SUDAN) INPUT COORDINATES

Thirteen trigonometric points were observed in order to calculate a 3-dimensional transformation between Adindan and the Sudanese new reference points coordinates expressed in IGS05 in Sudan. They are 13 first order pillars. Their Adindan coordinates were collected as coordinates of table 5. The third dimension of table 5 (height) is a mean sea level height which is approximately equal to the geoid height. But the intended height for the establishment of the transformation parameters is the ellipsoid height and the Adindan datum of the Clarke 1880 ellipsoid has no ellipsoid height [5]. For this reason there were a new ellipsoid heights have been determined by iterating and smoothing the Clarke 1880 ellipsoid coordinates with their mean sea level height. In other words the "Height" coordinate is an altitude for most of the points. Since the Adindan system is a bi dimensional one, and since we used a 3 Dimensional Helmert transformation model to estimate transformation parameters, we used an iterative process to have computed Adindan ellipsoid heights. The horizontal coordinates and their ellipsoid height were shown in table 6. The geodetic ellipsoid of the Adindan reference system is Clarke 1880 (English) whose features are as in table 3.

Table 5: The Adindan (Sudan) triangulation coordinates (on Clarke 1880 ellipsoid) selected for the transformation parameters computation (the heights are mean sea level height not ellipsoid height).

	North latitude	East longitude	Height
	(degrees minutes seconds)		(m)
G002	21 52 20.510	31 21 56.991	327.50
G018	19 26 34.591	30 21 31.043	298.30
G021	19 02 29.974	30 16 25.315	373.50
G036	17 50 25.970	31 19 55.063	355.50
G214	16 10 30.625	32 35 55.768	479.80
G216	16 14 52.314	32 40 38.867	549.30
G217	16 14 31.862	32 40 51.838	407.32
G218	16 09 49.097	32 45 20.063	434.04
G247	14 37 41.997	35 44 03.440	523.37
G249	14 23 18.194	35 56 53.216	578.20
G652	13 14 33.620	33 05 57.000	501.90
G901	12 34 46.251	34 05 56.010	450.06
G905	12 49 01.230	33 58 56.099	441.22

6.2 ITERATIVE COMUTATION OF ADINDAN (CLARKE 1880 ELLIPSOID) HEIGHT

The process used was as follows:

First, pseudo Cartesian Adindan coordinates using he = H (altitude) was processed. From this set and from Sudan new geodetic reference set the 3 translation parameters were calculated. Using this temporary 3 translation parameters to transform Sudan new geodetic reference Points into Adindan + he , then Adindan new ellipsoid heights. The obtained new ellipsoid heights can be seen in table 6. From these computed heights and their original Adindan plane coordinats the final Cartesien Adindan coordinates were obtained and used to compute the final 3 translation parameters between the Sudan knew WGS84 datum network and the Adindan reference frame (table 7).

6.3 ADINDAN OUTPUT COORDINATES

So as to decide which set of parameters we keep to realise an Adindan (with new ellipsoid height) reference frame, we performed some coordinates comparisons between the use of the four computed parameters (three translations and one scale factor), the three computed ones (three translations) and the three translations ones published by the NIMA.

Table 6: The Adindan (Sudan) triangulation coordinates (on Clarke 1880 ellipsoid) selected for the transformation parameters computation (the height is new Clarke 1880 ellipsoid height).

	North latitude (degrees minutes seconds)	East longitude	Height (m)
G002	21 52 20.510	31 21 56.991	333.552
G018	19 26 34.591	30 21 31.043	304.083
G021	19 02 29.974	30 16 25.315	380.073
G036	17 50 25.970	31 19 55.063	358.491
G214	16 10 30.625	32 35 55.768	480.614
G216	16 14 52.314	32 40 38.867	549.834
G217	16 14 31.862	32 40 51.838	407.737
G218	16 09 49.097	32 45 20.063	434.357
G247	14 37 41.997	35 44 03.440	517.333
G249	14 23 18.194	35 56 53.216	567.736
G652	13 14 33.620	33 05 57.000	500.504
G901	12 34 46.251	34 05 56.010	447.070
G905	12 49 01.230	33 58 56.099	438.107

Table 7: Adindan new ellipsoid Cartesian coordinates.

	X (m)	Y (m)	Z (m)
G002	5056757.910	3082520.434	2361227.297
G018	5192006.595	3041094.212	2109566.633
G021	5209212.927	3040811.309	2067654.260
G036	5188066.299	3158359.100	1941533.117
G214	5162483.107	3301396.446	1765331.968
G216	5156112.687	3307302.221	1773075.546
G217	5155937.897	3307647.757	1772432.219
G218	5153693.500	3315675.787	1764093.062
G247	5011106.410	3605394.598	1600331.833
G249	5003040.086	3628003.915	1574642.485
G652	5202482.046	3391347.557	1451536.300
G901	5156050.122	3490762.917	1380015.242
G905	5158349.719	3477026.187	1405643.756

Table 8: The GPS Geographic Coordinates (observed relative to Sudan IGS network epoch 2005.0)

	latitude (degrees minutes seconds)	longitude (degrees minutes seconds)	Ellips. Height (m)
G002	N 21 52 20.547455	E 31 21 59.451795	337.4061
G018	N 19 26 35.336135	E 30 21 33.371423	306.2209
G021	N 19 2 30.829160	E 30 16 27.620929	381.9369
G036	N 17 50 27.136189	E 31 19 57.459552	360.9299
G214	N 16 10 32.295922	E 32 35 58.276118	483.3360
G216	N 16 14 53.963890	E 32 40 41.382692	552.7296
G217	N 16 14 33.513467	E 32 40 54.354368	410.6173
G218	N 16 9 50.770628	E 32 45 22.585886	437.2637
G247	N 14 37 44.108464	E 35 44 6.241140	522.6840
G249	N 14 23 20.350000	E 35 56 56.054621	573.1138
G652	N 13 14 36.126770	E 33 5 59.593503	500.6076
G901	N 12 34 48.880116	E 34 5 58.653640	447.5745
G905	N 12 49 3.751063	E 33 58 58.721626	438.7897

Table 9: The GPS Cartesian Coordinates (observed relative to Sudan IGS network epoch 2005.0)

	X (m)	Y (m)	Z (m)
G002	5056596.5900	3082504.8393	2361429.8197
G018	5191844.7290	3041078.1182	2109770.8792
G021	5209051.1856	3040794.9725	2067858.5289
G036	5187904.4037	3158343.1591	1941737.2272
G214	5162320.4785	3301380.8894	1765537.4975
G216	5155950.0611	3307286.6654	1773281.1038
G217	5155775.2540	3307632.2034	1772637.7713
G218	5153530.8379	3315660.2623	1764298.6274
G247	5010942.8006	3605380.1620	1600538.0991
G249	5002876.2239	3627990.1446	1574848.0210
G652	5202318.3388	3391334.0501	1451741.1175
G901	5155887.2204	3490749.0003	1380217.9958
G905	5158187.2645	3477012.0684	1405845.4032

7. HELMERT TRANSFORMATION

Helmert transformations parameters were calculated between the GPS Cartesian Coordinates (observed relative to Sudan IGS network epoch 2005.0) set (see table 9) and the Adindan new ellipsoid Cartesian coordinates (table 8), using the GPS Bernese Software. Processed results were estimated three different sets of parameters: -3 translations -3 translations and one scale factor -3 translations, one scale factor and 3 rotations. The complete outputs are given in the tables 10, 11 and 12. The residuals are at the few meter level. This is accurate enough to enable the localization of points in the existing maps of Sudan.

Table 10: Three Translations parameters

3 Translations parameters	
RMS OF TRANSFORMATION :	**1.0906 M**
PARAMETERS:	
TRANSLATION IN X :	**-162.6090 +- 0.3025 M**
TRANSLATION IN Y :	**-15.0696 +- 0.3025 M**
TRANSLATION IN Z :	**204.4903 +- 0.3025 M**

Table 11: Three Translation parameters and one scale factor

3 Translations parameters and One scale factor	
RMS OF TRANSFORMATION :	**1.0745 M**
PARAMETERS:	
TRANSLATION IN X :	**-168.9711 +- 4.4197 M**
TRANSLATION IN Y :	**-19.1788 +- 2.8637 M**
TRANSLATION IN Z :	**202.3027 +- 1.5452 M**
SCALE FACTOR :	**1.2381 +- 0.8581 MM/KM**

Table 12: Three Translations parameters, one scale factor and 3 rotations

3 Translations parameters, one scale factor and 3 rotations	
RMS OF TRANSFORMATION :	**0.9241 M**
PARAMETERS:	
TRANSLATION IN X :	**-169.6582 +- 9.8029 M**
TRANSLATION IN Y :	**-18.7252 +-10.8578 M**
TRANSLATION IN Z :	**203.4487 +- 8.2775 M**
ROTATION AROUND X-AXIS:	**- 0 0 0.46570 +- 0.15653 "**
ROTATION AROUND Y-AXIS:	**- 0 0 0.34679 +- 0.29870 "**
ROTATION AROUND Z-AXIS:	**- 0 0 0.14192 +- 0.42728 "**
SCALE FACTOR :	**1.2381 +- 0.7380 MM/KM**

8. ACCURACY

The accuracy of the points was taken from the final combination of the standard deviation. For the tied points (Adindan triangulation points with the new ellipsoid heights) it can be considered as a relative accuracy to the Sudan knew WGS84 datum network reference points. Since the observations sessions are quite homogeneous (4 hours for the points observation) and the processing strategy is the same, the accuracies are almost the same in each group of points. The accuracy of Adindan triangulation Points with the new ellipsoid heights are given in table 13 .

Table 13 : The accuracy of Adindan triangulation Points with the new ellipsoid heights .

Point	sX (mm)	sY (mm)	SZ (mm)
G002	4.3	3.5	2.6
G018	3.8	2.6	1.9
G021	3.9	2.4	1.9
G036	4.2	3.0	1.9
G214	4.2	3.0	1.7
G216	4.2	3.0	1.8
G217	3.5	2.7	1.6
G218	5.1	3.3	2.1
G247	4.1	3.4	1.7
G249	4.1	3.4	1.7
G652	4.3	3.1	1.6
G901	4.3	3.5	1.5
G905	4.7	3.7	2.1

9. RESULTS AND ANALYSIS

So as to decide which set of parameters we keep to realise an Adindan reference frame, we performed some coordinates comparisons between the use of the 4 computed parameters (3 translations and one scale factor), the 3 computed ones (3 translations) and the 3 translations ones published by the NIMA. NIMA translation parameters (shown in table 14) compared to the three translation parameters (table 10 and 15) and the three translation parameters plus one scale factor (table 11) .

Table 14: NIMA translation parameters

From	To	Tx (m)	Ty (m)	Tz (m)
"WGS84"	Adindan	**161**	**14**	**-205**

Table 15: WGS to Adindan- Sudan (with new ellipsoid height) translation parameters

From	To	Tx (m)	Ty (m)	Tz (m)
"WGS84"	Adindan	**162.6**	**15.1**	**-204.5**

Coordinates comparison between NIMA (WGS84 to Adindan) three translations parameters model and (WGS84 to new Adindan ellipsoid) three translations computed model of (table 16 column 2 and 3), and between NIMA (WGS84 to Adindan) three translations parameters model and (WGS84 to new Adindan ellipsoid) three translations and one scale factor computed model (table 16 column 4 and 5).

Table 16; Comparison between NIMA (WGS84 to Adindan (Sudan) translation parameters coordinates and (WGS84 to Adindan (Sudan) new ellipsoid) translation coordinates.

	3 translations		3 translations One scale factor	
Point number	DE (m)	DN (m)	DE (m)	DN (m)
G002	0.103	-0.259	0.265	-1.031
G018	0.138	-0.175	0.435	-0.616
G021	0.141	-0.161	0.45	-0.547
G036	0.107	-0.119	0.279	-0.338
G214	0.064	-0.061	0.07	-0.051
G216	0.062	-0.063	0.058	-0.063
G217	0.061	-0.062	0.057	-0.062
G218	0.059	-0.06	0.045	-0.049
G247	-0.042	-0.007	-0.454	0.213
G249	-0.049	0.002	-0.49	0.255
G652	0.048	0.042	-0.013	0.454
G901	0.014	0.065	-0.181	0.568
G905	0.018	0.057	-0.161	0.527

Taking into account that in the three different sets of parameters the residuals are similar (about 1-2 meters), it is proposed to keep the three Translations parameters model for the following reasons :

a) there is no enough information to estimate rotations parameters
b) it keeps the consistency of the WGS84 network
c) there have no information to have reliable ellipsoid height
d) the network doesn't cover all Sudan
e) they are close to those computed by the NIMA

10. CONCLUSIONS

The contribution of IGS network to geodesy are fundamentally due to the effort of the many site operators worldwide. In Sudan (for the first time there are a unified GPS (WGS84) network observed, processed and adjusted properly (coordinates shown in table 4). Points of the network are only 10 stations distributed along a line extending from the North boarder of Sudan to the South so that it is very important establish more stations well distributed over the area of Sudan. The author used the considered IGS network as the reference for the other 13 stations measured with GPS (WGS84 datum) and Clarke 1880 ellipsoid(Adindan Sudan datum with new ellipsoid height) . The 13 common points were used to determine the transformation parameters between Adindan (Sudan) and WGS84 datum. The parameters were compared with NIMA showing very small negligible difference. Accordingly lines of small and large scale were tested using the two parameters (NIMA and the established Wgs84 to Adindan) such as the following:

Small scale maps:

The project distance (measured directly on maps) between one point near Wadi Half a (Town at the Northern boarder of Sudan (400 000, 2 400 000, UTM Adindan) and one point near Roseries (Town at the South- West of Sudan 600 00, 1 300 000 UTM Adindan) is 1147562.634 m in UTM Adindan and 1147562.069 m in UTM Sudan new geodetic reference. This difference of 57 cm for a distance longer than 1000 km can not be seen on any map.

Large scale maps:

The project distance (measured directly on maps) between one point near Wadi Halfa (Town at the Northern boarder of Sudan (400 000, 2 400 000, UTM Adindan) and 450 000, 2

400 000 UTM Adindan) is 500.000 m in UTM Adindan and 499.999 m in UTM Sudan new geodetic reference. This difference of 1 mm for a distance of 500 m can not be seen on any map even very large scale map.

11. RECOMMONDATIONS

The above stations coordinates shown in tables 5,6,7,8,and 9 were manipulated relative to the 10 IGS stations shown in table 4, which are representing the ideal observation WGS84 datum network in Sudan and the transformation parameters tested by NIMA were obtained to this network, so it is no doubt useful to have a coverage of the area of Sudan with more station relative to the mentioned network and then there must be transformation parameters which will ideal parameters for any area in Sudan.

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