GPS COORDINATE TRANSFORMATION PARAMETERS FOR JAMAICA

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ABSTRACT

The Surveying and Mapping community now has the benefit of real-time 3-dimensional coordinates at the centimetre level, through the Global Positioning System (GPS). The reference frame, World Geodetic System of 1984 (WGS84), within which a user ascertains these coordinates is essentially geocentric. In Jamaica all coordinate data and mapping are based on a non-geocentric coordinate system known as the Jamaican Datum of 1969 (JAD69), which like many others around the world was realized by making basic assumptions about the geoid-ellipsoid separation at the origin. WGS84 coordinates are therefore not compatible with the JAD69.

This paper presents the results of work carried out to define the relationship between the two coordinate systems, through three types of transformation parameters, namely Block Shifts, Molodensky and Seven Parameter Similarity. Three of the forty-two primary control stations together with a Continuously Operating Reference Station (CORS), previously tied to the island network, forms a fiducial network at which WGS84 coordinates were determined. The two coordinate data sets for the four fiducial stations were used to solve the parameters. Tests were carried out on nine points with coordinates known in both systems. The results indicate that the Block Shift and Molodensky values transforms WGS84 coordinates to JAD69, accurate to ±1-2m and the seven parameter similarity values produce JAD69 coordinates accurate to ±0.5m or better. Arguments are put forward to suggest why coordinate transformation is an interim solution and that the development of a Geocentric Datum is preferred for Jamaica.

INTRODUCTION

Jamaica is a mountainous island of 10,991km^2 in the Caribbean Sea at about latitude 18° N and longitude 77° W. The Island is elongated, lying principally in an east-west direction. Its span is approximately 230km in the east-west direction and 80km in the north-south direction. Its tallest peak, the Blue Mountains in the east rises to 2,256m. Parts of Jamaica are unpopulated wilderness. A road-less jumble of limestone pinnacles and glades forms a solid foundation for the country's control network.

Control data in Jamaica is based on the Clarke 1866 Ellipsoid with its origin defined in terms of datum values referred to as Jamaica Datum of 1969 (JAD69). The coordinates (Geographic or Cartesian) in Jamaica of points determined by GPS are not compatible with local coordinate values and must be transformed to the Jamaica Coordinate System.

Currently there is no accurate and officially published set of transformation parameters. The Jamaica Government Survey Department developed a provisional set of Molodensky parameters from WGS72 coordinate values determined from a Doppler campaign at five points carried out by Geodetic Survey Co. (GSC) of Houston Texas, in 1981. It was therefore necessary to plan and carry out modern observations using GPS, and determine transformation parameters between WGS84 and JAD69. These parameters, for most practical applications in Jamaica, need to be of sufficient accuracy to convert points across the two datums to ± 1 metre in the absolute sense and 1 ppm in the relative sense.

SIGNIFICANCE OF TRANSFORMATION PARAMETERS FOR JAMAICA

All coordinate data, hydrographic charts and national mapping in Jamaica are published on the basis of a local realization of the Clarke 1866 reference ellipsoid. For GPS coordinates to have meaning and current application in Jamaica, they have to be transformed to the JAD69 datum with their geographic values computed on the Clarke 1866 Ellipsoid. The alternative is for all coordinates in Jamaica, and products based on them, to be based on the datum used by GPS. This would involve considerable measurement and analysis. As an interim method this paper proposes transformation parameters to convert GPS coordinates to the existing JAD69 datum.

To meet the aggressive production goals for the proposed Land Administration and Management Project (LAMP), there is the need for more efficient and modern methods of cadastral surveying & mapping. The unique capabilities offered by GPS technology have proven to promote faster and more economical cadastral surveying. **[6]**. Again a readily available set of transformation parameters will be needed to transform coordinates of control points that would be used to "tie" cadastral surveys to control. This would enhance the datum definition aspect of the free adjustment in WGS84 of the GPS data, since the WGS84 value for a control point determined autonomously is likely to be about 10m in error. The parameters will be needed again to transform all WGS84 coordinates to the local datum. The foregoing also holds true for control surveys in engineering projects such as highways.

There can also be instances where a client requires coordinates in WGS84. In order to properly satisfy this requirement either a point in the Jamaica National GPS Network is used in the survey, or a more accessible control point is occupied, and its JAD69 coordinates transformed to WGS84.

Strategic marks occupied with high accuracy geodetic receivers for long sessions and post processed with reference to IGS Stations, have a good enough quality to be integrated into the existing control database. However, there is no means of transforming their WGS 84 values to the local system given the absence of transformation parameters.

For the purposes of Real Time Kinematic (RTK) GPS Surveying, some software packages make provision for a site calibration to allow for a "localised" determination of the transformation parameters at the site being surveyed. This requires the occupation of at least four (4) known control points on the periphery of the site. This is not always an easy or inexpensive process, but with good transformation parameters perhaps fewer points will be good enough to orient the survey into the local system.

So, with suitable transformation parameters, the WGS84 coordinate of any point in the control database can be computed. This effectively increases the density of the network of available WGS84 coordinated points. More widespread use can then be made of the "shorter range" single frequency GPS receivers in some of the applications mentioned above, where only the "longer range" dual frequency receiver could be used given a sparse network of known WGS84 points. Occupation time can also be significantly reduced in the case of a denser network of points with WGS84 coordinates, as this is a function of the length of the baseline between receivers.

Finally, there can be spatial data (e.g. geographic information systems data and remote sensing imagery) relevant to Jamaica but developed on the WGS84 coordinate system. In order to integrate such data into the local database a transformation of the coordinates in such a database to the local coordinate system must first be done to achieve consistency.

On the basis of the foregoing, there is no doubt that there is great significance to the existence of good quality GPS coordinate transformation parameters.

JAMAICA DATUM 1969 (JAD69)

The JAD69 was realized through some very basic assumptions made at the origin (Fort Charles) of the network. Quite simply, the deviation of the vertical was assumed to be zero in both components ($\xi = 0$, $\eta = 0$) and the geoid - ellipsoid separation also assumed to be zero ($N=0$).

The results of the Primary Triangulation adjustment of 1969 and the subsequent 1984 adjustment of the secondary and tertiary national networks are all published with reference to JAD69. The constraints ($\xi = 0$, $\eta = 0$, $N = 0$) which were imposed in the selection of JAD69 mean that it is a local datum that is useful for surveying and mapping in this small portion of the earth's surface where the geoid - ellipsoid separation does not, on average, exceed 2m **[5]**. The drive to a global datum that facilitates meaningful international geodetic connections, giving rise to intercontinental geodetic networks, crustal motion and plate tectonic studies has been increased by the advent of position fixing methods based upon extra terrestrial observation. Such positions are given with respect to a globally based reference system.

JAD69 is a local datum and as such geodetic coordinates in Jamaica have no international relevance and coordinates from, say, GPS are meaningless in this local datum. Therefore, if the advantages of a World Geocentric coordinate system are to be exploited, the change from a local datum must be made. The effect of the increased geoid-ellipsoid separation on corrections to measurements can easily be overcome by substantially improved methods **[13]** of accurately modelling the geoid. The modelling of the differences (transformation parameters) between the two (local and global) systems is not the final answer to the problem, but rather an interim solution. The local datum must be replaced by a datum fully compatible with say GPS.

Since the vast majority of GPS users (motorists, sailors, aircraft pilots and digital products), cannot be expected to have an understanding of coordinates, datums and their transformations, it is therefore important that the coordinate system used be compatible with the global technology that they now use **[12]**. Adopting a geocentric datum would make Jamaica compatible with all other geocentric datums, hence navigators moving from say North America to Jamaica will no longer have to worry about datum shifts as they move from an American map sheet to a Jamaican map sheet.

COORDINATE TRANSFORMATION MODELS

The more widely used coordinate transformation models in geodetic work include:

The Block Shift Method

A very simple method of determining transformation parameters is by the block shift approach. Here the Cartesian coordinates of common points within the two datums are respectively subtracted to yield $\triangle X$, $\triangle Y$, $\triangle Z$ values. These values are usually different for each of the common points. The procedure simply averages the shifts obtained over the entire area. Alternatively, if the shifts determined at the common points are significantly different, a block shift contour map for each component could be produced by simple interpolation procedures.

Block shifts are usually of very limited accuracy and are not recommended but for the least accurate applications (±10m).

The Molodensky Method

The Molodensky method represents an improvement on the block shift method in that it takes into consideration differences in the size (Δa) and shape (Δf) of the two reference ellipsoids. This gives rise to a five (5) parameter (ΔX, ΔY, ΔZ, Δa, Δf) approach. The abridged Molodensky formulae are given by **[10]**. The $\Delta \phi$, $\Delta\lambda$ and Δh can also be computed across a network and contoured for point extraction. This method is often programmed in hand-held GPS receivers, and can be expected to deliver accuracies of ±5m.

The Bursa-Wolf (Seven Parameter Similarity) Method

In the preceding two approaches, it is assumed that the respective XYZ axes of both datums are parallel. In the traditional definition of local datums, the emphasis was on minimizing the average geoid - ellipsoid separation over the region. Hence, it is presumptuous to now assume that the axes are parallel when no attempts were made to achieve such a condition. It therefore becomes necessary to solve for three (3) additional parameters namely the rotations about the XYZ axes (see Figure 1).

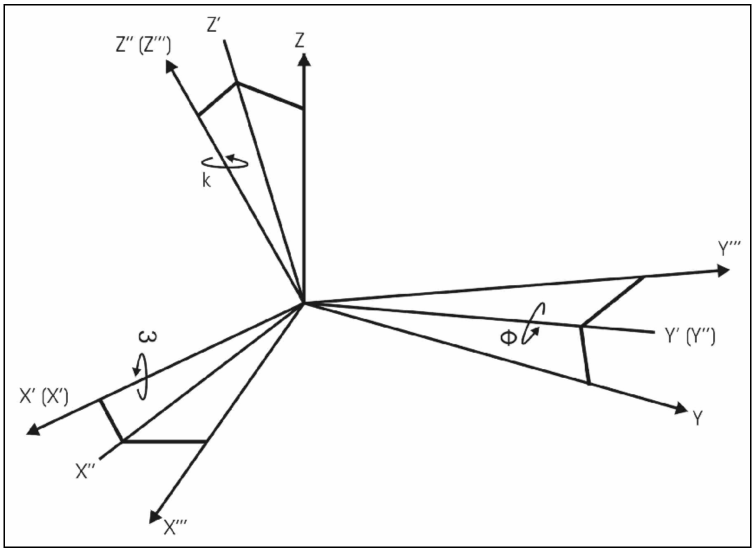

Figure 1. 3-D Axes Rotations

It is generally accepted that there can also be a scale difference between the two networks of points. This gives rise to a seven parameter (Δx, Δy, Δz, ω, φ, κ, s) similarity approach known as the Bursa - Wolf Method represented in matrix form as:

$$\begin{bmatrix} X_{Tf} \\ Y_{Tf} \\ Z_{Tf} \end{bmatrix} = (1+S) \begin{bmatrix} 1 & \kappa & -\phi \\ -\kappa & 1 & \omega \\ \phi & -\omega & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad \ldots\ldots\ldots(1)$$

The seven parameter similarity transformation may be modelled into a least squares solution with the coordinates of the common points being the observations **[8]**.

It is quite likely that different parts of a traditional geodetic network will have varying distortions in scale and orientations. These distortions may be due to systematic errors in the data. If distortions exist then it may be better to solve for a number of sets of local parameters that better represent the local and regional areas, rather than determining one set of parameters for the whole network. Also, transformation parameters over a large area will represent mean values of scale, rotational translation for the area, and will tend to smooth out distortions. Therefore, the total network could be divided into sub-nets to check consistency throughout the whole area. However, it is necessary to be sure that any differences in the parameters from one region to another are statistically significant **[8]**. On the other hand, when the data set is broken into localised or regional groups, the number of redundancies in each group is reduced and the effect of observational errors is absorbed directly into the parameters **[2]**.

The effects of systematic errors can be assessed using "check-points". One of the points that was used to determine the seven parameters, can be eliminated in a second determination of parameters. If the differences in these two sets of parameters are acceptable, then the solution is stable. Also, the coordinates of the eliminated points can be transformed by the set of parameters from the second solution and compared to the measured values. This test can also be performed on other points that were not apart of the transformation solution.

The primary output of the least squares solution is the estimate of the parameters, their standard error and their associated VCV matrix. Secondary to these are the adjusted coordinates of local datum points and adjusted base line lengths between the points. After the adjustment, the coordinates of each point should be tested for outliers. Even though the coordinates could be obtained from precisely tested adjustments they may still contain unknown systematic errors such as, the terrestrial and GPS surveys not occupying the same points (mis-centering). The corrections to baseline lengths must also be investigated. Statistical tests should be applied to the individual parameters and groups of parameters **[8]**. With this method accuracies at the ± 1 metre level can be expected **[10]**.

The Molodensky Badekas (Seven Parameter Similarity) Model

When the Bursa-Wolf method is invoked for small networks, the rotation parameters are highly correlated with the translation parameters. For example, a rotation about the Z-axis has almost the same effect as a translation of the Jamaican network (at latitude 18ºN and longitude 77ºW) along the X-axis. The Molodensky-Badekas formulation avoids this correlation problem **[8]**.

Although the displayed precisions of the of the translations from this method is an order of magnitude better than those from the Bursa-Wolf, and rotations are less correlated with translations, it is not felt that the actual translation parameters are better than those from Bursa-Wolf.

Grid File (Distortion Modelling)

The preceding transformation methods are intended to transform the network from one coordinate to another without changing the shape of the network, that is, they are conformal transformations. It is possible to transform coordinates from one datum to another and at the same time improve the shape of the network, with knowledge of the distortions in the network.

The process involves re-adjusting and transforming the geodetic network of the terrestrial control to the Global datum, using all historical measurements and new GPS observations and constraining the Global (GPS) determined coordinates. This will produce a data set of points with the "new" global coordinates and "old" local values and their respective differences (shift values). The shift values (ΔE and ΔN or Δϕ and Δλ) of the irregularly spaced geodetic network are modelled onto a regular grid. The grid interval may be determined to achieve a transformation accuracy of 2 - 5cm. The grid distortions, that is, residuals at coordinate points transformed by conformal parameters, may be modelled using minimum curvature surface or least squares collocation, both of which yield similar accuracies **[3]**.

THE JAMAICAN CONTROL NETWORK

The Jamaica triangulation control network (see Figure 2) was adjusted in 1969 on the Clarke 1886 ellipsoid. There was no attempt at making this ellipsoid geocentric and hence up until 1982 there was no knowledge as to the displacement of its centre from that of the mass of the earth, or of the rotation of its axes about the pole or any scale differences.

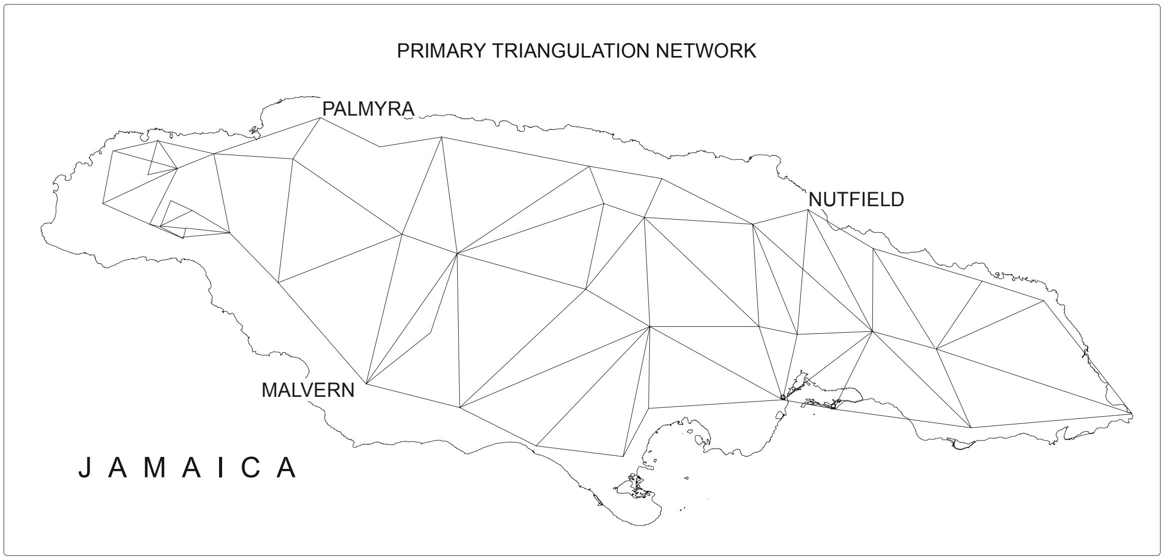

Figure 2. The Jamaica Primary Control Stations

In 1981, Geodetic Survey Co. of Houston, Texas **[5]** surveyed five local control stations in Jamaica by Satellite Doppler Translocation Survey and reported that “Mean Datum shift parameters between WGS72 and JAD69 were determined to an accuracy of one meter RMS.” The report went on to state “Station NE Cay was deleted from the main processing due to a poor fit.” The Block Shift parameters given as the mean shifts at the other four points are shown in Table 1.

Table 1. GSC's WGS72- JAD69 Block Shift Parameters

Parameter	WGS72 to JAD69
Dx (m)	-50
Dy (m)	-212
Dz (m)	-381

The Government Survey Department (GSD) developed a set of Molodensky parameters to transform between JAD69 and WGS84 (see Table 2), by an approach similar to that used by **[9]**.

Table 2. GSD Block and Molodensky Parameters

Parameter	WGS72 to NAD27	NAD27 to JAD69	WGS84 to WGS72	WGS72 to JAD69	WGS84 to JAD69
a (m)					6 378 137
1/f					298.257223563
DX (m)	8	-78	0	-70	-70
DY (m)	-160	-47	0	-207	-207
DZ (m)	-172	-213	-4.5	-385	-389.5
Da					69.4
Df					0.000037264639

The 20m discrepancy between the X-shifts in both (GSC and GSD) in these determinations could be explained against the background that a 0.554" rotation about the Z-axis of WGS72 with respect to WGS84, is highly correlated with a transformation in the X-axis at our longitude (77°W).

The values in the fifth column of table 2 are the only GPS Coordinate Transformation parameters available and being used in Jamaica to date. These parameters were tested using points coordinated with GPS for which local coordinates are known. A summary of the comparison is given in Table 3.

Table 3. *WGS84–JAD69 Coordinate Differences for nine points (Northings, Eastings and heights) after GSD Molodensky Parameters Application.*

POINTS	Diff. N (m)	Diff. E (m)	Diff H(m)
GPSD	-0.904	+2.181	+6.472
MARTTW	-1.069	+2.134	+6.540
MKJP C	-0.967	+2.097	+6.273
MKJP C	-0.948	+2.102	+6.274
FORT	-1.093	+2.368	+6.110
CATH	-1.326	+2.949	+5.812
MULG	+0.099	+4.167	+4.046
EDDI	+0.033	+4.077	+6.307
NGLH	+0.297	+4.886	+4.931

The differences in Table 3 are due to inaccuracies in the parameters and are caused by the very method by which they were derived – adding together other datum transformation parameters. The NAD27 – JAD69 values (see Table 2) for example, were not determined from a satisfactory distribution of points. In addition to this, they were determined by way of the Block Shift approach, hence assuming that the axes are parallel.

In the absence of a geoid computed in respect of JAD69, the elevations are not expected to be better than ±1m, particularly in the western part of the network. The JAD69 elevations were estimated by applying the difference in height (Δh) between WGS84 and JAD69, at the origin. It is not expected that this difference (15.941m) is consistent across the island.

The New Network and Parameters

A new control network using existing triangulation stations was designed and referred to as the Jamaica National GPS Network. Its coordinates in the WGS84 reference frame were determined using GPS. Transformation parameters separating the two datums were solved for using a variety of methods. The existing triangulation may be referred to as the old network. It was proposed to develop the new network in two levels, namely: a Fiducial Network and what we will refer to as a GPS Network.

The Jamaica Fiducial Network

Since it is the intention to establish the new geodetic network within a global reference frame, i.e., WGS84, it was necessary that the new geodetic network be tied to points within the IGS global network of points with WGS84 coordinates. Three such points, for adequate redundancy, which provide good geometric stability were identified (AOML, CRO1 and MOIN).

It was also decided to use four points that are part of the existing triangulation to form a braced quadrilateral over the island, constituting the Jamaica Fiducial Network. Two or perhaps three would be sufficient to make the connection to the Global IGS Network. However, given the shape of the island, a rectangular network of points was considered more desirable. The four selected were Palmyra, Malvern and Nutfield (Survey Department Primary Stations), and JAMA (a Continuously Operating Reference Station-CORS; tied to the national triangulation by the Survey Department). Figures 3 and 4 illustrate the layout of these networks.

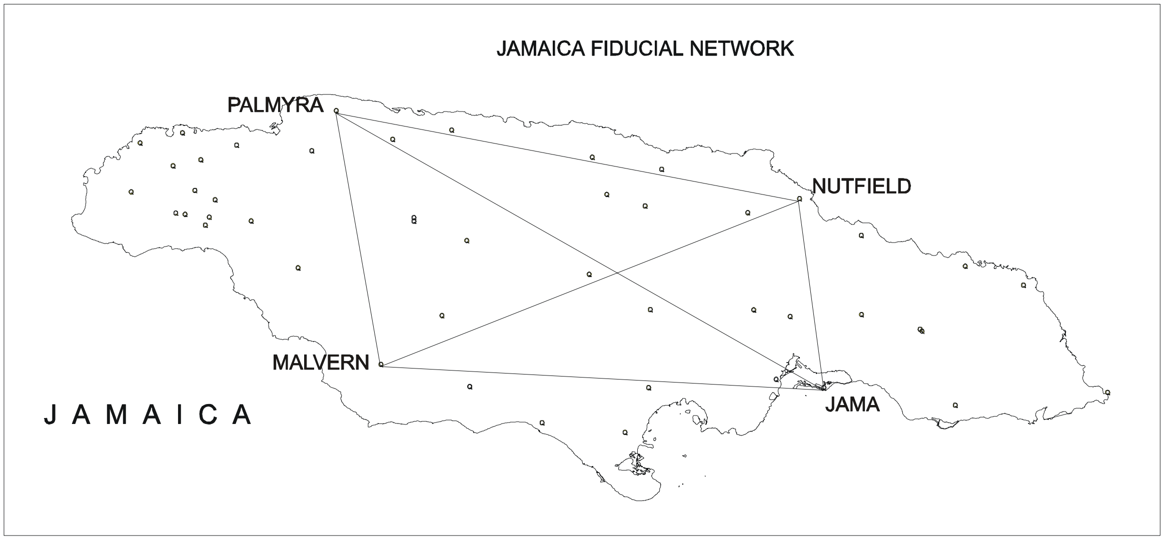

Figure 3. The Jamaica Fiducial Network

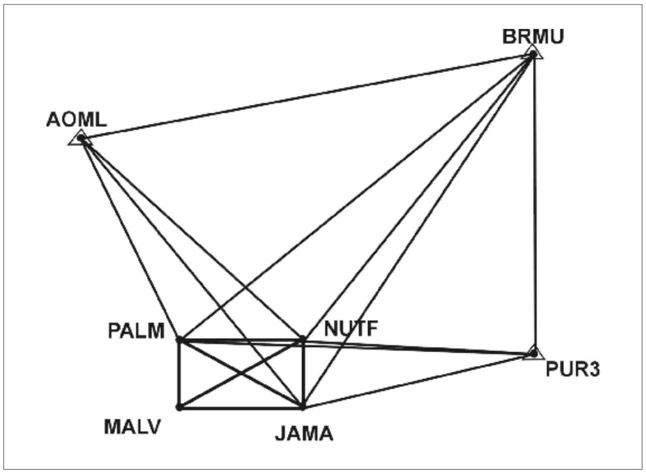

Figure 4. The Control for the Jamaica Fiducial Network

The elevations of the four Jamaican points are not to the highest standards. In fact, only NUTFIELD and JAMA have spirit-leveled heights (not corrected for gravity) while the other elevations are the results of trigonometric heighting in a network where triangle height misclosures of ±1 - 2m are not uncommon. There have been arguments put forward in the literature for the exclusion of heights **[11]** and their inclusion **[4]** as the latter considers elevations to be of a completely separate measurement and adjustment process and a different datum from horizontal coordinates, especially in the case of traditional (triangulation) networks.

Since the elevations of most of the other Jamaica Primary points are not very reliable, the transformation process is not expected to deliver high accuracies in the height component of the coordinates. This situation could only be otherwise properly addressed had there been a well-determined geoid model based on the local coordinate system.

Notwithstanding these limitations, an attempt was made to determine the difference in the ellipsoid heights for the station of origin (Fort Charles), since its MSL value equals JAD69 ellipsoid height, N being assumed to be zero. This should aid the estimation of JAD69 ellipsoid heights at other stations.

An error of 6.4m in elevations introduces only a 1ppm scale effect. Our solutions with all ellipsoidal heights set to zero reflects no significant change in the seven parameters except for a - 2.5ppm scale change. This difference in scale could be attributed to inconsistencies in the heights of the stations. EDM height traversing (using reciprocal vertical angles) would be useful in checking the elevations of the stations and improving the quality of the heights, but would have been a little onerous, considering the time and resources available. The network however, is definitely weak in scale. The triangulation distances are shorter than their corresponding GPS measurements, as evidenced by a scale factor of -9.88ppm, when the parameters are determined without the use of elevations i.e. computing on the ellipsoid surface.

These points will nevertheless be used to provide the linkage between the Jamaica Datum and the WGS84, when their coordinates are determined from a GPS observation campaign. They will provide the fixed values for any future Geodetic work within Jamaica. It is expected that the baselines between the points will be determined to better than ±1cm, which in the case of the shortest line translates to ±0.25ppm.

JAMA has a permanent high precision three-dimensional GPS facility, which down loads data to the NGS archives over the Internet, making JAMA readily suitable (with WGS84 coordinates) for use in any future high accuracy positioning work.

The Jamaica Fiducial Network will provide a framework of accurately defined positions, that form a geometrically acceptable braced quadrilateral, that can be used in any future local network adjustments (redefinition or renovation). This network being referenced to the WGS84 will ensure direct compatibility with the geoid model CARIB97 that covers Jamaica.

TRANSFORMATION PARAMETER RESULTS

Block Shift Parameters

Block shift parameters were computed between JAD69 and WGS84 coordinates of the fiducial stations. The results along with their standard errors are given in Table 4.

Table 4. *WGS84 – JAD69 Block Shift Parameters*

Parameter	WGS84 to JAD69
Dx (m)	-65.334 ± 0.96
Dy (m)	-212.460 ± 1.49
Dz (m)	-387.630 ± 0.69

These values were tested on nine checkpoints that had coordinates known in both systems. The WGS84 coordinates were converted to JAD69 by adding the respective block shift values. The differences between the published JAD69 Northings, Eastings and Heights and the computed values are shown in Table 5.

Table 5. *WGS84–JAD69 Coordinate differences for nine check points after Block Shift parameters application.*

POINTS	**Diff. N (m)**	**Diff. E (m)**	**Diff H(m)**
GPSD	-0.322	-1.117	-0.114
MARTTW	-0.493	-1.159	-0.064
MKJP B	-0.390	-1.199	-0.316
MKJP C	-0.369	-1.197	-0.309
FORT	-0.514	-0.936	-0.478
CATH	-0.800	-0.367	-0.780
MULG	+0.688	+0.750	-2.480
EDDI	+0.662	+0.741	-0.230
NEGRIL LH.	+0.913	+1.418	-1.560

Molodensky Parameters

The Molodensky parameters comprise of three block shift values and two parameters for the differences between the two ellipsoids' semi-major axes and flattening. These parameters are listed in Table 6.

Parameter	WGS84 to JAD69
a (m)	6 378 137
1/f	298.257223563
DX (m)	-65.334
DY (m)	-212.460
DZ (m)	-387.630
Da	69.4
Df	0.000037264639

Table 6. *WGS84 JAD69 Molodensky Parameters*

The coordinates of the nine checkpoints were computed by inserting their WGS84 values and the parameters in table 7 into the Molodensky equations. The differences between the resultant JAD69 values, after conversion, and the published JAD69 N, E and H values are shown in Table 7.

Table 7. *WGS84–JAD69 Coordinate differences for nine points after Molodensky parameters application.*

POINTS	**Diff. N (m)**	**Diff. E (m)**	**Diff H(m)**
GPSD	-0.716	-1.113	-0.233
MARTTW	-0.884	-1.153	-0.183
MKJP B	-0.785	-1.196	-0.433
MKJP C	-0.765	-1.193	-0.431
FORT	-0.910	-0.933	-0.478
CATH	-1.126	-0.336	-0.840
MULG	+0.341	+0.588	-2.597
EDD1	+0.274	+0.748	-0.296
NEGRIL LH.	+0.516	+1.419	-1.628

Bursa–Wolf – Seven Parameters Similarity

The seven Bursa-Wolf Similarity parameters were computed using the program "Trans3d" **[7]**. This program requires the input of both (JAD69 and WGS84) sets of Cartesian coordinates for the fiducials and their respective VCV matrices. The standard errors of the Northings, Eastings and Heights, as obtained from a simulation adjustment for the JAD69 coordinates, and those obtained from the TRIMVEC software output for the WGS84 coordinates, were converted to their XYZ equivalents using Jacobian matrices **[7]**. The least squares solution of the parameters and their associated standard errors as shown in Table 8.

Table8. *WGS84–JAD69 Seven Parameters*

Parameter	WGS84 to JAD69
DX (m)	33.722 ±44.33
DY (m)	-153.789 ± 20.718
DZ (m)	-94.959 ± 39.362
Rx (sec)	-8.581 ± 1.314
Ry (sec)	-4.478 ± 0.628
Rz (sec)	4.540 ± 1.406
Sc (ppm)	-8.95 ± 2.078ppm

The seven parameters along with the WGS84 Cartesian coordinates of the nine checkpoints were used to compute new JAD69 coordinates. The differences between the two sets of values after conversion to Northings, Eastings and Heights are given in Table 9.

Table 9. *WGS84–JAD69 Coordinate differences for nine points after Seven Parameters application.*

POINTS	**Diff. N (m)**	**Diff. E (m)**	**Diff H(m)**
GPSD	0.4105	-0.1263	0.004
MARTTW	0.3608	-0.0673	0.006
MKJP B	0.3216	-0.1105	0.004
MKJP C	0.3137	-0.1386	0.001
FORT	0.0756	0.0834	-0.058
CATH	0.2669	0.5302	-1.320
MULG	-0.2709	0.2855	-1.78
EDD1	0.3798	0.0387	-1.08
NEGRIL LH.	-1.1568	0.3746	0.020

ANALYSIS OF RESULTS AND DISCUSSION

The computed differences between the converted coordinates of test points in Tables 5, 7 and 9,represented graphically in Figures 5,6 and 7 clearly reflects residuals for the nine test points. They are much smaller than was anticipated (vis. Block – 10m, Molodensky – 5m and Similarity 1m).

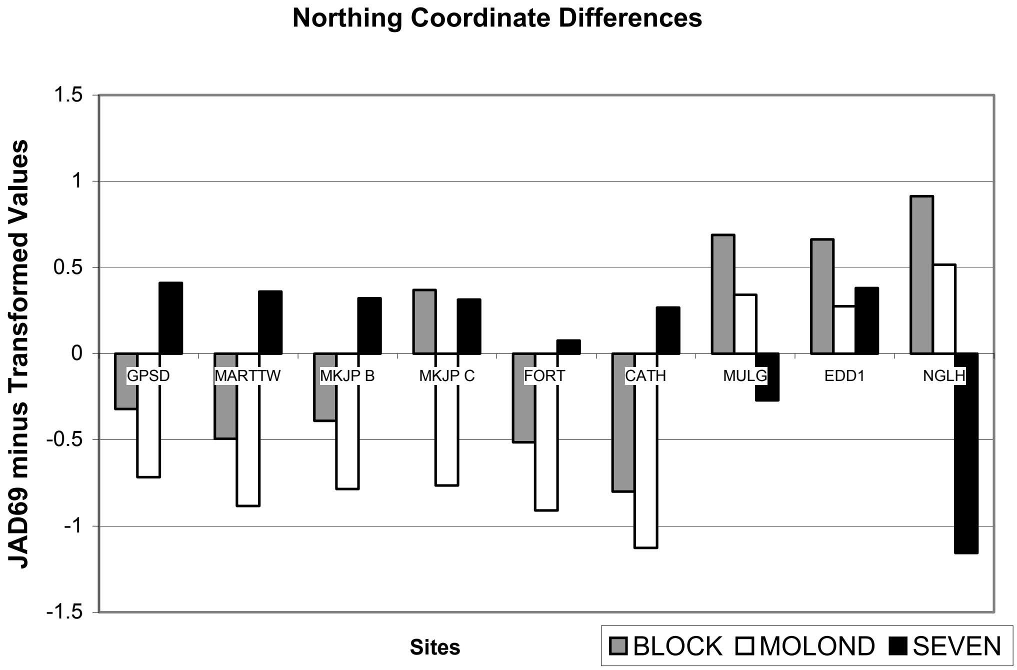

Figure 5 Northing Coordinate Differences

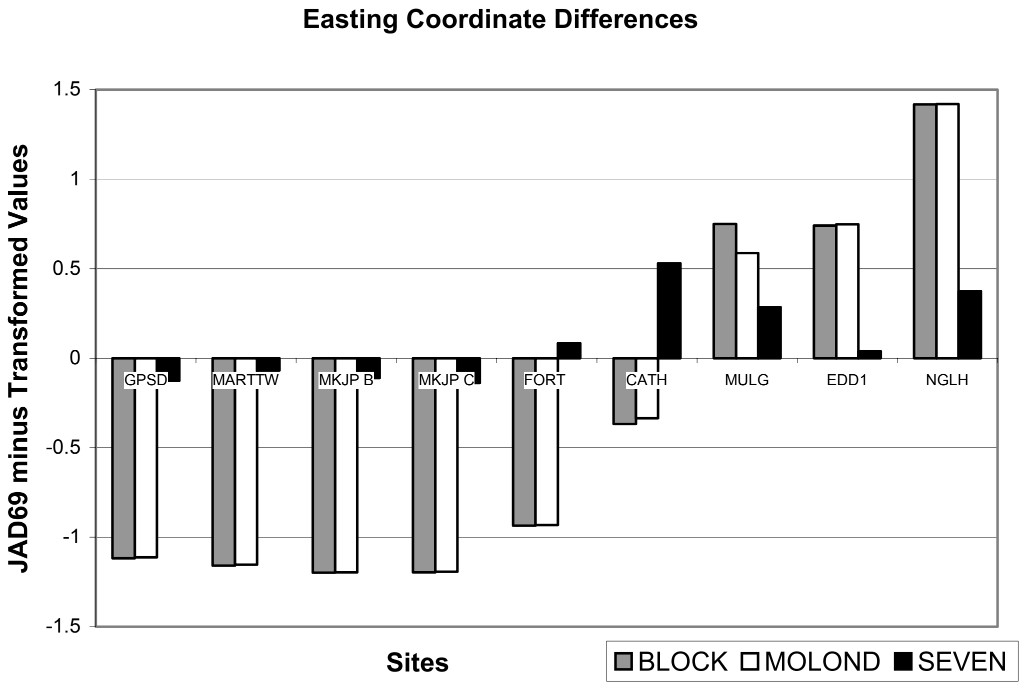

Figure 6 Easting Coordinate Differences

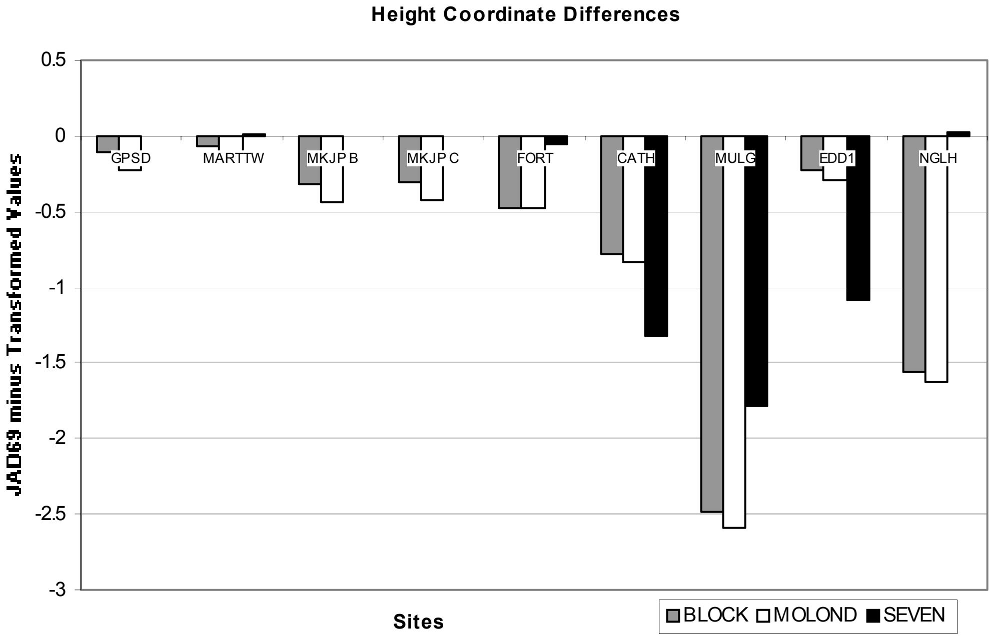

Figure 7 Height Coordinate Differences

These differences should ideally be zero. However, this could only be realized had both the Local/Terrestrial network and the fiducial network been perfect. Such a situation could never be achieved and is therefore one explanation as to why Coordinate Transformation is not the total solution to Datum Problems, as there is little chance of obtaining results that would yield coordinates differences well below the decimeter level, given the distortions in local networks, brought about by the traditional measurements (Theodolite angles and Catenary/EDM measurements) processes used in their execution. A comparison (Table 10) of the six (6) terrestrial network distances with those of the fiducial network (reduced to JAD69), reveals differences of up to 2m, a clear indication that the terrestrial network is weak in scale and needs renovation.

Table 10. *Comparison of Terrestrial and GPS distances between fiducial marks*

Line	Triangulation	GPS	Diff	Ratio	PPM
JA-MA	99,000.77	99,002.038	1.268	1/78,000	12.81
MA-PA	57,508.11	57,508.700	0.590	1/97,470	10.25
PA-NU	105,213.20	105,214.494	1.294	1/81,300	12.30
NU-JA	41,518.54	41,518.892	0.352	1/118,000	8.48
JA-PA	124,715.74	124,717.336	2.096	1/59,500	16.81
MA-NU	100,441.39	100,442.460	1.070	1/93,900	10.65

The coordinate differences for the transformed points show very little consistency except within localized regions (see figure 8). The first four points form a cluster in the southeast end of the island, and are close to the origin (the fifth point) of the Terrestrial network. The other points are well dispersed across the island.

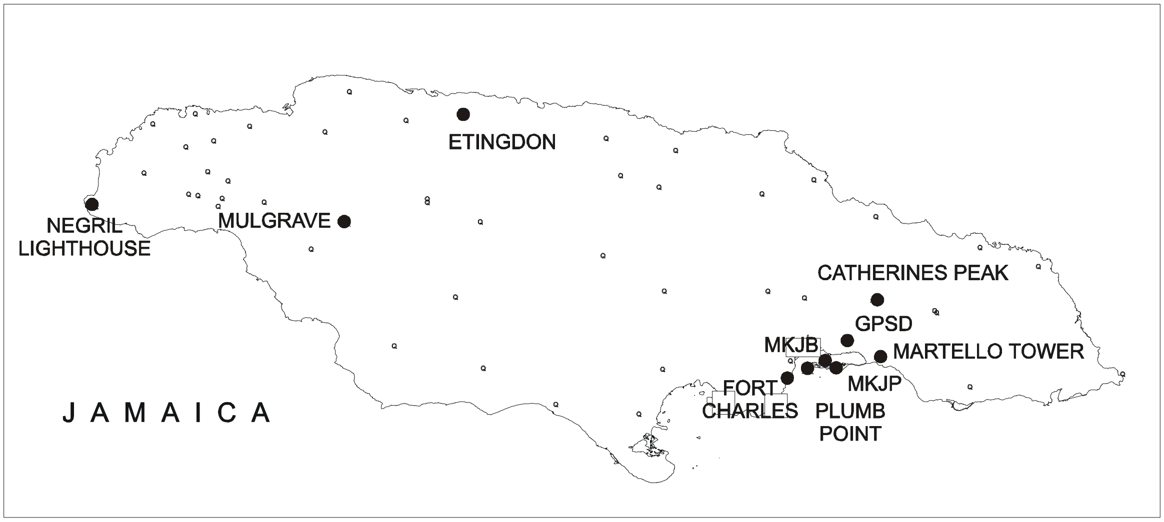

Figure 8. Test Points

The height differences from all three transformations take on significant proportions at the station MULG. This is a secondary control point. The height networks, even at the Primary level, were never of a convincingly high standard. Of even greater significance is the fact that the published heights are not orthometric (spirit levels corrected for gravity) and the elevations of transformed test points are not corrected for geoid-ellipsoid separation. There is no geoid model specific to JAD69. N was set to zero at the origin of the local network, hence MSL values are close to ellipsoid heights near the origin. The further away we move from this area, is the likelihood that this assumption will breakdown. Evidence of this is shown in the Satellite Doppler Survey report **[5]** where geoidal heights progress from 0.0m through 0.70m to 1.3m at Fort Charles (origin), Malvern and Negril Lighthouse, respectively. Should the JAD69 computed (from transformation) ellipsoidal heights be adjusted by amounts of these orders of magnitude, then the differences would be reduced by corresponding amounts.

Except in the case of the Northings, there is no significant difference between the Block Shift differences and that of Molodensky, though the latter, accounting for differences in the ellipsoids, is expected to deliver better results. The Similarity Transformations are clearly superior to the Block Shift and Molodensky, with differences at the centimetre to decimetre level obtained.

It will be observed that the standard errors of particularly the shifts in the similarity parameters are quite large. Given the size (East - West 230km) of the island, it is unlikely that a “fix” on the position of the reference system origin, being 6378km away, could be achieved to any better accuracy, as the analogy with intersections and “angles of cut” are considered. Notwithstanding, as proven at the test points, these large standard errors have very little effect on the transformed coordinates.

Also note the point raised earlier about a rotation of the Z axis being directly correlated (has the same effect) with a translation in X, was supported by a value of 0.99 in the parameters’ correlation matrix. Likewise, on the basis of a value of –0.99, a positive rotation about the X axis will produce a negative effect on the Z translation and visaversa. This is precisely what happened to the translation parameters in the seven parameters solution i.e. a positive Z rotation produced a positive adjustment to the X shift and a negative X rotation caused a positive adjustment to the Z translation. Multivariate statistical tests were performed on the scale and rotation parameters. Assuming that the input standard deviations of observation are reliable, then a statistical test of the scale factor found it is significant (at the 95% confidence level), and is consistent with those computed in table 11. The rotations can also be accepted as being significant.

In the three methods, the results obtained for heights of Catherine Peak & Eddington defy expectations with regards to the accuracy of the transformations. The Block and Molodensky Parameters produces smaller differences than the more accurate Seven Parameters Method, a situation which is most likely due to the inaccuracies of the heights in the Terrestrial Network.

RECOMMENDATIONS

These parameters will be suited for different applications and instrumentation. The Block Shifts and Molodensky parameters are useful for those hand-held GPS receivers capable of accepting three (3) and five (5) parameters respectively and will therefore be very useful to GIS mapping, boaters, hikers etc. In Cadastral Surveying, for the purposes of tieing to control, it should now not be necessary to do “site calibration” with one control point and the seven parameters entered into the real-time GPS receiver controller unit or the post processing software. This should provide connection to the local coordinate datum to ±0.5m or better.

It has become very clear that the elevations of our control, as established by trigonometric heighting, are not of the highest standards. An island revision of the heights of triangulation points is therefore required. This could be executed by reciprocal vertical angles in EDM height traversing or GPS heighting.

The absence of a geoid computed with respect to the local datum has presented some difficulties in properly analysing the quality of the height transformations. When these transformations are to be applied in practice, geoid heights will be required. It is therefore necessary that an accurate local geoidal model be developed.

Given the inconsistencies in the local network a revision by way of a total readjustment is necessary. The careful selection and observation of a few lines in the network should precede this. The six lines in the fiducial network are a start, as there are longer lines that can be observed, that is, if the proposed Jamaican GPS Network option is not adopted.

Finally, and if not most significantly, there is a need for a complete redefinition of the datum. For the many reasons that have been explained in this paper, the development of transformation parameters for a non-geocentric datum is an interim solution. Research towards the adoption of a geocentric datum for Jamaica with all its attendant problems (Newsome, 1999) must be pursued immediately. All existing maps and data could still be used even when the new datum is introduced. These could be tagged as distinct from any new maps and data produced on the geocentric datum.

CONCLUSIONS

Three sets of transformation parameters namely; Block, Molodensky and Similarity, have been derived. They all produce results consistent with their accuracies that have been quoted in the literature. In the case of the Block Shift and Molodensky Transformations, which do not exhibit significant differences in this research, the transformation of WGS84 coordinates to the JAD69 coordinates system can be expected to be within ±1-2m of JAD69 values. The seven-parameter similarity values, on the basis of the results at the test points, can produce JAD69 coordinates accurate to ± 0.5m or better.

The Jamaica Fiducial Network (JFN) can serve as a foundation for any future national control activities, be it a revision of the existing network or a redefinition of the datum.

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